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PLASTIC MARINE POLLUTION

ONESNAŽENJE MORJA S PLASTIKO

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Abstract

A large amount of plastic products end up in the oceans as plastic waste. Plastic parts break down into a considerable amount of microplastics that affect marine biota. The effect of plastic particles on marine biota is analyzed and a short overview of the amount and dimensions of plastic particles in the world's oceans are given herein. This paper deals with the connection between waste streams and the calculated distribution of plastic concentration in the oceans. Using an oceanographic model of floating debris dispersal this was estimated at a minimum of 5.25 trillion plastic particles in the world's oceans, weighing a total of 268,940 tons. After quantifying the plastic debris, a comparison is made among the world's oceans. Discrepancies from the expected results are identified and explained. Finally, some ideas and solutions are given for reducing the amount of plastic litter in the oceans.

Keywords: microplastics, pollution, ocean, marine biota, measurements.

Izvleček

V oceanih se kopiči velika količina odvrženih plastičnih izdelkov. Plastični izdelki razpadajo v večje število mikroplastičnih delcev, ki vplivajo na življenje v morju. V prispevku smo analizirali vpliv plastičnih delcev na živi svet v morskem okolju ter podali kratek pregled količine in velikosti plastičnih delcev v oceanih. Članek obravnava povezavo med morskimi tokovi in izračunano razdelitvijo koncentracije plastičnih delcev v oceanih. S pomočjo rezultatov oceanografskega modela za beleženje plavajočih delcev razpadle plastike je bilo ocenjeno, da je minimalno število plastičnih delcev v svetovnih morjih 5,25 trilijona z maso 268.940 ton. Glede na izvedeno kvantifikacijo plastičnih delcev smo primerjali stanje med najpomembnejšimi oceani. Analize kažejo odstopanja od pričakovanih rezultatov, ki smo jih v članku komentirali. Prikazali smo nekatere predloge in rešitve za zmanjšanje količin odpadne plastike v oceanih.

Ključne besede: mikroplastika, onesnaženje, ocean, morska biota, meritve.

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1. Introduction

"*By 2050 there will be more plastic than fish in the world's oceans*" Washington Post, 20 January 2016. Plastic Oceans are becoming a terrifying possibility for the future due to the failure to control land-based plastic trash (Raubenheimer and McIlgorm, 2017).

The world is slowly realizing the enormous impact of the invention of plastic in the early nineteenth century. As currently the plastic economy is a linear system, with discarded plastic never fed back into the economy, there is a consequential major build-up of durable plastic trash (Raubenheimer and McIlgorm, 2017). A portion of this litter ends up the oceans. The statistics on this topic are alarming. The National Academy of Sciences in the USA estimated in 1997 that around 6.4 million tons of litter enter the world's oceans every year (van Doorn et al., n.d.). Currently, estimations approximate around 8 million tons per year ("Plastic Oceans Foundation," n.d.). It is clear that this problem should not be neglected. It affects the oceans and their ecosystems and eventually perhaps our health, due to the bio-magnification process up the food chain (Reisser et al., 2013). In addition to bio-magnification, marine plastic debris also creates conditions under which marine organisms possibly move into new environments. These non-domestic species are one of the greatest causes of the loss of biodiversity (Barnes and Milner, 2005). Oceanic fauna must further deal with changes to its environment as the plastic input accumulates. Accidental ingestion and entanglement leads to disastrous effects on marine life and ecosystems (Gregory, 2009; McCauley and Bjorndal, 1999; Schuyler et al., 2012; Tekman et al., n.d., p. Litterbase; Verlis et al., 2013). This paper gives a short overview on "plastic oceans", the current situation, problems, and possible solutions.

2. Plastic in oceans: quantification

A variety of terms are used to describe the products of plastic breakdown, depending on the size of the resulting plastic particles. The prefixes micro, meso, and macro are poorly defined when used to describe plastic pollution. Generally accepted microplastic boundaries are based on the size of a typical neuston net mesh (0,33 mm) with an upper boundary of approximately 5.0 mm. Mesoplastic has a lower limit of 4.75 mm, which is the size of standard sieves used for sample analysis in most expeditions, with no defined upper limit. In the considered studies the upper boundary of mesoplastic was set at 200 mm, which is representative of a typical plastic water bottle, chosen because of the ubiquity of plastic bottles in the oceans. Macroplastic has no established lower boundary, though we set it at 200 mm, while the upper boundary is unlimited.

PlasticsEurope, a trade association representing European plastic producers, reported in 2011 that 250 million tons of plastic is produced worldwide every year, increasing this estimate to 288 million tons in 2012. Of this huge amount only a fraction ends up in our oceans, yet still a sufficient amount so as to cause a lot of consequences (Wurpel et al., 2011).

Oceanologists found the first open-ocean plastic debris in the 1970s (Morét-Ferguson and Siuda, 2011). Studies to quantify and collect data followed quite rapidly in the Atlantic Ocean. Law et al. (2010) presented an analysis of a 22-year long ship survey in the North Atlantic Ocean and Caribbean Sea from 1986 until 2008 (2010). This report revealed plastic as the primary source of ocean pollution, taking up a 62-percentage share. These numbers were confirmed to be quite general across the world by the Alfred Wegener Institute (AWI), which summarized 1,340 scientific reports on marine litter research (Tekman et al., n.d.). Figure 1 shows their findings on the share of *plastic debris among oceanic litter.*

Law et al. (2010) reported an overall average concentration of 20,238 pieces/km^2. The order of tens of thousands of magnitude was confirmed in an important recent study by Cózar et al. (2014). The average plastic concentrations in the Caribbean Sea and the Gulf of Maine were significantly less with respectively around 1,414 pieces/km^2 and 1,534 pieces/km^2. This confirms lower concentrations close to the shore and shows that plastic has been converging in accumulation zones, mostly in the subtropical ocean gyres (Cózar et al., 2014; Eriksen et al., 2013, 2014; Law et al., 2010; Morét-Ferguson and Siuda, 2011). In addition to the North Atlantic Gyre, the South Pacific Gyre showed an average plastic concentration of 26,898 pieces/km^2 (Eriksen et al., 2013). Similar studies around Australian waters resulted in an average plastic concentration of 4,256 pieces/km^2 (Reisser et al., 2013). Several studies have confirmed comparable results of plastic pollution in all five subtropical gyres (Cózar et al., 2014; Eriksen et al., 2013, 2014; Law et al., 2010; Morét-Ferguson and Siuda, 2011).

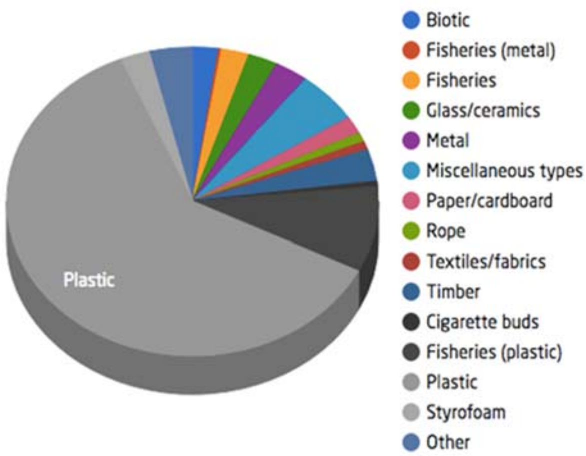

***Figure 1**: Global composition of marine litter, plastic accounts for an average of 61%. Source:* http://litterbase.awi.de/ (accessed 21 May 17).

***Slika 1:** Globalna sestava morskih odpadkov, vsebnost plastičnih delcev v povprečnem morskem odpadku je 61 %. Vir:* http://litterbase.awi.de/ (dostop 21. 5. 2017).

Exceptions to this consistent concentration of marine litter concentration are found in the Mediterranean with 116,00 pieces/km^2, the Northwest Pacific with 174,000 pieces/km^2, and the Northeast Pacific with 334,271 pieces/km^2 (Moore et al., 2001). These are all orders of magnitude larger.

In total, oceanographic model estimations predict that marine litter approximates around 5.25 trillion plastic particles, equivalent to 268,940 tons (Eriksen et al., 2014).

3. Effects of plastic on marine biota

The large and increasing abundance of plastic litter in the marine ecosystem has the greatest direct effect on marine biota. Encounters through ingestion and entanglement are the main interaction types, as can be seen in Figure 2.

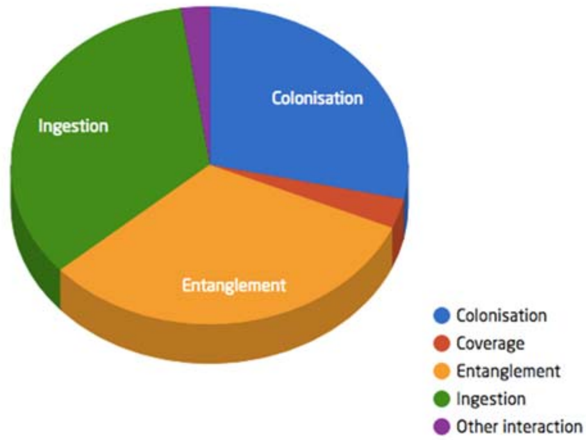

***Figure 2**: Various types of encounters of marine biota with plastic on sea. Source:* http://litterbase.awi.de/ (accessed 5.21.17).

***Slika 2**: Različna razmerja med morskimi organizmi in plastiko v morju. Vir:* http://litterbase.awi.de/ (dostop 21. 5. 2017).

Ingestion is the most prominent problem (34%). The most susceptible fauna are birds and filter feeders who focus their feeding activities on the sea surface (Moore et al., 2001). Some organisms have more problems with plastic debris than others, depending on their feeding ecology. Of the marine turtles, for example, benthic phase turtles show a strong selectivity for soft, transparent plastic, probably due to its resemblance to their natural prey, which is jellyfish (Schuyler et al., 2012). Animals that cannot mistakenly feed on plastic run a lower risk for these encounters. However, many types of marine fauna select their food based on color and size instead of through other means, e.g. olfaction. Smaller marine fauna such as zooplankton and mussels can indiscriminately ingest these harmful particles (Verlis et al., 2013). Ingestion risks thus also depend on the color of the plastic and the organism's ability to discriminate among these characteristics (Gregory, 2009; Schuyler et al., 2012; Verlis et al., 2013). It is also possible that some plastic fragments from marine wildlife could have originated from secondary ingestion, since their prey had fed on anthropogenic litter (Verlis et al., 2013).

Feeding on this litter has serious consequences for the affected organisms (and further along the food chain). It can result in death through perforation or blockage of the digestive system. Sub-lethal effects like nutrient dilution (McCauley and Bjorndal, 1999) and exposure to toxins leaching from the plastic particles lead to a decreased quality of life and possible starvation (Verlis et al., 2013). Apart from these alarming effects, the bio-magnification process up the food chain must not be ignored, as it can eventually affect our food and health (Reisser et al., 2013).

Entanglement is another frequent problem caused by marine debris (32%). When animals get stuck in a garbage patch, they are prone to capture by their predators, as they are unable to escape (Gregory, 2009). Other consequences can include drowning or starvation (Schuyler et al., 2012).

A third interaction between the marine biota and litter is colonization or fouling. This mostly happens with bigger plastic particles. Organisms start accumulating on the particles, which can eventually reduce the plastic's buoyancy and eventually cause it to sink (Eriksen et al., 2014; Moore et al., 2001). This encounter makes the situation even more problematic, as buoyant particles no longer stay on the surfaced but are even more vertically mixed into the oceanic ecosystem. Another problem that arises through interaction comes from toxins obtained through the sorption of seawater (Cózar et al., 2014).

4. Comparison between oceans: situation and interpretation

As previously noted, plastic pollution levels differ among different oceans. As it mostly converges in five subtropical gyres, namely the North Pacific, North Atlantic, South Pacific, South Atlantic, and Indian Ocean, comparison is focused on these zones. Eriksen et al. used an oceanographic model calibrated with extensive data to estimate global distribution and the count and weight densities of four different size classes across the five researched gyres (2014). The particle tracking model was constructed in two stages; first a hydrodynamic model describes oceanic circulation and then virtual particles are introduced into the flow field and allowed to move freely through hydrodynamic forcing. The ocean surface currents are extracted from the oceanic circulation modeling system HYCOM/NCODA (Eriksen et al., 2014). The particle tracking model was calibrated using data from 1,571 locations all over the oceans (Figure 3). Eriksen (2014) determined the abundances and mass of microplastics starting at the lowest size of 0.33 mm.

The visual surveys conducted on various gyres showed interesting results. Both the estimates and observations showed the spread of plastic of all sizes throughout all oceans, converging in the subtropical gyres (Eriksen et al., 2013; Law et al., 2010). The oceanographic model predicted that 55.6% of all plastic particles would be found in the Northern Hemisphere ocean regions and 44.4% would be found in the Southern Hemisphere regions; this was unexpected as the Southern part is significantly less populated and was thus expected to be less polluted. The results are shown in Figure 4. From the Northern part the major plastic concentration was situated in the North Pacific, whereas in the Southern part this occurred in the Indian Ocean. The fact that the pollution ranges between the same concentrations for both hemispheres could be justified by strong oceanic currents between the hemispheres, resulting in a large-scale redistribution of the litter. Another reason could be that the Northern hemisphere loses more plastic in the ocean than the Southern, caused by vertical mixing, onshore stranding, degradation, or other processes.

Explanations for the highest abundance of plastic in the North Pacific gyre were partly found in the fact that the amount of plastic increases slowly over time. As it degrades in the ocean, larger pieces can accumulate fouling organisms, which reduce buoyancy and eventually sink the material. Smaller pieces, however, keep their buoyancy and remain afloat (Moore et al., 2001; Reisser et al., 2013). Moore (Moore et al., 2001) also hypothesized that the extreme high plastic concentration could be because the study area was right in the center of the gyre, opposed to other studies that operated more at gyre borders. This still left questions, as other studies were conducted along a transect through the researched gyre. Also, these interpretations did not show why the North Pacific gyre, specifically, had the biggest garbage patch. Van Sebille et al. (2012) researched the dynamics of marine litter and its evolution and found a more reasonable logic behind the high numbers in the North Pacific gyre. They defined this zone as the largest 'attractor' of surface litter and confirmed through their studies that a significant fraction of marine debris would likely eventually end up in that patch. An important side note here is that this does not mean that this is the ultimate destination of all plastic ocean litter, but it is an important sink.

Another reason for the high share of debris in the North Pacific could be because the high population on the coast of East-Asia, which makes up one-third of the world's coastal population (Cózar et al., 2014).

Examination of the size distribution across the oceans highlights a strong discrepancy. Cózar et al. (2014) and Eriksen et. al (2014) confirmed this gap between the expected and observed abundance. They noted that microplastics (< 5 mm) were lost in huge quantities, possibly in the process of degrading into smaller fragments.

The most frequent size class peaks at around 2 mm and a significant gap is seen below 1 mm (Cózar et al., 2014). The predominance of plastic between the 1 and 5 mm size range agrees with the experimentally tested fractal processes of the degradation of plastic fragments in seawater over time (Timár et al., 2010), but the loss of microplastics smaller than 5 mm was unexpected according to models (Cózar et al., 2014).

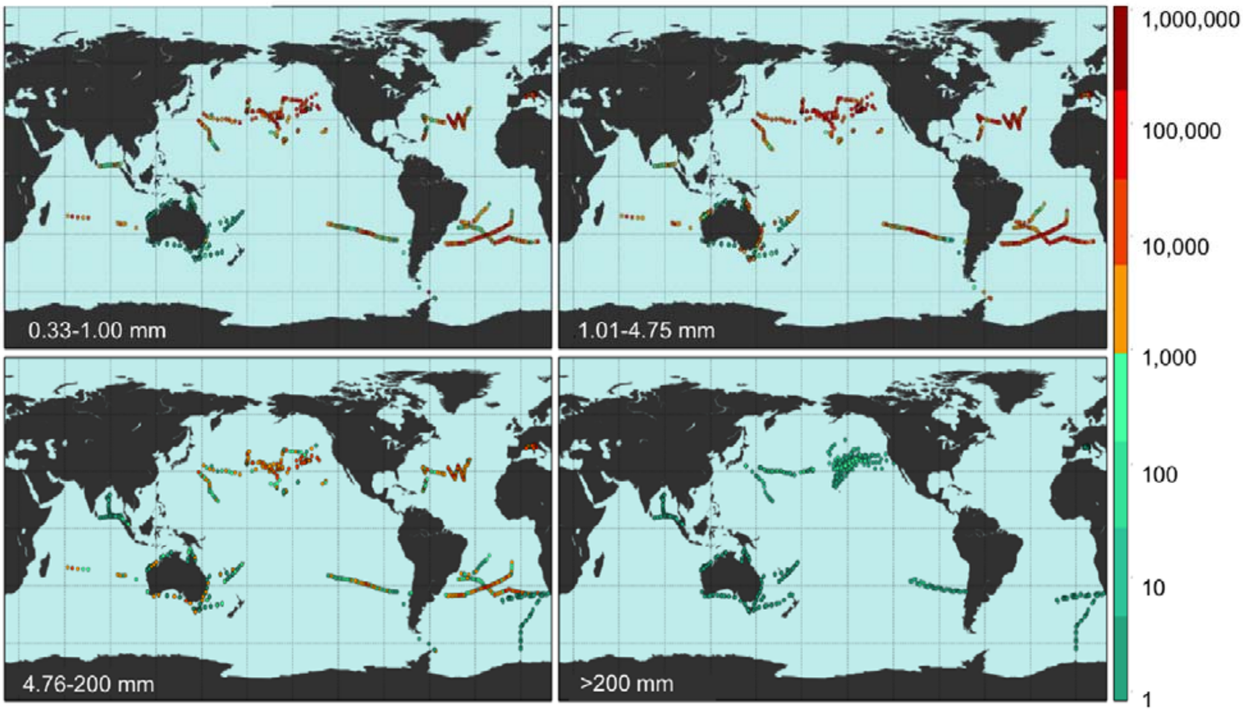

***Figure 3**: Field locations count density measurement (Eriksen et al., 2014).*

***Slika 3**: Položaj opravljenih meritev gostote (Eriksen et al., 2014).*

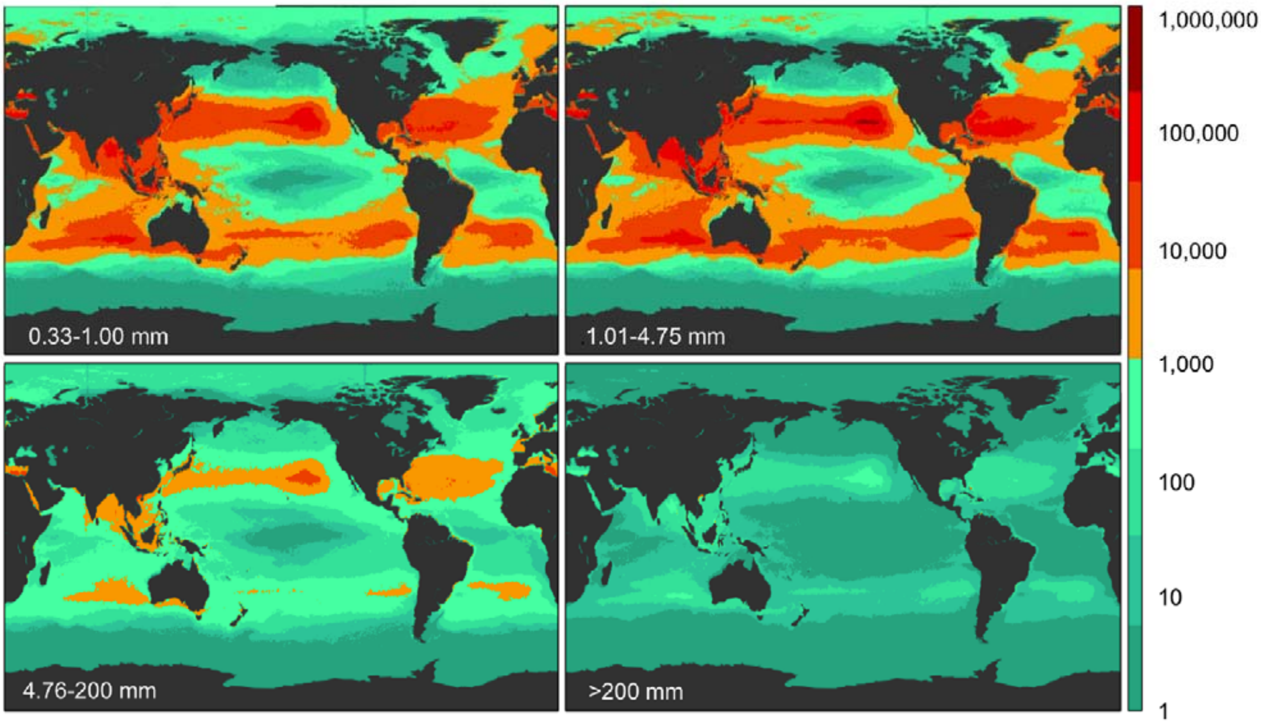

***Figure 4**: Model results for global particle count per size class. Source: (Eriksen et al., 2014).*

***Slika 4**: Rezultati modela globalnega števila delcev glede na razred velikosti delcev. Vir: (Eriksen et al., 2014).*

5. Possible solutions

Several aspects should be addressed in handling this problem. On the one hand, input into the oceans should be controlled and, on the other hand, the elimination of plastic should be increased before being released into nature. Also, changing the waste system towards a circular economy is of huge importance in ushering in a cleaner future (Raubenheimer and McIlgorm, 2017). Plastics in the oceans are primarily a land policy issue, which has not yet been given the attention it deserves and needs. The introduction of a new, internationally legally binding instrument based on the Montreal Protocol could be the first step towards a cleaner ocean, as products would be more recyclable (Raubenheimer and McIlgorm, 2017). However, innovative ideas such as one from the Plastic Bank by Port Moody, B.C., which opened its first repurposing center, effectively turning waste plastic into currency (Starr, 2013), or legislation like the Protocol to the International Convention for the Prevention of Pollution from Ships (MARPOL) to control the shipping sources of plastic debris (Derraik, 2002), have not yet reached desirable results. The recycling industry aims to reuse plastic and diminish garbage, and thus the inevitable plastic debris in the oceans, but improvements are yet to be made.

Recently the foundation of the Ocean Cleanup Project (OCP) by CEO Boyan Slat has generated a fresh round of discussion about this topic. This young engineer developed a technology that uses the force of the ocean to its advantage in order to start cleaning up the North Pacific gyre, as this is the biggest garbage patch. The technology has been applauded and the recent announcement by the CEO in May 2017, namely that the patch could be cleaned by up to 50% within the next 5 years, is very promising (https://www.theoceancleanup.com/). Nevertheless, scientists such as Marcus Eriksen feel like this is just a quick patch and not a solution. It should be kept in mind that the ocean gyres are not the only places where plastic pollution accumulates. Also, the development of technologies like these could prevent people from looking for real solutions, as this project will not address the source of the plastic input into the oceans.

6. Conclusions

With plastic production and consumption increasing to 288 million tons per year (Eriksen et al., 2014), of which a portion eventually ends up in the oceans, affecting marine biota, ecosystems, and us, human beings (McCauley and Bjorndal, 1999; Schuyler et al., 2012; Verlis et al., 2013), it is vital to address this problem. Studies have shown that plastic breaks down into a considerable amount of microplastics in the oceans (Cózar et al., 2014; Eriksen et al., 2014; Harshvardhan and Jha, 2013). This size class is the most dangerous one, as it has all kinds of harmful effects on marine biota, working its way up to the food chain. The existence of accumulation zones in the five subtropical gyres has been proven with the North Pacific patch having the greatest concentration of plastic in the world's oceans (Cózar et al., 2014; Eriksen et al., 2014, 2013; Law et al., 2010; Moore et al., 2001). It is undeniable that great steps must be taken to handle this imminent issue, but it is still debatable where exactly to start.

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