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THE PROBLEM OF PLASTIC WASTE AND MICROPLASTICS IN THE SEAS AND OCEANS: IMPACT ON MARINE ORGANISMS

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ABSTRACT

A global problem of today is the large amount of waste in the seas and oceans, primarily plastic waste. It is estimated that every year 1.25 to 2.41 million tons of plastic material is being carried by rivers into the seas and oceans. Waste is a major problem for marine organisms, causing entanglement, choking, strangulation, malnutrition and death. In 1972 the problems caused by microplastics, particles smaller than 5 mm, were first observed. Such particles bind pathogenic microorganisms on to their surface. Increasing quantities of microplastics have been found in the stomachs of fish, and also in shellfish that feed by filtering sea water. Ingested by marine organisms, such plastics may eventually pass through the food web and can end up ingested by humans. In addition, plastic releases chemical compounds whose effect on marine organisms and humans has still not been studied. Many international and state organizations offer solutions through recycling plastic waste, as well as reducing the production of plastic materials and informing the public about the problem.

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INTRODUCTION

As defined by the United Nations Environment Programme (UNEP) 2009 in the publication 'Marine Litter: A Global Challenge', waste in the sea is any persistent, manufactured or processed solid material discarded or washed into the sea or coastal area. It is not possible to give exact quantities, but the UNEP report estimates that only 15% of the waste is floating on the surface of the sea, 15% is hovering in the water column, and 70% is on the sea bottom. The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) have estimated that land sources account for up to 80% of world sea pollution, of which 60% to 95% is plastic waste. The problem of plastic waste first appeared in the 1950s when massive production of plastic began, with about 1.5 million tons per year being produced. Because it is a highly practical material, being flexible, lightweight and easy to handle, it has quickly entered into everyday use, particularly in America. Plastic production is steadily increasing and has now reached 300 million tons per year, of which about 50% is in the form of such products as plastic bags, drinking bottles, cutlery, straws, ear sticks, etc., which are discarded after a single use (Nerland et al., 2014). Rivers, sea level changes, floods and winds are the principle 'culprits' for bringing waste from land into the sea; other waste is the result of fishing activities, shipping, marine facilities such as oil platforms and sewage systems. Data from 2010 shows that between 4.8 and 12.7 million tons of plastic waste has been released into the world seas and oceans (Van Cauwenberghe et al., 2015). Once it enters the sea, plastic becomes a major problem for marine organisms. Remains of fishery materials, plastic bags and other plastic waste can be twisted around parts of an animal's body, which inhibits normal growth and development, movement, reproductive activity and feeding activity, besides which animals often swallow plastic waste considering it food (Laist, 1997). A special problem is presented by microplastics, plastic particles smaller than 5 mm. In 1972 the first data on plastic in this size range was recorded in the Sargasso Sea; the name microplastics was first used in 2004. Microplastics are divided into two groups: primary microplastics including polyethylene fibres from cosmetic products such as body scrubs, various cleaning agents, toothpastes, etc., which drain through the sewage and flow with the waste water into the seas and oceans. There are also secondary microplastics that are formed in the process of disintegration of larger plastic particles under the influence of the sun, salt water, waves and other abiotic factors (Moore, 2008).

Plastics and microplastics in the world

All plastic that goes into the sea is moved and redistributed by the wind and sea currents. In the oceans there are extensive and constant sea currents, which also form large circulating systems, known as gyres. Once plastic ends up in such an eddy, it usually remains in it because there is no current to draw it out. There are five large ocean gyres that accumulate huge amounts of floating plastic waste (Eriksen et al., 2014) (Fig. 1).

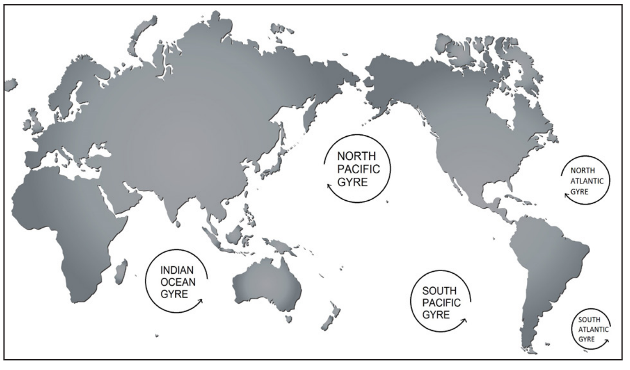

Fig 1. Five world largest oceans garbage gyres

In 1997 US Captain Charles Moore discovered that there was a large amount of accumulated floating waste in the northern Pacific Ocean, often in the media called 'The Great Pacific Garbage Patch'. This patch extends over 1.6 million square kilometres, which is three times larger than the area of France, or 29 times larger than Croatia. Every year, about 8 million tons of plastic gets into the oceans, where it is estimate that more than 150 million tons are already present (Rujnić-Sokele, 2015). Assuming that plastic production will continue to increase at the present rate, by 2025 there will be nearly 250 million tonnes of plastic in the oceans, which is 1 ton of plastic for every 3 tons of fish; by 2050 there will be more plastic than fish. Because of the immediate urgency of the plastic waste problem, extensive research on the subject is being initiated. Among them is a study that covers eighteen areas on six continents, which has demonstrated a proportionate increase of plastic and microplastics particles with population density. The research was initiated by the 'The Ocean Cleanup Foundation', involving six universities and one airline company. They have discovered that the greatest microplastics concentrations are in the North Sea, the Mediterranean Sea, along the Asian coast and along the densely populated coast of Brazil (Van Cauwenberghe et al., 2015). 'The 5 Gyres Institute' is an organization for research into the Great Pacific Garbage Patch. It is the first organization to research plastic pollution in all five main subtropical gyres and the first to estimate the total amount of plastic on the surface of the world's oceans: nearly 270,000 metric tons and 5.25 trillion pieces (Eriksen et al., 2014). This organization promotes awareness of microplastic damage in the world, and delivers measures and regulations for cosmetic companies to reduce the primary source of microplastics.

Plastics and microplastics in the Adriatic Sea

Pollution with plastic waste in the Adriatic Sea is substantial, primarily because of the waste that sea currents bring from Greece, Albania and Montenegro (Tutman et al., 2017). In order to learn more about the waste problem in the Adriatic Sea, the project 'Derelict Fishing Gear Management System in the Adriatic Region', briefly 'DeFishGear', has been initiated. It includes seven countries: Greece, Albania, Montenegro, Bosnia and Herzegovina, Italy, Croatia and Slovenia. The project leader in Croatia is the Institute of Oceanography and Fisheries in Split. The purpose is to solve the problems of waste in the Adriatic Sea, to exchange experiences and to raise the awareness in these countries about the seriousness of the plastic waste problem. Within the project, the first assessment of pollution in the Adriatic Sea was made, based on data from pilot areas (Hvar and Tribunj). Cooperation with fishermen and fishing unions was established. Containers for the disposal of waste collected by fishermen during 'Fishing for Litter' initiative were set up in the Bay of Vira on Hvar Island and in Tribunj. In this activity, 8 fishing boats with 14 fishermen from the fishing community 'Hvar' and 12 fishing boats with 25 fishermen from the fishing community 'Adria' from Tribunj (Pavičić et al., 2015) participated. In total, between November 2014 and March 2016, 30.8 tons of waste were collected from the sea in the central Adriatic, an average of 50 - 100 kg per boat in a month, or an average of about 5 kg per boat in one fishing trip (Tutman et al., 2017). To oversee the 'DeFishGear' project activities, the Association for Nature, Environment and Sustainable Development 'Sunce' from Split was chosen. In 2014, the Association 'Sunce' compiled a program known as the 'Marine and Coastal Management Strategy' whose main goal is to monitor waste in the Adriatic Sea. According to the recommendations of European Commission's technical working group for waste at sea and beaches, four locations were selected that meet the default parameters of the waste monitoring project in the Croatian part of Adriatic Sea. Two beaches were chosen in the Split-Dalmatia region (Zaglav beach on the island of Vis and Punta beach in Omiš), and two in the Dubrovnik-Neretva region (the beach along the Neretva River and Saplunara Beach on the island of Mljet). Within waste collected at these locations, the most frequently found objects were pieces of plastic and styrofoam of 2.5 to 50 cm size, ear sticks and plastic bottle caps (Tutman et al., 2017). In other research, it has been established that the coastline of the River Po Delta receives a plastic flux of approximately 70 kg (km day^{-1}) (Liubartseva et al., 2016). The most polluted sea surface area (> 10 g km^{-2} floating debris) is represented by an elongated band shifted to the Italian coastline and narrowed from northwest to southeast (Liubartseva et al., 2016). Also on the Northern Adriatic coast, small plastic debris in sediments from five beaches was investigated to evaluate its occurrence and abundance. A total of 1345 items of debris (13.491 g) were recorded, fragments being the most frequent type of small plastic debris (Munari et al., 2017). Microplastics (<5 mm) accounted for 61% of debris, showing a wide distribution on the Adriatic coast, even far away from densely populated areas, but there were greater quantities of microplastics at sites subjected to stronger riverine runoff (Munari et al., 2017). In the central Adriatic Sea, plastic debris extracted from 64 samples of sediments were analysed. Plastic particles ranged from 1 to 30 mm in length. Microplastics (1–5 mm) accounted for 65.1% of debris, mesoplastics (5–20 mm) made up 30.3% of the total amount, while macro debris (> 20 mm) accounted for 4.6% of total plastics collected (Mistri et al., 2017).

Researchers from the mentioned project 'DeFishGear' were first to deal with the presence of microplastics in the digestive tracts of fish in the Adriatic Sea. Three commercially important species of fish with different habitats and dietary preferences were examined: striped red mullet (*Mullus surmuletus*), common pandora (*Pagellus erythrinus*) and sardine (*Sardina pilchardus*). In all three species particles were found that could potentially be microplastic. Out of total 203 individuals of striped red mullet (*Mullus surmuletus*), within 63 of their stomachs (31.03%) plastic fragments were found (Šiljić et al., 2015). Another study examined the occurrence of microplastic litter in the gastrointestinal tract of common sole (*Solea solea*) and its distribution in the northern and central Adriatic Sea. The digestive tract contents of 533 individuals collected during 2014 and 2015, from 60 sampling sites, were examined. Microplastics were recorded in 95% of sampled fish, with more than one microplastic item found in around 80% of the examined specimens (Pellini et al., 2018).

Influence on the living world

These huge quantities of waste have a negative impact on life in the sea, causing entanglement, suppression, strangulation, malnutrition and frequently death. The most affected are usually fish, marine mammals, birds and sedentary fauna such as corals. Of all the observed interactions of marine organisms with waste, 92% of them were with plastic waste (Gall and Thompson, 2015). In 71% of cases, the animals were entangled in plastic ropes or nets, in 37% of cases animals swallowed plastic pieces, of which 17% of species swallowed or tangled in plastic waste are on the Red List of Endangered Species of the International Alliance for Nature Conservation (Gall and Thompson, 2015). Approximately 640,000 tonnes of fishing gear is lost, left or dropped into the sea per year (Macfadyen et al., 2009). These abandoned fishing nets continue to catch fish and other marine animals for years and decades. Entanglements were recorded in all seven species of sea turtles (100%), 67% seals (22 out of 33), 31% whales (25 out of 80) and 25% species of marine birds (103 out of 406) (Kühn et al., 2015). Sea animals often mistake plastic for food (jellyfish, plankton). It is estimated that at least 170 species of vertebrates and invertebrates ingest anthropogenic waste during their lifetime (Vegter et al., 2014). Apart from via the mouth, in fish microplastics can also be absorbed through the gills. Once plastic gets inside the body, it causes problems with digestion leading to gastrointestinal blockage which results in death (Baulch and Perry, 2014). Microplastics are transmitted through the food web and in the end may be ingested by humans (Browne et al., 2013). In the case of fish, the highest concentration of microplastics is found mainly in the stomach and intestines, and since these components are normally removed before consumption, it is not transferred to humans (Browne et al., 2013).

Shellfish are generally consumed whole with their digestive system so a greater amount of microplastics is ingested by humans. Since shellfish feed by filtering the seawater, and on average filter approximately 40 L of seawater per day (in optimal conditions up to 80 L), they accumulate a much larger amount of microplastics within their body (UNEP/WHO/IAEA, 1988). It is estimated that the average European introduces up to 11,000 particles of microplastics into their body per year by consuming shellfish (Van Cauwenberghe and Janssen, 2014). It has been confirmed that micoplastics have been found integrated into the epithelial cells of the intestinal tract of mussels (Von Moos et al., 2012). There were also specimens where these particles were translocated through the intestinal wall into the circulatory system (Browne et al., 2008). Due to the difficulty of estimating microbial toxicity within the body, effects on human health are still uncertain. It is generally assumed that nanoplastics (<1 µm) are a greater risk than microplastics, since they can enter human cells; however, nanoplastics have not yet been sufficiently investigated. Besides that, there is another problem: floating waste gets covered with shells, diatoms and algae and in this way such marine species are transmitted to places where they are not naturally found, resulting in the problem of invasive species (Rujnić-Sokele, 2015).

Microorganisms and toxic chemicals

The most common type of plastic polymers are polyethylene (about 50%) and polypropylene (about 40%), and they are the main components of microplastics in the sea (Nerland et al., 2014). More than 300 chemical compounds are used as additives in plastic production and constitute several categories: plasticizers or softeners, enhancers, fillers, pigments, flame retardants, modifiers, etc., many of which are harmful to the environment. Such chemicals have the ability to accumulate in sediment and in the tissues of organisms, and have a detrimental effect on the physiological functions (Browne et al., 2013). It has been established that polymers such as polyvinyl chloride, polystyrene and polycarbonate release toxic monomers that are associated with cancer and reproductive abnormalities in humans, rodents and invertebrates (Lithner et al., 2011). PVC is an extremely harmful form of plastic for the environment because it contains more than 90% of all additives. The use of some additives is regulated, because of their easy release from plastics into the environment and their mutagen, neurotoxic and reproductive toxicity. In addition, microplastics can also serve as a substrate for different microbial communities, or as a vector in the transmission of foreign (potentially pathogenic) microbial species. According to Browne et al. (2013), animals inhabiting marine sediments are extremely vulnerable and subject to the harmful influence of microplastics which can accumulate about 100 times higher concentrations of toxic compounds than the sediment. The fibrous and elongated forms of microplastics are more toxic than spherical forms, and they are more prone to accumulate in benthic organisms, detritivores and scavengers (Wright et al., 2013).

Solutions for the future

In order to resolve this global problem effectively, it is important to start from the beginning with the production itself. The European Commission has begun implementing regulations on the reduction of plastic production, especially single-use plastic products. The ban will apply to plastic ear sticks, plastic cutlery, straws, mixing sticks for drinks and balloon holders. All these products will have to be produced only from sustainable materials. EU member states will have to reduce the use of plastic food containers and drink cups, and by 2025 will need to organize the collection of 90% of disposable plastic bottles, for example through a return program. According to a report by the US oceanic organization 'Ocean Conservancy' which was made in cooperation with the McKinsey Center for Business and Environment, the measures that would give the best results in minimizing the entry of plastic waste into the seas and oceans are: expanding waste disposal services, closing waste leakage into the environment during transport and on open landfills, incineration or gasification of waste in large areas, and manually sorting and recycling in smaller areas (Rujnić-Sokele, 2015). It is also important to inform individuals about the harmful influence of plastic waste on the environment and to develop awareness about reducing the amount of waste and the importance of recycling.

It has also been noted that plastics can be degraded, although the procedure is complex and time-consuming. Bacteria can be used to degrade plastic, in order to accelerate the process. Researchers at the University of Dublin have discovered a type of *Pseudomonas bacteria* that is capable of producing polyhydroxy alkanoate (PHA) from PET. More precisely these bacteria feed with terephthalic acid, which is the basic ingredient of PET. PHA is a biodegradable plastic material that is used in many areas, for example medically for surgical stitches, and is degraded in any kind of environment (Kenny et al., 2008). Chinese scientists have proved that the Indian meal moth (*Plodia interpunctella*) larvae eat a polyethylene film (Yang et al., 2015). Researchers from the Oceanographic Institute of Woods Hole, Massachusetts have found a bacterium that feeds on plastics at the bottom of the Sargasso Sea. However, the part of the sea from which they extracted plastics is poor with phosphorus and other nutrients, so bacteria were forced to eat plastic to survive (Zettler et al., 2013). The latest research is from Japan where researchers have isolated a new type of *Ideonella sakaiensis* bacterium that destroys basic ingredients of PET - terephthalic acid and ethylene glycol - by hydrolysis, with the help of two enzymes. The bacteria were found in a recycling plant (Yoshida et al., 2016).

CONCLUSION

Over the past few years the amount of plastic that ends up in the seas and oceans has been rapidly increasing. However, the pollution problem did not receive significant attention until it became visibly harmful for ecosystems and organisms, which is now the major reason for urgent global action. Non-governmental organizations have an important role in promoting awareness of marine waste and informing the public. More scientific institutions should be involved in research into this issue, and should participate in cooperation with state administrations in creating strategies and legal regulations for reducing plastic pollution. Examples of bacteria that feed on plastics show how nature is adapting to this problem, but that is a slow process and there is an urgent need to help the environment in the struggle to fix the damage that we ourselves have caused.

SAŽETAK

PROBLEM PLASTIČNOG OTPADA I MIKROPLASTIKE U MORIMA I OCEANIMA: UTJECAJ NA MORSKE ORGANIZME

Globalni problem današnjice je velika količina otpada u morima i oceanima, ponajprije plastičnog otpada. Procjenjuje se da svake godine putem riječnih tokova u mora i oceane dospije 1,25 do 2,41 milijuna tona plastike. Otpad predstavlja veliki problem morskim organizmima, uzrokujući zaplitanje, gušenje, davljenje, pothranjenost i smrt. 1972. godine otkriven je problem mikroplastike, čestica plastike koje su manje od 5 mm. Takve čestice na sebe vežu patogene mikroorganizme. Sve više mikroplastike pronalazi se u želucima riba, ali i u školjkašima koji se hrane filtriranjem mora. Morske životinje unose plastiku u svoj organizam, naposljetku putem hranidbenog lanca dolaze i do čovjeka. Osim toga, plastika otpušta kemijske spojeve za koje još nije dovoljno dokazano kako djeluju na morske organizme, ali i na ljude. Mnoge svjetske i državne organizacije navode rješenja putem recikliranja plastičnog otpada, kao i smanjivanja same proizvodnje plastičnih materijala te informiranja javnosti o navedenom problemu.

Ključne riječi: more, otpad, ribe, ljudski utjecaj

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