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Πλαστικά Απορρίμματα και Παγκόσμια Ρύπανση των Ωκεανών

Εκατομμύρια Τόνοι Πλαστικών Απορριμμάτων στους Ωκεανούς έχουν Εξαφανισθεί;

Βαλαβανίδης Αθανάσιος

Τμήμα Χημείας, Πανεπιστήμιο Αθηνών, Πανεπιστημιούπολη Ζωγράφου, 15784 Αθήνα

Περίληψη

Η παγκόσμια παραγωγή πλαστικών (πολυμερή, πρώτες ύλες και δευτερογενή προϊόντα) υπολογίζεται σε 300 εκατομμύρια τόνους για το 2014 και αυξάνεται κάθε χρόνο κατά 3-5%. Τις τελευταίες δεκαετίες η παραγωγή πλαστικών συσκευασιών, ιδιαίτερα για τρόφιμα, έχουν αυξηθεί δραματικά και είναι κυρίως μίας χρήσης που απορρίπτονται καθημερινά σε μεγάλες ποσότητες σε αστικές περιοχές, χώρους αναψυχής, από πλοία και από πολυάριθμες βιομηχανικές εγκαταστάσεις και βιοτεχνίες. Σύμφωνα με μελέτες το 40% των πλαστικών συσκευασιών απορρίπτεται σε αστικές χωματερές, το 14% ανακυκλώνεται, αλλά το 32% καταλήγει τελικά σε θάλασσες, ποτάμια, λίμνες κλπ. Οι ωκεανοί δέχονται ετήσια τεράστιες ποσότητες πλαστικών που υπολογίζονται σε μερικά εκατομμύρια τόνων. Τα πολυμερή απαιτούν μεγάλο χρόνο για να διασπασθούν αλλά και τα μικροπλαστικά σωματίδια που προκύπτουν από τη διάσπαση των πλαστικών ρυπαίνουν σε μεγάλη έκταση τα υδατικά συστήματα με τελική κατάληξη το θαλάσσιο περιβάλλον.

Τα τελευταία χρόνια η επιστημονική κοινότητα άρχισε να διερευνά συστηματικά τον διασκορπισμό των πλαστικών απορριμμάτων, τις φυσικοχημικές διασπάσεις σε μικρότερα τμήματα, την εκχύλιση πρόσθετων τοξικών χημικών ουσιών και το σχηματισμό μικροπλαστικών (<1 mm). Τα βιοδιασπώμενα πλαστικά, παρά την αρχική τους φιλοδοξία να μειώσουν την περιβαλλοντική ρύπανση, αποδείχθηκαν επιπρόσθετη πηγή ρύπανσης λόγω της θραύσης σε μικρότερα τμήματα που διατηρούν τις ιδιότητες των πλαστικών για μεγάλο χρονικό διάστημα. Η ανασκόπηση αυτή συγκέντρωσε τις σημαντικότερες επιστημονικές έρευνες (μέχρι και τον Μάιο του 2016) και τα αποτελέσματα πολυετών δειγματοληπτικών αποστολών στους ωκεανούς της Γης. Τα αποτελέσματα έδειξαν ότι η ρύπανση των ωκεανών είναι εκτεταμένη λόγω της ανθεκτικότητας των πολυμερών και την κατάτμηση σε μικρότερα πολυμερή σωματίδια.

Πλήρες κείμενο της εργασίας στα αγγλικά [39 σελίδες]: [αρχείο PDF, 7,4 MB]

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Global Plastic Waste and Oceans' Pollution
Million tons of plastic waste have gone missing in the world oceans?

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Abstract. The extraordinary global expansion of manufactured of plastics, 300 Million tons in 2013, which have become indispensable for everyday use of our human civilization can be seen in their dramatic rise of waste in every corner of land and water. The current global annual production of plastic represents ~40 kg for each of the 7 billion humans on the planet. Plastic products have many advantages over older materials (glass, wood, leather, metals) they are versatile, lightweight, flexible, moisture resistant, strong, and relatively inexpensive. In the last decades, the massive globalization of single use food plastic packaging and thrown away mentality, increased dramatically the volume of plastic waste in cities, beaches, transportion by sea and industries. Studies showed that 40% of plastic waste goes to landfills, 14% is recycled but 32% ends in the marine environment as litter. The Earth's oceans were found by selective surveys of waste to contain millions of tones of plastic pieces, mostly in the form of microplastics. Since plastic are resistant to degradability under natural conditions it takes years to break into pieces drifts under wind and surface currents into the marine environment.

Recent studies had been shown that long-term surface transport (years) leads to the accumulation of plastic litter in the center of the ocean basins. This could mean that plastic pollution is moved more easily between oceanic gyres and between hemispheres than previously thought. According to calculations millions of tons of plastic waste in the ocean shave gone missing and are not accounted, so scientists wonder where "where all these plastics are missing?". The review covers the most important scientific studies and marine surveys of the last years (until May 2016) concerning the plastic pollution and the widespread appearance of microplastics in the ocean gyres and in the sea sediments even in remote marine areas. Also, the review presents studies on the biodegradability of plastic waste in the marine environment and their adverse effects on marine biota. Finally, the review presents the various national and international policies in tackling the plastic pollution in the oceans.

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Introduction : Global Polymer and Plastics Production

The global production in 2014 of polymer materials and plastics reached 311 million metric tons, an increase of 3.9% from 299 in 2013. China is the largest producer of plastics in the world, with around 25% of the global production. NAFTA countries (USA, Canada, Mexico) produced 19.4%, the rest of Asia countries 16.4% (India, Indonesia, South Korea, etc), the European countries (27 EU +Switzerland +Norway) produced around 57 million metric tons (~20%) and Japan 4.4%.[1,2]

In Europe, there are 60,000 plastics factories, with 320 billion Euro annual turnover, and direct employment of 1.45 million people. In the last decades the European Union produced 25.2 million tons of post consumer plastics waste. Today, an average person in developed countries consumes 100 kg of plastic each year, mostly in the form of flexible packaging materials and household items.[2]

Figure 1. Global Plastics production was 300 million tons (Mt) in 2013, of which 57 million tons were produced in the European Union countries. The main producers of plastics are China 25%, NAFTA countries (USA, Canada, Mexico) ~20%, EU27 20%. Plastics–the Facts 2014 [http://www.plastics.gl/market/plastics-the-facts-2014/]. Plastics Europe-The Facts 2014/2015 [www.plasticseurope.org/] (accessed April 2016).

Polymers, in general, are high molecular weight organic molecules, or macromolecules, composed of many repeated subunits. Polymers range from familiar synthetic plastics such as polystyrene (PS) and polyethylene (PE) to natural biopolymers such as DNA and proteins. Plastics are referred to typically organic polymers of high molecular mass which are used for various technical applications. In the last decades the plastics industry grows at a rate of 3-5% and is driven by growth in end use markets, such as packaging, automotive, infrastructure, transport rails, and telecommunication mainly from emerging economies (China, India, Brazil, South Africa, South Korea, etc). Polymers and plastic materials in the last decades continuously substitute metals, glass, paper and other traditional materials for a great variety of applications due to their lightweight and strength, the design flexibility they offer for any shape and durability, and especially the low cost.[3,4]

Plastic products have many advantages over older materials they are versatile, lightweight, flexible, moisture resistant, strong, and relatively inexpensive. Those are the attractive qualities that lead people all over the world to increase very fast the consumption of plastic goods. Plastics are durable and very slow to degrade, becoming ultimately persistent waste difficult to recycle. People are voracious consumers of items that facilitated their activities at home, in factories and in small businesses. Inevitably, large amounts of plastic are discarded daily. In the last decade the production process used to make plastics consumed about 10% of oil and gasoline both produced and imported by the U.S.A.[4]

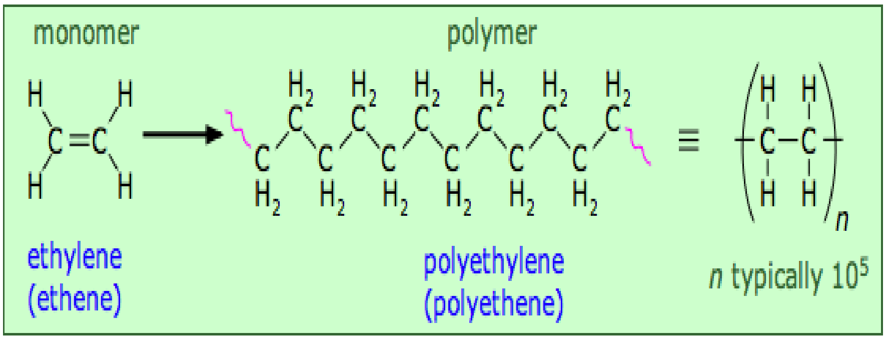

Figure 2. Plastics and natural materials such as rubber or cellulose are composed of very large molecules called polymers. In a linear polymer such as polyethylene, rotations around carbon-carbon single bonds can allow the chains to bend or curl up in various ways [http://chemwiki.ucdavis.edu/].

Global Plastic Waste. A Major Environmental Problem

Plastics are proving to be much more mobile than other man-made materials such as ceramics, glass, wooden items, metals and paper. It took ceramics, glass, wood and metals thousands of years to achieve anything resembling a global distribution, with very little incursion into marine environments. From being a local 'litter' problem a few decades ago, plastics pollution is increasingly recognized as a major environmental problem on land, in the water bodies and especially in the sea.

Plastic items are not biodegradable, instead they degrade slowly into minute sized microplastics (sizes from 1 mm to 1 μm), which spread easily and pollute extensively the marine environment causing the so-called microplastics pollution.[5]

Plastic waste encompasses a wide range of polymeric materials, including, rubbers, elastomers, textiles, fibers, thermosets and thermoplastics, with some 200 plastics families in production including polyethylene (PE), high-density polyethylene (HDPE) and low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), polyvinylchloride (PVC) or Vinyl (V), polyethylene terephthalate (PET), Polycarbonate (Other plastic, suitable for food), nylon, polyvinyl alcohol (PVA) and acrylonitrile butadiene styrene (ABS) synthetic rubbers. Plastics can be fabricated from feed-stocks derived from petroleum, natural gas, or bio-renewables.

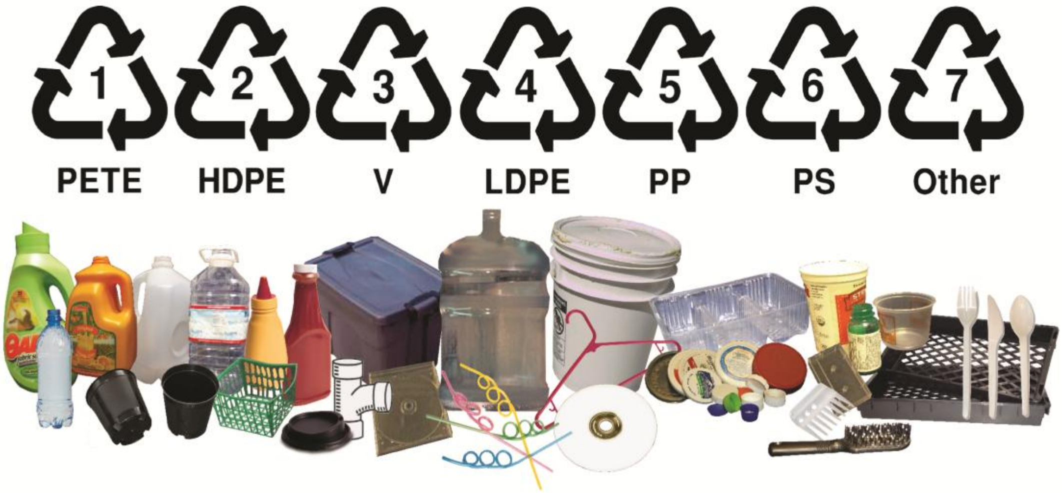

Figure 3. The majority of plastic material can be recycled after use but need to be separated at source and be clean to feed the recycling process.

In response, there has been a rapidly expanding body of scientific papers on the subject within the last few years and many innovative research projects are trying to establish the fate of million tons of plastic waste in the world oceans. The extraordinary global expansion of manufactured of plastics, which have become indispensable for everyday use of our human civilization, is causing problems for the marine environment. The current global annual production of plastic represents ~40 kg for each of the 7 billion humans on the planet, and more than ~100 Kg plastic production in developed countries.[6-8]

Scientists tried in the past to estimate the overall plastic waste in the form of municipal garbage, fishing gears, plastic tools, kitchen utensils, food packaging, pellets, plastic bags and bottles of water and soft drinks. Most of researchers realized that there are no reliable estimates of the amount of global plastic litter or debris that pollute land and water bodies and how much plastic waste reaches the marine environment from land-based activities, but all realized from production statistics that the quantities of plastic waste were nevertheless quite substantial.[9]

Figure 3. Millions of tons of plastic litter end up floating in world oceans broken into microplastics, the so-called plastic soup. Microplastics are found in the most remote parts of our oceans.

Various scientific reports from the 1970s appeared in the scientific literature with rough estimates of plastic waste at national and global scale. One study in 1975 estimated that the world's fishing fleet alone dumped into the sea approximately 135,400 tons annually of plastic fishing gear and 23,600 tons of synthetic packaging material.[10] Merchant vessels were investigated and found to be notorious polluters of seas with their plastic waste. A study estimated that in the 1980 more than 630,000 plastic containers were disposed each day from merchant ships in the seas, although the disposal at sea of plastic materials (garbage except food waste) is against the Inter-Governmental Marine Consultative Organization (IMCO, 1973 regulations).[11,12] Also, plastic pollution in the seas is caused by recreational fishing boats as it was established by US Coast Guards. According to their estimation more than 50% of garbage dumped in US waters is from recreational fishing boats.[13]

Land-based sources (industrial facilities, recreational beaches, inadequate waste facilities in coastal areas, dumping of municipal waste in surface landfills) have been proved to be major plastics polluters compared to sea-based sources.[14,15,16] There are so many applications of produced polymers that large amounts of plastic materials end up in the marine environment when accidentally lost, carelessly handled or left behind by tourists and bathers in beaches.[17,18] Rivers and municipal drainage systems can become carriers of plastic waste to the nearest shoreline and then at sea.[19]

Figure 4. Rivers can become major dumping areas of consumer plastic and subsequently carriers of municipal plastic waste to the oceans.

Other sea-based sources of plastic pollution include oil and gas platforms, aquaculture facilities, cargo ships and other vessels that throw or lose plastic containers to the sea. Studies showed that plastic debris and waste from land comes primarily from two sources: first, ordinary litter; and, second, material disposed in open dumps or landfills that blows or washes away, entering the ocean from inland waterways, wastewater outflows, and the wind. Also, major waterways (rivers) can transport a great deal of plastic waste. A project estimated that the Danube River, for example, transports 4.2 metric tons of plastic into the Black Sea each day.[20]

Lightweight plastic items tend to float in water and can be carried by currents great distances. For example, it has been reported that plastic cargo lost from ships has been found more than 10,000 kilometers from where it was lost. Also, currents can carry floating fishing nets hundreds of miles from where they were last used, as is the case with Northwestern Hawaiian Islands (collection efforts there rounded up about 52 metric tons of lost nets and other plastic debris).[21]

Managing municipal, industrial and packaging solid waste has become a big environmental issue in advanced industrial societies. In the last decade very effective and technologically advanced methods of plastic recycling is applied in many countries. There are numerous recycling methodologies and management initiative in a broad range of plastic materials. The most important is considered the separation at source and recycling or incinerating at high temperature for electricity generation and hot water for heating.[22,23]

Figure 5. Recycling of plastic waste has been proved to be very effective for the production of the initial feedstock polymer material. It is vital for plastic waste to be clean and separated at source foe efficient recycling.

The majority of the Life Cycle Assessment (LCA) studies concluded that, when single polymer plastic waste fractions with little organic contamination are recycled and replace virgin plastic at equivalent amount, recycling can be the environmentally preferred treatment option, compared to municipal solid waste incineration for electricity production and hot water. Also, feedstock recycling and the use of plastic waste as a solid recovered fuel in cement kilns were preferred to municipal solid waste incineration. Landfilling of plastic waste compared to municipal solid waste incineration proved to be the least preferred option for all impact categories.[24]

Plastic Pollution is Ubiquitous in the World Oceans

After a decade of intensive studies in all marine areas, seas and oceans, scientists now know that plastic waste has become nearly ubiquitous on the marine environment of the planet. Even in the remote shores of Alaska plastic was found floating of littering the beaches. Plastic waste has washed up on the most remote beaches of the continents, amassed in distant gyres (a gyre in oceanography is large system of rotating ocean currents involving with large wind movements), and has been discovered in the bodies of dead organisms from fish to birds to whales. One study evaluated the abundance of anthropogenic debris on 37 sandy beaches bordering the Salish Sea in Washington State and plastic debris in surface waters of the Salish Sea and the Inside Passage to Skagway, Alaska.[25-27]

Plastic waste has been found in marine animals since the early 20th century, but little is known about the impacts of the ingestion of debris in large marine mammals (like sperm whales) related to the ingestion of large amounts of marine debris in the Mediterranean Sea. The spatial distribution modeled for the species in the region showed that these marine animals can be seen near the waters of Almería, Granada and Murcia and in waters near the Strait of Gibraltar. These plastic materials can cause death by gastric rupture following impaction with debris.[28] Plastic debris in the world's oceans are associated with a number of problems including ingestion of plastics debris, along with adsorbed toxic chemicals, by marine biota.[29,30]

Large filter feeding marine organisms consume daily large amounts of microplastics waste (size 5 mm). Studies showed that Mediterranean fin whale (*Balaenoptera physalus*) and basking shark (*Cetorhinus maximus*) showed high concentrations of phthalates (MEHP) in their blubber due to the feeding with plastic waste.[31]

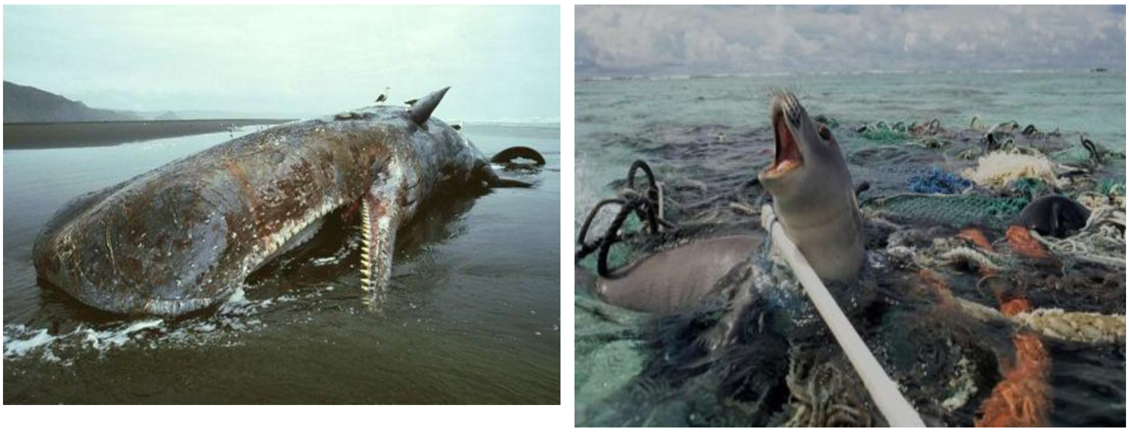

Figure 6. It has been estimated that 640,000 tons of fishing gear is lost in our oceans every single year. Thousands of sea mammals become entangled and trapped in nets and lines every year, and that's not including fish. Ingestion of plastics waste, along with adsorbed toxic chemicals, can cause death to large section of marine biota.

The oceans on Earth cover 71% of the Earth's surface and contain 99% of the habitable space on the planet. The Pacific ocean covers 28% of the Earth's surface, the Atlantic is half size of the Pacific, the Indian ocean is largest than the landmass of Eurasia, the Southern ocean contains cold waters that encircle the Antarctic continent and the Arctic ocean that is almost the same size as the Antarctic continent. The oceans remain home to several hundred thousand of different plant and animal species and they are essential to all living beings, both in the water and on land. The oceans also play an essential role in the carbon cycle, and currently absorb about half of all of the atmospheric carbon, thereby reducing or slowing the effects of global warming.[32]

Solid plastic waste in the vast oceans of the Earth's is considered now as one of the most important pollution factor (petroleum spills, agricultural effluents, industrial and municipal liquid waste, etc) that is moved throughout the world's oceans by the prevailing winds and surface currents. This had been shown for the Northern hemisphere where long-term surface transport (years) leads to the accumulation of plastic litter in the center of the ocean basins.[33,34]

Results from studies confirm similar patterns for all southern hemisphere oceans. Surprisingly, the total amounts of plastics determined for the southern hemisphere oceans are within the same range as for the northern hemisphere oceans, which is unexpected given that inputs are substantially higher in the northern than in the southern hemisphere. This could mean that plastic pollution is moved more easily between oceanic gyres and between hemispheres than previously assumed leading to redistribution of plastic items through transport via oceanic currents. Furthermore, there might also be important sources of plastic pollution in the southern hemisphere that had not been accounted for, such as currents from the Bay of Bengal that cross the equator south of Indonesia.[35]

Degradation of Plastic Waste and Biodegradable Polymers

Synthetic polymers are recognized as persistent environmental pollutants that take years to disintegrate by chemical, physical and biological factors in the natural environment. Despite the new biodegradable polymers that have been introduced in the market in recent years, the problems of environmental plastic pollution have increased substantially. Polymers which are easy digestible by microorganisms, chemically modified starch, starch-polymer composites, thermoplastic starch, biodegradable packing materials, and biopolyesters (poly-β-hydroxyalkanoates) have decreased to a limited degree the plastic waste in the last decade. The main problem associated with designing biodegradable polymers is the optimization of their chemical, physical and/or mechanical properties, as well as their biodegradability.[36]

Most plastic materials are categorized by their durability, exceptional mechanical properties, flexibility and can be molded in a great variety of shapes. The multiple applications of plastic materials and the widespread pollution caused in the last decades advanced many studies on their biodegradability under natural conditions. Studies have been contacted for the microbial colonization and degradation of polyethylene (PE) plastic bags and other polymers. All studies showed that plastics take long time to disintegrate into oligomers, monomeric constituents, other low molecular chemicals or carbon dioxide.[37,38]

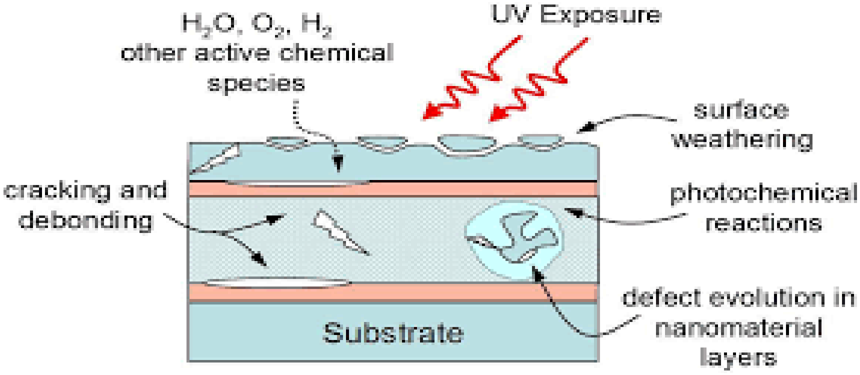

Figure 7. Polymers can disintegrate under the influence of oxygen, reactive oxygen species (oxidations of chemical bonds), UV-radiation (photochemical reactions, bond dissociation), surface weathering, cracking under wind and sea current forces, and finally by microorganisms decomposing plastic materials.

Many polymer companies researched and tested different types of biodegradable plastics. At present there are many commercially available biodegradable plastic materials, such as natural plastics produced by microorganisms, or plastics with polymer blends, such as starch and photo-biodegradable plastics. Typically, these are made from renewable raw materials such as starch or cellulose. Interest in biodegradable plastic packaging arises primarily from their use of renewable raw materials (crops instead of crude oil) and end-of-life waste management by composting or anaerobic digestion to reduce landfilling.[39,40,41] Various studies were conducted on the degradability (laboratory tests) of different types of degradable plastics in a variety of marine environments.[42,43]

These studies produced conflicting results and it remains unclear whether degradable plastics are less harmful than conventional plastic. Bacteria and microbes are ubiquitously abundant in the marine environment, capable of decomposing complex organic matter but plastic materials are compact chemical polymers with strong chemical bonds and toxic additives to make them mechanically strong and flexible. Hence, the question arises whether microbial degradation of plastic waste is possible and whether it has the capacity to decompose them and reduce the gradual accumulation of plastics in various marine environments. Most of the studies on microbiological degradation of plastic are restricted to the upper ocean layer. Plastic has a longer half-life than most natural floating marine substrates, and a hydrophobic surface that promotes microbial colonization and biofilm formation, differing from autochthonous substrates in the upper layers of the ocean. A study described a diverse microbial community growing on plastic material from North Atlantic surface water, which differed from the bacterial composition of the surrounding water. Biodegradation of polymers has been proved to be a slow process.[44]

Figure 8. Biodegradable plastic materials can be “degradable” but still last for a long time in the environment. Hydrolytic degradation has certain environmental requirements, a material may degrade readily in one environment and be long-lasting in another.

Resistivity of plastic waste to chemical weathering, mechanical erosion, and biological degradation has become a big environmental problem. Plastic waste has increased in abundance over the past several decades along shorelines, beaches, rivers and in open sea. In a study, highly used polyethylene plastic (PE), was incubated for 20 months in 2 m water depth in the Baltic Sea but showed no biodegradation.[45] The initial positive buoyancy and the hydrophobicity of PE may be altered by UV–radiation, oxidation, high temperatures and biofilm formation. After 3 weeks of floating at the ocean surface, PE bags start to sink below the seawater–air interface.[46] Adhesion of more particles onto the PE surfaces and wind-induced downwelling caused bags to sink further, until eventually they settle onto the seafloor.[47] In great depth of the sea water the light decreases and the rate of abiotic plastic degradation decreases in deep waters. Although there are restricted data on the dimension of plastic pollution of the seabed at depths more than 30 meters, plastic debris litter has been found on the seafloor of every ocean.[48,49]

It has been found that on the continental slope and in bathyal plain of the northwestern Mediterranean Sea 70% of the total debris consisted of plastic bags. Once on the ocean floor, plastic material is buried into the seabed by ongoing sedimentation and passes the thin oxygenic surface layer before reaching the anoxic sediment below. It is unknown how degradation rates of plastic in sediments are affected by the lack of oxygen and light. Different types of debris were observed, particularly pieces of plastic bottles, glass bottles, glass vials, and fishing gear. The results showed considerable geographical variation in concentrations, which ranged from zero to 101,000 pieces of waste per km^2.[50] As microorganisms in the sediment largely control carbon sequestration and nitrogen conversion, play an important role in marine biochemical cycles and are crucial in biological degradation of deposited plastic litter.[51]

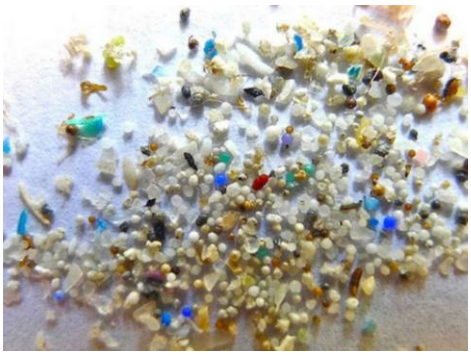

Figure 9. The degradation of plastic items produce a vast number of small sized plastic beads, microplastics (<1 mm) that spread in the sand in the sea beds.

The predominant type of plastic PE appears to be much more resistant to chemical weathering than polypropylene (PP), as indicated by studies of FTIR spectra suggesting that PP degrades more readily under natural conditions on freshwater beaches.[52] The degradation of plastic in the marine beaches and at sea produces small sized pieces (microplastics) which spread in the sand and sea sediment beds. A recent study showed that microplastics (<1 mm, 0.001 m) that originate by degradation of larger plastic waste items have reached the most remote of deep sea environments. Also, the study found smaller plastic particles sized in the micrometer (μm, 1 μm = 10^{-6} m). The abundance of up to 1 microplastic per 25 cm^3 was observed in deep-sea sediments collected at four locations (Atlantic Ocean and Mediterranean Sea) representing different deep-sea habitats ranging in depth from 1,100 to 5,000 meters.[53]

These microplastics retain all the properties of polymers and in this respect represent a potential danger to marine ecosystems from the accumulation of toxic plastic debris on the sea floor. The accumulation of such debris can inhibit gas exchange between the overlying waters and the pore waters of the sediments, and disrupt or smother inhabitants of the benthos. Also, albatross, fulmars, shearwaters and fish mistake floating plastics and microplastics in the beaches and in the sand floor for food. Studies showed that around 40% of all seabird species are known to ingest plastic litter with their food. Sea turtles and cetaceans ingest plastic bags, fishing line and other small sized microplastics. Around 267 species of marine organisms worldwide are known to have been affected by plastic debris.[54] Synthetic polymers in the marine environment and microplastics in deep-sea sediments are considered by many scientists as a long-term threat for the environment.[55,56]

Biodegradable Plastics: Solution to the Plastic Waste?

From the 1970s plastic producers investigated the application of biodegradable plastics as a solution to the environmental problem of plastic waste. At present there are mainly two types of biodegradable plastic on the market : a) plastic materials that are plant-based hydro-biodegradable plastic (polylactic acid, PLA, made from corn starch or cellulose, polyhydroxyalkanoate) and b) petroleum-based (polyolefins), with transition metals and oxo-biodegradable (OBD) plastic, that require a great deal of time to degrade under certain circumstances.[57]

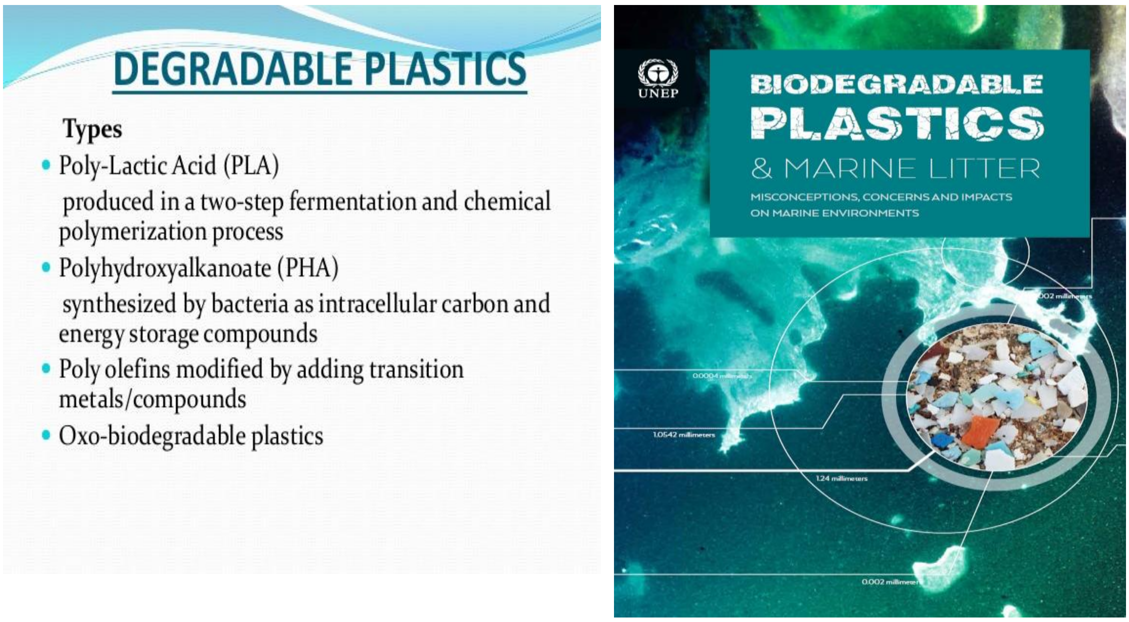

Figure 10. There is a great variety of biodegradable plastics. But, biodegradable plastics are not the answer to reducing marine litter, says the United Nations Environment Programme (UNEP). Kershaw PJ. *Biodegradable Plastics and Marine Litter. Misconceptions, Concerns and Impacts on Marine Environments.* UNEP publications, Nairobi, 2015.[58]

In 2015, a study by UNEP and partners (commissioned by Global Programme of Action for the Protection of the Marine Environment, and Land-based Activities) estimated that from 280 million tons of plastic produced globally each year, only a very small percentage is recycled. Instead, some of that plastic ends up in the world's oceans, costing several billion dollars annually in environmental damage to marine ecosystems. The report argued that widespread adoption of products labelled “biodegradable” will not significantly decrease the volume of plastic entering the ocean or the physical and chemical risks that plastics pose to marine environment. This report showed that there are no quick fixes, and a more responsible approach to managing the lifecycle of plastics will be needed to reduce their impacts on our oceans and ecosystems”.[58]

Oxo-biodegradable (OBD) plastic is conventional polyolefin plastic with an added small amounts of metal salts [there are no "heavy metals" which are restricted under the EU Packaging Waste Directive 94/62 Art 11)]. These salts catalyze the degradation process to speed it up so that the OBD plastic will degrade abiotically at the end of its useful life in the presence of oxygen much more quickly than ordinary plastic. At the end of that process it is no longer a plastic as it has been converted via carboxylation or hydroxylation reactions to small-chain organic chemicals that will then biodegrade.[59,60]

Figure 10. Samples of starch-based biodegradable plastic mulch (BioTELO®) recovered after 24 months burial in the field at three experimental locations. (Photo credit: J. Moore-Kucera, Texas Tech University10).[http://articles.extension.org/pages/67951/current-and-future-prospects-for-biodegradable-plastic-mulch-in-certified-organic-production-systems].

OBD plastics have to pass the eco-toxicity tests (ASTM D6954); additionally they must be designed not to degrade deep in landfill so that they will not generate methane. There is no evidence of any danger to wildlife from OBD; almost all the plastic fragments found in studies on the marine environment are fragments of conventional plastic, unsurprisingly as this still makes up the vast majority of plastics.[61,62]

There are various problems with biodegradable plastic bags and criticisms from environmentalists. The first criticism concerns research which showed that plastic bags do not degrade completely as the producers are claiming. And second, priming plastic bags for destruction is itself an ecological crime. Supermarkets in England distributing biodegradable bags to consumers claim that "bags are able to degrade completely within about 3 years, compared to standard bags which take 100 years or longer". The big supermarket Tesco reckons that bags will decompose within 18 months "without leaving anything that could harm the environment". But whether it actually happens seems to depend a lot on where the "biodegradable" plastic ends up. If it gets buried in a landfill it probably won't degrade at all because there is no light or oxygen.[63]

In general, most of the plastics used at present do not degrade to a large degree when released in to the environment. Photodegradation by UV radiation, thermo-oxidation, hydrolytic degradation and action of microorganisms are the most important mechanisms to degrade polymers. New plastic products incorporate chemical additives to achieve polymers, after use, to become brittle and then break down into smaller pieces. When polymers reach sufficiently low molecular weight can be metabolized by microorganisms which convert them into CO_2 or incorporate it into biomolecules. However this process is very slow and it can take 20-30 years to fully break down. Biodegradable plastics accelerate this process, but these processes decreased in seawater due to lower temperature and lack of oxygen.[64,65,66]

An extensive report in Belgium in 2013 compared the benefits and challenges of biodegradable and oxo-degradable polymers for the environment. The results of the literature showed that there are various problems of degradability in the long-term and the use of biodegradable plastic to mitigate environmental marine pollution.[67]

For a manufacturer to employ the claim of biodegradability of plastic materials, a set of specified standards need to be met. ASTM International (formerly, American Society for Testing and Materials) has prepared standards to measure biodegradability (ASTM D6400). The ASTM D6400 encompasses several ASTM standardized tests, such as the "inherent biodegradability" of the plastic material via ASTM D5988-03. This test measures the microbial conversion of the plastic’s carbon (C) atoms to CO_2, over time (90% of C atoms must be mineralized, that is, converted to CO_2 within 180 days by microorganisms (ASTM, 2003). In the laboratory, CO_2 release is measured through a relatively inexpensive titration method.[68,69]

Plastic films (mostly PE) are used in agriculture and particularly in protected horticulture (mulching, low tunnels, greenhouses). The market of plastics used for these purposes in Europe involves hundreds of thousands of hectares and thousands of tons of plastic films per year. The conventional agricultural plastic films used today are high and low density polyethylenes, PVC, polybutylene or copolymers of ethylene with vinyl acetate. A major negative consequence of this expanding use of plastics in agriculture is related to plastic wastes and the associated environmental impact (a small percentage is recycled). A large portion of this plastic is left on the fields or burnt uncontrollably by the farmers releasing harmful substances. Several experimental biodegradable agricultural films have been exposed in the fields under real cultivation conditions in several locations in Europe, as well as in the laboratory. The Mater-Bi grade NF 803/P was found to be best suited for blow extrusion of thin biodegradable agricultural films. It has been shown that it is possible to develop very thin biodegradable mulching films made of this grade that perform satisfactory for the specific applications and may replace conventional (thicker) polyethylene films.[70,71,72]

Figure 11. Agricultural plastic mulch films increased substantially in the last decades leading to environmental pollution. Rigorous research in the last decade aimed to develop degradable agriculture mulch film and films for greenhouses.

The dramatic increase in plastic film mulching in water-efficient agriculture is primarily due to its versatile nature that has proven to be very beneficial over the last decade in the arid region. However, as carelessly used plastic mulch films lead to agro-environmental pollution, there has been vigorous research recently to develop degradable film materials for mulching. This review describes the use of plastic film for mulching in water-efficient agriculture practices with special reference to progress made in degradable film materials. Moreover, this review includes water-efficient mechanisms and techniques of mulching film cultivation, photodegradable and biodegradable plastic polymers (PHA, PCL etc. synthetic- and natural-based polymers films), their degradation process and developmental deficiencies, and an outlook of degradable film materials. There exists great potential for the further development of water-efficient agriculture; however, it is dependent upon effective research and the wide-spectrum applications of degradable film materials.[73]

Figure 12. Silage in agriculture was developed with plastic films (very resistant) to store animals' grains and straw during the winter.. Degradation steps of P-Life degradable plastics. After completion of their lifetime as plastic products, plastics with P-Life additive start to degrade once they are disposed in the natural environment. [http://www.p-life.com.hk/en/page/WsPage.php?news_id=3] (accessed May 2016).

Bioplastic production which are biodegradable has been expanded in the last years with new products in the market. The future prospects were presented in various studies, but the problem of plastic waste in the environment and especially in the marine environment remains a crucial problem.[74,75]

In the USA various biodegradable plastic products are available in the market and some of them were tested for house compost facilities. An environmental organization tested 5 types of bioplastic bags to see how well they would compost. The test showed that none of them broke down completely after 25 weeks in home compost conditions (shredded, mixed and 77 degree Fahrenheit, 25^{o}C). A product from Italian bioplastic manufacturer Novamont came closest to what be truly compostable, with a product called Mater-bi is a biodegradable and compostable bioplastics developed over twenty-five years of research by using corn starches, cellulose, vegetable oils and biodegradable synthetic polyesters. MATER-bi plastics are certified by certification bodies in accordance with the main European and international standards. Also, they tested one type **of** Oxo-Biodegradable bag which did not begin to break down even after 25 weeks at 140 degrees F (60^{o}C). The study concluded that most bioplastic products currently being marketed (USA) carry incomplete and/or misleading labeling. Also, they tested packaging developed by Frito-Lay for its Sun Chips made from "90 % renewable, plant-based materials. Tests showed that the bags disintegrated down completely into compost in a hot, active home or industrial compost pile.[76]

The Institute for Local Self-Reliance (est. 1974, Washington DC, USA) tested several biodegradable products from conventional plastics and their claims for biodegradability by the manufacturers [BioGreen bottle of LDPR, Aquanatra ENSO, water bottle from PET, PerfGo Green biodegradable plastic bags, PolyGreen PE plastic newspaper bags (oxo-biodegradable), PlanetGreen Bottle Corporation, Reverte oxo-degradable PET bottle, etc]. The report concluded that most of these claims were unsubstantiated. The companies selling these products were taking advantage of markets that are unaware of the difference between certifiable compostable and biodegradable products and those that are not.[77]

Packaging plastic materials (plastic and paper particularly food packaging which is discarded after use), as well as plastic bags are causing great headaches to environmentalists because they represent a severe source of pollution when recycling fails. Whereas paper consists of the natural polymer cellulose, most synthetic packaging polymers are based on polyethylene (PE), which has a much lower weight, higher strength, and causes less pollution during production. Biodegradation and bioerosion render plastics brittle so that they readily disintegrate when exposed to mechanical stresses. Plastics break into microplastics form much (dust-like micron- and nanometer-sized particles), which are carried away by wind or rain and accumulate in the marine environment. Scientists today recognized that "bio" does not imply quantitative and rapid degradation to produce exclusively CO_2 and water. Biodegradation can also produce water-soluble and even toxic metabolites that are washed away by rain and thus pollute groundwater and the marine environment.[78]

The degradation potential of plastic litter in the marine environment inevitable remains a crucial factor on how long plastic waste persist in the sea and how it disintegrate into smaller pieces. A recent study in Greece collected from the submarine environment (Saronikos Gulf) polyethylene terephthalate bottle (PET, for water and soft drinks) which were characterized using infrared spectroscopic techniques (ATR-FTIR) to investigate their degradation potential. The study showed that PET bottles remain robust for around 15 years and afterwards start to disintegrate.[79]

Plastic Debris, Microplastics, and Ocean Pollution Worldwide

Concern about the potential impact of microplastics in the marine environment has gathered momentum during the past few years. The number of scientific investigations has increased, along with public interest and pressure on decision makers to respond. The extent to which microplastics represent a hazard to marine life – and may provide a pathway for transport of harmful chemicals through the food web – is still being assessed. A number of international initiatives are under way to determine the physical and chemical effects of microplastics in the ocean, and to identify ways to address this emerging issue.[80,81,82]

It was in 2004 for the first time that the presence of microplastics was described in the shorelines and in water column of the oceans. In the beginning microplastics were identified as small plastic pieces (plastic litter breaking under photodegradation and oxidative reactions, and mechanical abrasion) around 50 μm in size. Later studies on microplastics extended the characterization to smaller than 5 mm in size.[83,84]

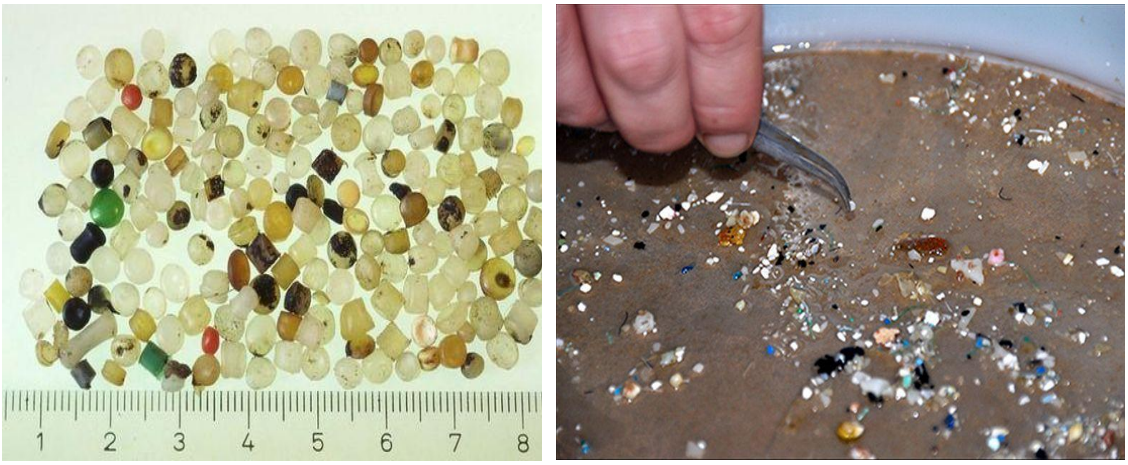

Figure 13. Microplastics are widespread in the sea surface, on shorelines and on the sea beds of many marine areas and oceans.

Over the past decade (2004-2014), a large number of scientific publications on microplastics pollution in the marine environment were published in four main journals (high-impact journals), which together were responsible for around 63% (68 articles) of all published articles (*Marine Pollution Bulletin* (30%), *Environmental Science and Technology, Environmental Pollution* and *Marine Environmental Research*.[85]

Analysis of scientific data published for the microplastic debris in the marine environment showed that the most important classes of plastics were polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC). This plastic litter proliferate, migrate, and accumulate in natural habitats from pole to pole and from the ocean surface to the bottom of the sea.[86,87]

The majority of the studies over the past decade on microplastics pollution in the marine environment were from USA and Western Europe, South Korea, China and Japan scientists. Most of these studies focused on the measurements of the concentrations of microparticles in the marine environment, including areas that are naturally protected as well as more remote ones. Although scientific evidence has quickly been reported in the scientific literature regarding the fate of microplastics and their impact on these environmental systems, many critical issues are still poorly understood (like trends of transport, fate after many years, physicochemical effects on their structure, and impact on the marine environment and biota).[88,89,90,91]

Figure 14. Microplastics. Samples collected in the bottom of oceans polluted by macro (>2.5cm) and micro (<5mm) debris. Microplastics have been measured in protected and in remote areas of the oceans.

Due to their minute size and their presence in both pelagic and benthic ecosystems, a growing number of scientific studies and surveys showed that microplastics are potentially bioavailable for ingestion by a wide range of organisms. Several studies report that these particles may be ingested by invertebrates, e.g., polychaetes, crustaceans, echinoderms, bryozoans, and bivalves, as well as vertebrates such as fishes and birds, in addition to plankton and zooplankton organisms.[92,93,94]

Other studies investigated the bioaccumulation by absorption of toxic chemicals into the pores of microplastics and their transport and later release in the marine environment. It has been shown that persistent organic pollutants (POPs), metals and other pollutants that occur universally in sea water at very low concentrations are picked up by meso-/microplastics via partitioning because of the hydrophobicity of POPs that facilitate their concentration in the meso-/microplastic litter at a concentration that is several orders of magnitude higher than that in sea water. These contaminated microplastics when ingested by marine species present a credible route by which the POPs can enter the marine food web. The extent of bioavailability of POPs dissolved in the microplastics to the biota and their potential bio-magnification in the food web has not been studied in detail. Once ingested, the absorbed contaminants enter the bodies and metabolism of marine organisms. The interactions inside their bodies alter the distribution, biotransformation and toxicity of environmental contaminants. This may lead to an increase in the concentration of contaminants and the potential risk for these to be incorporated into superior trophic chains, thus threatening the health of marine animals. [95,96,97]

A large number of studies provided data on the impact of plastic waste and microplastics to wildlife and especially seabird species. A recent study performed a spatial risk analysis using predicted debris distributions for 186 seabird species and adjusted the model using published data on plastic ingestion by seabirds. The study found that 60% of species (scientific studies from 1962 to 2012) had ingested plastic litter. Also, on average 29% of individual seabird species had plastic in their gut. The study observed that the highest area of expected impact by plastic waste in seabirds occured at the Southern Ocean boundary in the Tasman Sea between Australia and New Zealand. The scientists predicted that plastics ingestion will increase in seabirds and it will reach 99% of all species by 2050.[98]

Figure 15. Scientists scrutinized the impact of plastic waste on seabirds such as albatrosses and shearwaters. They concluded that most of these creatures' guts contained plastic litter mistaken for food (on the left *Puffinus tenuirostris).*

Another aspect of plastic waste is the transfer of plastic derived toxic chemicals, like polybrominated diphenyl ethers (PBDEs) in the abdominal adipose of oceanic seabirds (short-tailed shearwaters, *Puffinus tenuirostris*). A study by Japanese scientists detected in samples collected from the guts of seabirds in North Pacific Ocean, higher-brominated congeners (PBDEs). These compounds were not present in pelagic fish (the food of seabirds). PBDEs were detected in plastic waste found in the stomachs of birds. According to the study these data suggested the transfer of plastic-derived chemicals from ingested plastics to the gut tissues of seabirds.[99] Plastic ingestion is generally considered to be a more serious environmental and toxicity problem for marine animals than entanglement in marine debris because large proportions of wildlife populations are affected. Among seabirds, the albatrosses and petrels (Procellariiformes) have particularly high incidences of ingestion of plastic waste, with many species having plastic in more than half of all individuals examined.[100-102]

Microplastics in the marine environment can be digested by zooplankton and thus enter the planktonic food web. Recent studies focused on the issue of potential threats of microplastics on simple grazing experiments with fluorescent microspheres and zooplankton. A study tested experimentally the potential of different Baltic Sea zooplankton organisms and consisted of two parts: a) direct ingestion experiments with zooplankton and b) studies on food web transfer of microplastics. Mysid shrimps, copepods, cladocerans, rotifers, polychaete larvae and ciliates were exposed to 10 μm fluorescent polystyrene microspheres. These experiments showed ingestion of microspheres in all taxa studied. The highest percentage of individuals with ingested spheres was found in pelagic polychaete larvae, *Marenzelleria* spp. Microscopy observations of mysid intestine showed the presence of zooplankton prey and microspheres after 3 h incubation.[103]

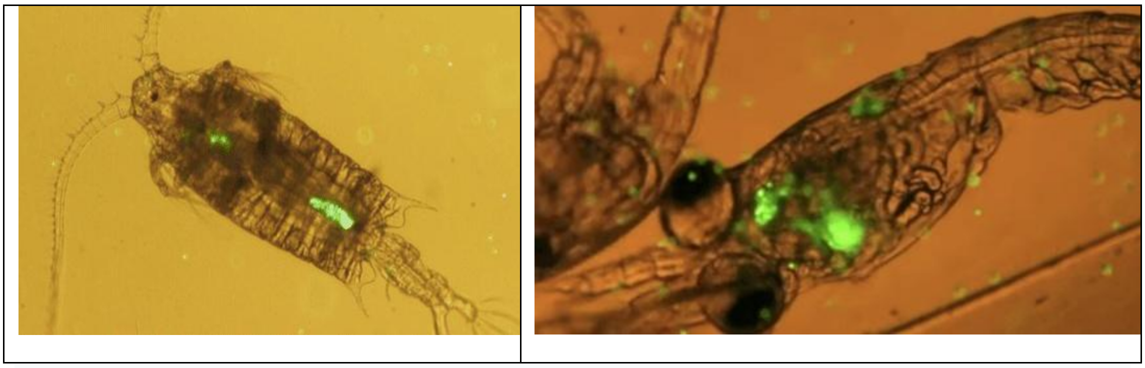

Figure 16. •Microplastics can be ingested by zooplankton organisms and can be detected by bioimaging techniques (using fluorescent polystyrene microspheres). [http://pubs.acs.org/doi/abs/10.1021/es400663f].

Another study showed that microplastics are ingested by, and may impact upon, zooplankton. Scientists used bioimaging techniques to document ingestion and adherence of microplastics in a range of zooplankton common to the northeast Atlantic. Using fluorescence and coherent anti-Stokes Raman scattering (CARS) microscopy they identified that 13 zooplankton taxa had the capacity to ingest 1.7–30.6 μm polystyrene beads.[104]

Studies showed that microplastics can be digested by fish as has been observed in various marine habitats worldwide and in laboratory studies. One of the many studies in the last decade, detected microplastics in 10 species of fish from the English Channel. The study examined more than 500 fish were examined and found microplastic beads in the gastrointestinal tracts of 35% of fish. A total of 351 pieces of plastic were identified using FT-IR Spectroscopy; polyamide. The study showed that there was no significant difference between the abundance of plastic ingested by pelagic and demersal (live and feed near the bottom of seas) fish. [30] Another study focused on the presence of plastic debris in the stomach contents of large pelagic fish (*Xiphias gladius*, *Thunnus thynnus* and *Thunnus alalunga*) caught in the Mediterranean Sea (2012-2013). Around 20% of fish were found to have ingested plastic waste from the marine environment: microplastics (<5 mm), mesoplastics (5–25 mm) and macroplastics (>25 mm). The results showed that around 30% of bluefin tuna (representing endangered species by IUCN) have micro-, meso- and macro-plastics in their gut tissues.[105]

Plastic Waste in the Oceans and Ocean Gyres

In the last years there is a rising concern among scientists and environmentalists regarding the accumulation of floating plastic debris in the open oceans, the quality of ocean waters and their marine biota. The magnitude and the fate of this pollution, especially the predominance of plastic waste, are still open questions. Regional surveys, and previously published reports, showed a worldwide distribution of plastic waste on the surface of the open ocean, mostly accumulating in the convergence zones of each of the five subtropical gyres with comparable density. Also, the global load of plastic on the open ocean surface was estimated to be on the order of tens of thousands of tons, far less than expected. The most well-publicized “patch,” the so called “great Pacific garbage patch,” is an accumulation zone roughly centered at 31°N, 139°W where large-scale anticyclonic (clockwise) ocean circulation acts to trap and retain floating debris, especially plastic waste. Despite the increasing research efforts to understanding the spatial distribution and temporal variance of marine plastic waste, the ecological implications are still largely unknown, particularly in regard to the potential consequences for lower tropic levels (e.g., phytoplankton and marine bacteria).[106]

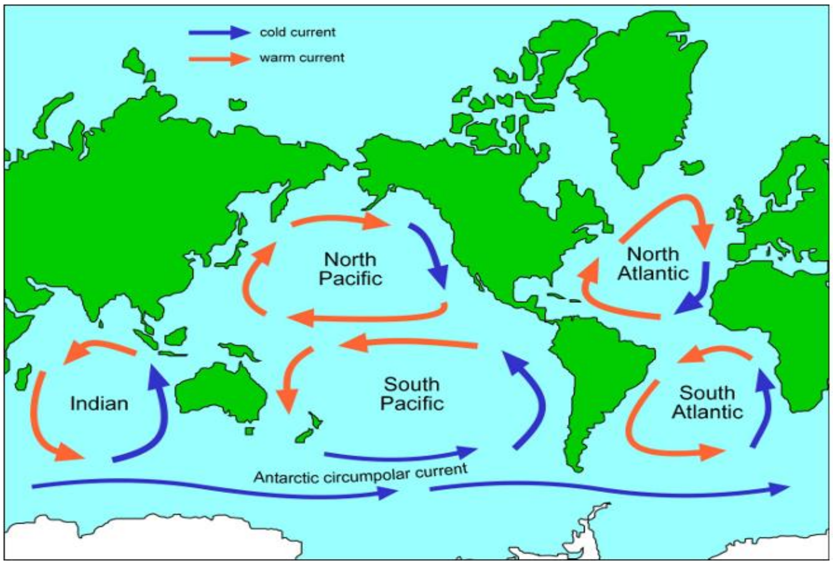

Figure 17. Ocean gyres circle large areas of stationary calm water. Debris and litter especially plastic waste, drift into these areas and, due to the region's lack of movement, can accumulate for years. These regions are called "garbage patches". The Indian Ocean, North Atlantic Ocean, and North Pacific Ocean all have significant litter patches. [Science Learning. http://sciencelearn.org.nz/Contexts/The-Ocean-in-Action/Sci-Media/Images/Map-of-ocean-gyres and National Geographic. Ocean Gyres, http://education.nationalgeographic.org/encyclopedia/ocean-gyre/].

A working group of researchers estimated that just 20 countries, out of a total of 192 countries with extensive coastlines (2-5 km), are responsible for 83% of the plastic litter that accumulate into the world's oceans. Researchers estimated that 192 countries produce some 275 million metric tons (Mt) of plastic waste each year, of which 4.8–12.7 million metric tons of mismanaged plastic waste is thought to have entered the ocean in 2010. Scientists emphasized that, without improvements to waste management infrastructure, with recent increased coastal populations economic growth, and increased use of plastic materials, the volume of plastic waste in the oceans could more than double by 2025.[107]

In 2014 another important study observed that the size distribution of floating plastic debris point at important size-selective sinks removing millimeter-sized (mm) fragments of floating plastic on a large scale. This sink may involve a combination of fast nano-fragmentation of the microplastic into particles of microns or smaller, their transference to the ocean interior by food webs and ballasting processes, and

processes yet to be discovered. Resolving the fate of the missing plastic debris is of fundamental importance to determine the nature and significance of the impacts of plastic pollution in the ocean. The dataset collected from the circumnavigation cruise [Malaspina 2010 expedition, floating plastic was collected with a neuston net (1.0- × 0.5-m mouth, 200-μm mesh) towed at 2–3 knots for periods 10–15 min, total tows 225] were 3,070 samples from around the world. The concentration of plastic litter ranged broadly, spanning over four orders of magnitude across the open ocean. The distribution pattern agreed with those predicted from ocean surface circulation models confirming the accumulation of plastic debris in the convergence zone of each of the 5 large subtropical gyres. The scientific group estimated the amount of plastic waste in the open-ocean surface between 7,000 and 35,000 tons. The plastic load in the North Pacific Ocean could be related to the high human population on the eastern coast of the Asian continent, the most densely populated coast in the world. Examination of the size distribution of plastic debris on the ocean surface shows a peak in abundance of fragments around 2 mm and a pronounced gap below 1 mm.
The scientists emphasized that the pathway and ultimate fate of the missing plastic litter are as yet unknown and it is likely to involve a combination of multiple sinks. They propose that missing microplastic may derive from nano-fragmentation processes, rendering the very small pieces undetectable to convectional sampling nets, and/or may be transferred to the ocean interior. The abundance of nano-scale plastic particles has still not been quantified in the ocean and the measurements of microplastic in deep ocean (sediments) are very scarce.[108]

A group of scientists (first author, Eriksen Marcus, co-founder of the 5 Gyres Institute in the US) traveled in the South Pacific subtropical gyre (March-April 2011, trip of 4,489 km) and took neuston samples (using a manta trawl lined with a 333 μm mesh) at 48 sites (averaging 50 nautical miles apart) in order to measure marine pollution (especially plastic litter) in the open ocean of the southern hemisphere which was largely undocumented until then. The results showed an increase in surface abundance of plastic debris in the center of the gyre and a decrease as we moved away, verifying the presence of a garbage patch. The average abundance and mass was 26,898 particles.km^{-2} and 70.96 g.km^{-2}, respectively. The study found that 89% of the plastic pollution was found in the middle third of the samples with the highest value occurring near the center of the predicted accumulation zone.[109]

Scientists in the last few years focused on oceanographic model predictions of where debris (including plastic waste) might converge in the global oceanic environment. Until now, estimates of regional and global abundance and weight of floating plastics have been limited to microplastics. They used published survey data, particularly from the Southern Hemisphere subtropical gyres and marine areas adjacent to populated. The oceanographic model assumed that the amounts of plastic entering the ocean depend on three principal variables: watershed outfalls, population density and maritime activity. The dataset used in this model was based on expeditions from 2007–2013 surveying all five sub-tropical gyres (North Pacific, North Atlantic, South Pacific, South Atlantic, Indian Ocean) and extensive coastal regions and enclosed seas (Bay of Bengal, Australian coasts and the Mediterranean Sea). In a 2014 report scientists estimated accumulated all data and estimated the total number of plastic particles and their weight floating in the world's oceans from 24 expeditions (2007–2013, 5 sub-tropical gyres, costal Australia, Bengal and the Mediterranean Sea). Using an oceanographic model of floating debris dispersal calibrated by all data, and correcting for wind-driven vertical mixing, they estimated a minimum of 5.25 trillion particles weighing 268,940 tons. When comparing between four size classes, two microplastic <4.75 mm and meso- and macroplastic >4.75 mm, a tremendous loss of microplastics was observed from the sea surface compared to expected rates of fragmentation, suggesting there are mechanisms at play that remove <4.75 mm plastic particles from the ocean surface.[110]

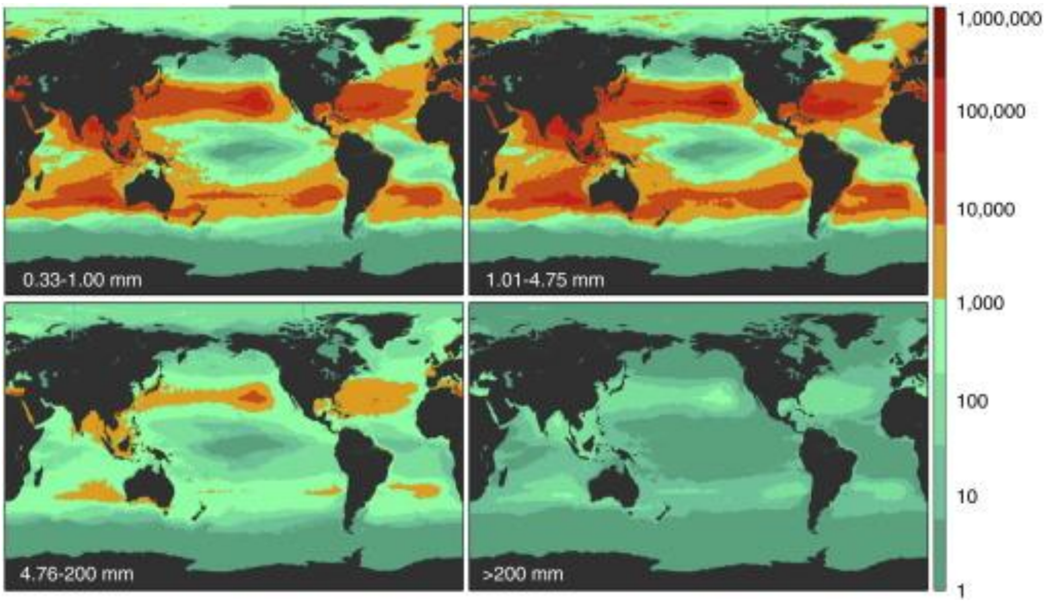

Figure 18. The Eriksen et al. survey and modeling of plastic waste. Combining data from 24 sampling missions with oceanographic computer modeling. Eriksen and colleagues predicted the global distribution of plastic particles in specific size classes. (Source:(2014) PLoS One http://dx.doi.org/10.1371/journal.pone.0111913.g002].[110]

Another recent study collected data on litter distribution and density (especially plastic waste) collected during 588 video and trawl surveys across in 32 sites of European waters. In their publication, scientists focused on the fact that they found litter to be present in the deepest areas of the sea and at some remote locations. The highest litter density occured in submarine canyons, whilst the lowest density was found on continental shelves and on ocean ridges. The study showed that plastic waste (various items and sizes) was the most prevalent litter item found on the seafloor. Litter from fishing activities (derelict fishing lines and nets) was particularly common on seamounts, banks, mounds and ocean ridges.[111]

Figure 19. Ocean pollution by plastic waste is becoming a bigger problem each year. When floating plastic litter gets in the ocean it usually ends up in one of the gyres. [https://www.pinterest.com/pin/237564949064006320/?from_navigate=true]

Other scientists emphasized the urgency to standardize common methodologies to measure and quantify plastics in seawater and sediments and their ecological consequences of widespread plastic pollution. An elevated number of marine species is known to be affected by plastic contamination, and a more integrated ecological risk assessment of these materials has become a research priority. Microplastics and chemical additives are accumulated by planktonic and invertebrate marine organisms and as a result are transferred along food chains. Negative consequences include loss of nutritional value of diet, physical damages, exposure to pathogens and transport of alien species. Because of plastic pollution complex ecotoxicological effects are increasingly reported in scientific publications.[112]

A recent study (2015) (Marine Debris Working Group at the National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara, with support from Ocean Conservancy) estimated the global standing stock of small floating plastic debris (microplastics) with the most comprehensive dataset, ocean models and ocean plastic input available. The scientific group compiled all available plastic data collected with surface-trawling plankton nets (more than 11,000 observations, including the surveys on papers of Cózar *et al* 2014[108] and Eriksen *et al* 2014[110]), using a rigorous statistical model, and then used the standardized dataset to scale the outputs of three ocean circulation models. The final report estimated that the accumulated number of microplastic particles in 2014 ranges from 15 to 51 trillion particles, weighing between 93,000 and 236,000 metric tons, which is only approximately 1% of global plastic waste estimated to enter the ocean in the year 2010. According to the research group these estimates are larger than previous global estimates, but vary widely because the scarcity of data in most of the world oceans, differences in model formulations, and fundamental knowledge gaps in the sources, transformations and fates of microplastics in the ocean.[113,114]

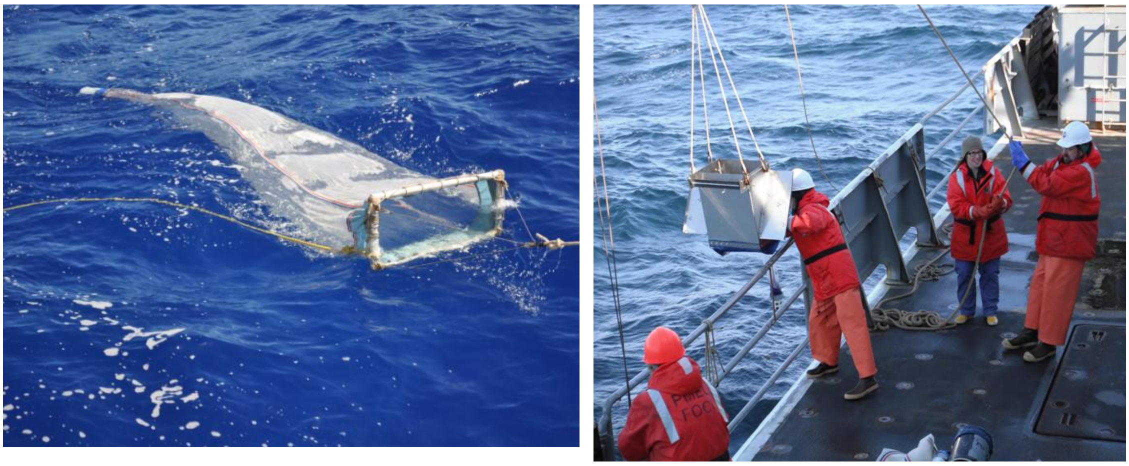

Figure 20. Most plastic debris collected in surface-towing plankton nets can be classified as microplastics (smaller than 5 mm in size),

Another problem of plastic waste pollution in the oceans that drew the attention of scientists was the potential for microplastics to sorb hydrophobic organic chemicals (some of them highly toxic) which in turn to transfer to aquatic organisms. Results of laboratory experiments and modeling studies indicate that hydrophobic chemicals can partition from microplastics to organisms but little information is available to evaluate ecological or human health effects from this exposure. Most of the available studies measured biomarkers that are more indicative of exposure than effects, and no studies showed effects to ecologically relevant endpoints. Therefore, evidence is weak to support the occurrence of ecologically significant adverse effects on aquatic life.[115]

Policies for the Reduction of Plastic Pollution in the Oceans

Marine pollution policies in many developed countries has change recently due to the long-time threads of plastic marine debris. Existing policies for waste management, especially plastic, marine debris monitoring and awareness campaigns were evaluated in many developed countries and recommendations included improved practices in law and waste management strategies; education, outreach and awareness; source identification of marine pollution; and increased monitoring and further research for microplastics, introduction of biodegradable plastics and adverse effects on marine biota. In many countries established programs were designed to remove macroplastics from beaches, waterfronts, and oceans despite the gaps of scientific knowledge. A few global initiatives do exist on plastic contamination, disposal, and pollution prevention. However, because plastic wastes are globally persistent, development of both international and regional management strategies are required to address the issue.[116]

The first action recommended at international meetings is the prevention of pollution from ships aimed at preventing disposal of waste at sea. The International Convention for the Prevention of Pollution of Ships (MARPOL) Annex V prevents pollution of plastic waste by ships through international agreements and domestic legislation. Some countries have their own domestic legislation (e.g. *US Marine Plastic Pollution Research and Control Act*). Many ports across North America have also adopted the *Green Marine* environmental program, requiring participants to provide adequate reception facilities at ports for ship generated waste. Canada has a framework policy to mitigate plastic marine pollution.[117]

The United Nations Environment Programme (UNEP) governs the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities, which provides a mechanism for development and implementation of initiatives to address transboundary issues. Microplastic and other marine debris issues are addressed by the same program. Additionally, UNEP collaborates with the International Oceanographic Commission of the United Nations Educational, Scientific, and Cultural Organization to develop guidelines to monitor marine litter. [118] The National Oceanic and Atmospheric Administration (NOAA) and UNEP developed the UNEP Honolulu Strategy after the Fifth International Marine Debris Conference in March 2011.[119]

The United States Environmental Protection Agency (USEPA) Marine Debris Strategy, and the Global Partnership on Marine Litter (GPML) focuses on three main objectives: land-based prevention, ocean assessment and cleanup, and land-based reduction of marine debris.[120] Also, many NGOs in various countries (Non-Governmental Organizations) started many years ago to monitor marine debris (especially plastic litter) and promote waste management education practices. The 5 Gyres institution focuses on impacts of plastic marine pollution in five subtropical ocean gyres where plastic accumulates to investigate distribution of microplastics and associated POPs. The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) advises for years the UN's system on the scientific aspects of marine environmental protection. Clean Seas Coalition (CSC, environmentalists, scientists, lawmakers, etc) targets Californian seas and beaches, including the North Pacific Gyre, for awareness of marine pollution. The International Coastal Cleanup (ICC) is a movement guided by Ocean Conservancy that unites volunteers around the world to clean up aquatic and marine environments and provide recommendations for the state Ocean Protection Council [Clean Seas Coalition, Clean Seas Coalition, [Available at http://cleanseascoalition.org/] (accessed 16). The Ocean Conservancy is also a current founding member of the Trash Free Seas Alliance, which "provides a constructive forum focused on identifying opportunities for cross-sector solutions for marine litter.[121]

European Union countries have advanced various environmental policies to reduce plastic pollution of the oceans and recycling of plastic waste. Many European nations have not only passed EPR (*extended producer responsibility* EPR, which was first formally outlined in an internal Swedish government report in 1990). laws to increase reuse and recycling of plastics. Many EU countries (Denmark, Sweden etc) for many years are diverting plastics waste to power plants for use as fuel for heat and electricity (a process called waste-to-energy, or WTE). In Europe, an estimated 25.2 million metric tons of post-consumer plastic was discarded in 2012, according to the manufacturers association PlasticsEurope. From the plastic waste produced 26% was recycled, 36% was recovered for fuel, and 38% went to landfills. Some EU nations (9 from 28) have banned landfills for plastic waste and other domestic waste. The plastic manufacturers, PlasticsEurope, recommended to the consumers for zero plastic waste going to European landfills by 2020.[122]

MARLISCO is a European initiative, which developed and implemented activities across 15 European countries, towards raising societal awareness and engagement on marine litter, through a combination of approaches: public exhibitions in over 80 locations; a video competition involving 2100 students; and a legacy of educational and decision-supporting tools. 12 national participatory events designed to facilitate dialogue on solutions brought together 1500 stakeholders and revealed support for cross-cutting, preventive measures.[123]

The Mediterranean Information Office for Environment, Culture and Sustainable Development (MIO-ECSDE, Athens, Greece), is the Federation of the wider existing spectrum of environmental, cultural and development NGOs active in the Mediterranean. MIO-ECSDE is active and cooperates in research and surveys on plastic pollution in the marine environment, especially in the Mediterranean Sea.

Another interesting programme is Derelict Fishing Gear Project in the Adriatic Sea (DeFishGear) is addressing wider context of the marine litter (among others, lost and abandoned fishing nets, microplastics, etc in the Adriatic Sea) of issue to ultimately provide a key strategic input on a regional level. The Adriatic region is facing a big gap when it comes to marine litter analysis. It results in a lack of appropriate mitigation measures aimed at reducing marine pollution evident in every country of the region. MIO-ECSDE [http://mio-ecsde.org/] organized the conference “Tackling marine litter in the Mediterranean” which took place in Athens, Greece in February 2016. Also, MIO-ECSD participated in the Conference under the title **"**Fate and Impact of Microplastics in Marine Ecosystems: From the Coastline to the Open Sea" **(**Spain, from in May 2016). In the last few years the number of conferences in Europe and in other continents on plastic waste, marine pollution, microplastics and toxic effects on marine biota has increased substantially.

Conclusions

Since plastic production began in the 1950s, plastic waste or litter or garbage, has been accumulating in Earth’s natural environment, especially in the marine environment and the oceans. This is the result of our consumer society, massive production of single use plastic packaging items and thrown away after use mentality. The results are obvious today in the natural environment and the threat of plastic debris on the marine environment were reviewed by numerous scientific studies and international surveys. Today, scientists, consumers and environmentalists agree that rigorous approaches are urgently required to mitigate the problem of plastic waste. Unlike other materials (wood, paper, grass, metals) plastic are strong, non-biodegradable and float in water. Weathering degradation of plastics items results in their surface embrittlement and microcracking. Finally, after many years plastics are breaking into small pieces, yielding microparticles (>1 mm), that are carried into water by wind or wave action. Also, microplastics can concentrate persistent organic pollutants (POPs) that can be ingested by marine biota. Bioavailability and the efficiency of transfer of the ingested POPs across trophic levels are not known and the potential damage posed to the marine ecosystem has yet to be quantified and modelled. Recent studies showed that microplastics have been accumulating in the oceans for at least over the last four decades. Plastic litter with a terrestrial source contributes ~80% of the plastics found in marine litter. Plastic litter has permeated marine ecosystems across the globe and driven by ocean currents, winds, river outflow and drift can be transported vast distances to remote, otherwise pristine, locations (the poles, ocean gyres and ocean depths). Over the past decade, increased scientific interest has produced an expanding knowledge base for microplastics, but fundamental questions and issues remain unresolved. International and national programmes have been initiated aiming to mitigate the spread of this marine pollution with limited success.

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