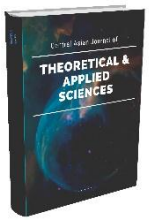

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HAZARDOUS CONTAMINANTS ASSOCIATED WITH PLASTIC AND THEIR ENVIRONMENTAL IMPACTS

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Abstract. *Plastic pollution is the accumulation of plastic objects and particles (e.g. plastic bottles, bags and microbeads) in the Earth's environment that adversely affects humans, wildlife and their habitat.[1][2] Plastics that act as pollutants are categorized by size into micro-, meso-, or macro debris.[3] Plastics are inexpensive and durable, making them very adaptable for different uses; as a result, manufacturers choose to use plastic over other materials.[4] However, the chemical structure of most plastics renders them resistant to many natural processes of degradation and as a result they are slow to degrade.[5] Together, these two factors allow large volumes of plastic to enter the environment as mismanaged waste and for it to persist in the ecosystem.*

Plastic pollution can afflict land, waterways and oceans. It is estimated that 1.1 to 8.8 million tonnes of plastic waste enters the ocean from coastal communities each year.[6] It is estimated that there is a stock of 86 million tons of plastic marine debris in the worldwide ocean as of the end of 2013, with an assumption that 1.4% of global plastics produced from 1950 to 2013 has entered the ocean and has accumulated there.[7] Some researchers suggest that by 2050 there could be more plastic than fish in the oceans by weight.[8] Living organisms, particularly marine animals, can be harmed either by mechanical effects such as entanglement in plastic objects, problems related to ingestion of plastic waste, or through exposure to chemicals within plastics that interfere with their physiology. Degraded plastic waste can directly affect humans through both direct consumption (i.e. in tap water), indirect consumption (by eating animals), and disruption of various hormonal mechanisms.

Keywords: *plastic pollution, environment, ecosystem, ocean, animals, humans, hormonal disruption*

Introduction

As of 2019, 368 million tonnes of plastic is produced each year; 51% in Asia, where China is the world's largest producer.[9] From the 1950s up to 2018, an estimated 6.3 billion tonnes of plastic has been produced worldwide, of which an estimated 9% has been recycled and another 12% has been incinerated.[10] This large amount of plastic waste enters the environment and causes problems throughout the ecosystem; for example, studies suggest that the bodies of 90% of seabirds contain plastic debris.[11][12] In some areas there have been significant efforts to reduce the prominence of free range plastic pollution, through reducing plastic consumption, litter cleanup, and promoting plastic recycling.[13][14]

As of 2020, the global mass of produced plastic exceeds the biomass of all land and marine animals combined.[15] A May 2019 amendment to the Basel Convention regulates the exportation/importation of

plastic waste, largely intended to prevent the shipping of plastic waste from developed countries to developing countries. Nearly all countries have joined this agreement.[16][17][18][19] On 2 March 2019 in Nairobi, 175 countries pledged to create a legally binding agreement by the end of the year 2024 with a goal to end plastic pollution.[20]

The amount of plastic waste produced increased during the COVID-19 pandemic due to increased demand for protective equipment and packaging materials.[21] Higher amounts of plastic ended up in the ocean, especially plastic from medical waste and masks.[22][23] Several news reports point to a plastic industry trying to take advantage of the health concerns and desire for disposable masks and packaging to increase production of single use plastic.[24][25][26][27]

There are differing estimates of how much plastic waste has been produced in the last century. By one estimate, one billion tons of plastic waste have been discarded since the 1950s.[28] Others estimate a cumulative human production of 8.3 billion tons of plastic, of which 6.3 billion tons is waste, with only 9% getting recycled.[29][30]

It is estimated that this waste is made up of 81% polymer resin, 13% polymer fibres and 32% additives. In 2018 more than 343 million tonnes of plastic waste were generated, 90% of which was composed of post-consumer plastic waste (industrial, agricultural, commercial and municipal plastic waste). The rest was pre-consumer waste from resin production and manufacturing of plastic products (e.g. materials rejected due to unsuitable colour, hardness, or processing characteristics).[30]

A large proportion of post-consumer plastic waste consists of plastic packaging. In the United States plastic packaging has been estimated to make up 5% of MSW. This packaging includes plastic bottles, pots, tubs and trays, plastic films shopping bags, rubbish bags, bubble wrap, and plastic or stretch wrap and plastic foams e.g. expanded polystyrene (EPS). Plastic waste is generated in sectors including agriculture (e.g. irrigation pipes, greenhouse covers, fencing, pellets, mulch; construction (e.g. pipes, paints, flooring and roofing, insulants and sealants); transport (e.g. abraded tyres, road surfaces and road markings); electronic and electric equipment (e-waste); and pharmaceuticals and healthcare. The total amounts of plastic waste generated by these sectors is uncertain.[30]

Several studies have attempted to quantify plastic leakage into the environment at both national and global levels which have highlight the difficulty of determining the sources and amounts of all plastic leakage. One global study has estimated that between 60 and 99 million tonnes of mismanaged plastic waste were produced in 2015. Borrelle et al. 2020 has estimated that 19–23 million tonnes of plastic waste entered aquatic ecosystems in 2016. while the Pew Charitable Trusts and SYSTEMIQ (2020) have estimated that 9–14 million tonnes of plastic waste ended up in the oceans the same year.

Despite global efforts to reduce the generation of plastic waste, losses to the environment are predicted to increase. Modelling indicates that, without major interventions, between 23 and 37 million tonnes per year of plastic waste could enter the oceans by 2040 and between 155 and 265 million tonnes per year could be discharged into the environment by 2060. Under a business as usual scenario, such increases would likely be attributable to a continuing rise in production of plastic products, driven by consumer demand, accompanied by insufficient improvements in waste management. As the plastic waste released into the environment already has a significant impact on ecosystems, an increase of this magnitude could have dramatic consequences.[30]

The trade in plastic waste has been identified as "a main culprit" of marine litter.[a] Countries importing the waste plastics often lack the capacity to process all the material. As a result, the United Nations has imposed a ban on waste plastic trade unless it meets certain criteria.[b]

There are three major forms of plastic that contribute to plastic pollution: micro-, macro-, and mega-plastics. Mega- and micro plastics have accumulated in highest densities in the Northern Hemisphere, concentrated around urban centers and water fronts. Plastic can be found off the coast of some islands because of currents carrying the debris. Both mega- and macro-plastics are found in packaging, footwear, and other domestic items that have been washed off of ships or discarded in landfills. Fishing-related items are more likely to be found around remote islands.[32][33] These may also be referred to as micro-, meso-, and macro debris.

Plastic debris is categorized as either primary or secondary. Primary plastics are in their original form when collected. Examples of these would be bottle caps, cigarette butts, and microbeads.[34] Secondary plastics, on the other hand, account for smaller plastics that have resulted from the degradation of primary plastics.[35] Microdebris are plastic pieces between 2 mm and 5 mm in size.[33] Plastic debris that starts off as meso- or macrodebris can become microdebris through degradation and collisions that break it down into smaller pieces.[3] Microdebris is more commonly referred to as nurdles.[3] Nurdles are recycled to make new plastic items, but they easily end up released into the environment during production because of their small size. They often end up in ocean waters through rivers and streams.[3] Microdebris that come from cleaning and cosmetic products are also referred to as scrubbers. Because microdebris and scrubbers are so small in size, filter-feeding organisms often consume them.[3]

Nurdles enter the ocean by means of spills during transportation or from land based sources. The Ocean Conservancy reported that China, Indonesia, Philippines, Thailand, and Vietnam dump more plastic in the sea than all other countries combined.[36] It is estimated that 10% of the plastics in the ocean are nurdles, making them one of the most common types of plastic pollution, along with plastic bags and food containers.[37][38] These micro-plastics can accumulate in the oceans and allow for the accumulation of Persistent Bio-accumulating Toxins such as bisphenol A, polystyrene, DDT, and PCB's which are hydrophobic in nature and can cause adverse health affects.[39][40]

A 2004 study by Richard Thompson from the University of Plymouth, UK, found a great amount of microdebris on beaches and in waters in Europe, the Americas, Australia, Africa, and Antarctica.[5] Thompson and his associates found that plastic pellets from both domestic and industrial sources were being broken down into much smaller plastic pieces, some having a diameter smaller than human hair.[5] If not ingested, this microdebris floats instead of being absorbed into the marine environment. Thompson predicts there may be 300,000 plastic items per square kilometre of sea surface and 100,000 plastic particles per square kilometre of seabed.[5] International Pellet Watch collected samples of polythene pellets from 30 beaches in 17 countries which were analysed for organic micro-pollutants. It was found that pellets found on beaches in the US, Vietnam and southern Africa contained compounds from pesticides suggesting a high use of pesticides in the areas.[41] In 2020 scientists created what may be the first scientific estimate of how much microplastic currently resides in Earth's seafloor, after investigating six areas of ~3 km depth ~300 km off the Australian coast. They found the highly variable microplastic counts to be proportionate to plastic on the surface and the angle of the seafloor slope. By averaging the microplastic mass per cm^3, they estimated that Earth's seafloor contains ~14 million tons of microplastic – about double the amount they estimated based on data from earlier studies – despite calling both estimates "conservative" as coastal areas are known to contain much more microplastic. These estimates are about one to two times the amount of plastic thought – per Jambeck et al., 2015 – to currently enter the oceans annually.[42][43][44]

Discussion

Plastic debris is categorized as macrodebris when it is larger than 20 mm. These include items such as plastic grocery bags.[3] Macrodebris are often found in ocean waters, and can have a serious impact on the

native organisms. Fishing nets have been prime pollutants. Even after they have been abandoned, they continue to trap marine organisms and other plastic debris. Eventually, these abandoned nets become too difficult to remove from the water because they become too heavy, having grown in weight up to 6 tonnes.[3] 9.2 billion tonnes of plastic are estimated to have been made between 1950 and 2017. More than half this plastic has been produced since 2004. Of all the plastic discarded so far, 14% has been incinerated and less than 10% has been recycled.[30] Plastics themselves contribute to approximately 10% of discarded waste. Many kinds of plastics exist depending on their precursors and the method for their polymerization. Depending on their chemical composition, plastics and resins have varying properties related to contaminant absorption and adsorption. Polymer degradation takes much longer as a result of saline environments and the cooling effect of the sea. These factors contribute to the persistence of plastic debris in certain environments.[33] Recent studies have shown that plastics in the ocean decompose faster than was once thought, due to exposure to sun, rain, and other environmental conditions, resulting in the release of toxic chemicals such as bisphenol A. However, due to the increased volume of plastics in the ocean, decomposition has slowed down.[45] The Marine Conservancy has predicted the decomposition rates of several plastic products. It is estimated that a foam plastic cup will take 50 years, a plastic beverage holder will take 400 years, a disposable nappy will take 450 years, and fishing line will take 600 years to degrade.[5] It was estimated that global production of plastics is approximately 250 mt/yr. Their abundance has been found to transport persistent organic pollutants, also known as POPs. These pollutants have been linked to an increased distribution of algae associated with red tides.[33] In 2019, the group Break Free From Plastic organized over 70,000 volunteers in 51 countries to collect and identify plastic waste. These volunteers collected over "59,000 plastic bags, 53,000 sachets and 29,000 plastic bottles," as reported by The Guardian. Nearly half of the items were identifiable by consumer brands. The most common brands were Coca-Cola, Nestlé, and Pepsico.[46][47] According to the global campaign coordinator for the project Emma Priestland in 2020, the only way to solve the problem is stopping production of single use plastic and using reusable products instead.[48][49] China is the biggest consumer of single-use plastics.[50]

Coca-Cola answered that "more than 20% of our portfolio comes in refillable or fountain packaging", they are decreasing the amount of plastic in secondary packaging.[51]

Nestlé responded that 87% of their packaging and 66% of their plastic packaging can be reused or recycled and by 2025 they want to make it 100%. By that year they want to reduce the consumption of virgin plastic by one third.

Pepsico responded that they want to decrease "virgin plastic in our beverage business by 35% by 2025" and also expanding reuse and refill practices what should prevent 67 billion single use bottles by 2025.[52] The United States is the world leader in generating plastic waste, producing an annual 42 million metric tons of plastic waste.[53][54] Per capita generation of plastic waste in the United States is higher than in any other country, with the average American producing 130.09 kilograms of plastic waste per year. Other high-income countries, such as those of the EU-28 (annual per capita generation 58.56 kg), also have a high per capita plastic waste generation rate. Some high-income countries, such as Japan (annual per capital generation 38.44 kg), produce far less plastic waste per capita.[55][56] The United States National Academy of Sciences estimated in 2019 that the worldwide entry of plastic into the ocean was 8 million metric tons of plastic per year.[57] A 2020 study by The Ocean Cleanup estimated that rivers convey between 0.8 and 2.7 million metric tons of plastic into the ocean, and ranked these river's countries. The top ten were, from the most to the least: Philippines, India, Malaysia, China, Indonesia, Myanmar, Brazil, Vietnam, Bangladesh, and Thailand.[58] In 2018 approximately 513 million tonnes of plastics wind up in the oceans every year out of which the 83,1% is from the following 20 countries: China is the most mismanaged plastic waste polluter leaving in the sea the 27.7% of the world total, second Indonesia with

the 10.1%, third Philippines with 5.9%, fourth Vietnam with 5.8%, fifth Sri Lanka 5.0%, sixth Thailand with 3.2%, seventh Egypt with 3.0%, eighth Malaysia with 2.9%, ninth Nigeria with 2.7%, tenth Bangladesh with 2.5%, eleventh South Africa with 2.0%, twelfth India with 1.9%, thirteenth Algeria with 1.6%, fourteenth Turkey with 1.5%, fifteenth Pakistan with 1.5%, sixteenth Brazil with 1.5%, seventeenth Myanmar with 1.4%, eighteenth Morocco with 1.0%, nineteenth North Korea with 1.0%, twentieth United States with 0.9%. The rest of world's countries combined wind up the 16.9% of the mismanaged plastic waste in the oceans, according to a study published by Science in 2015.[6][59][60]

All the European Union countries combined would rank eighteenth on the list.[6][59]

In 2020, a study revised the potential 2016 U.S. contribution to mismanaged plastic;[16] It estimated that U.S.-generated plastic might place the U.S. behind Indonesia and India in oceanic pollution, or it might place the U.S. behind Indonesia, India, Thailand, China, Brazil, Philippines, Egypt, Japan, Russia, and Vietnam. In 2019, it was estimated all OECD countries (North America, Chile, Colombia, Europe, Israel, Japan, S. Korea) may contribute 5% of oceanic plastic pollution, with the rest of the world polluting 95%.[61] Since 2016 China ceased importing plastics for recycling and since 2019 international treaties signed by 187 countries restricted the export of plastics for recycling.[62][63]

A 2019 study calculated the mismanaged plastic waste, in millions of metric tonnes (Mt) per year:

- 52 Mt – Asia
- 17 Mt – Africa
- 7.9 Mt – Latin America & Caribbean
- 3.3 Mt – Europe
- 0.3 Mt – US & Canada
- Mt – Oceania (Australia, New Zealand, etc.)[64]

Around 275 million tonnes of plastic waste is generated each year around the world; between 4.8 million and 12.7 million tonnes is dumped into the sea. About 60% of the plastic waste in the ocean comes from the following top 5 countries.[65] The table below list the top 20 plastic waste polluting countries in 2010 according to a study published by Science, Jambeck et al (2015).[6][59] All the European Union countries combined would rank eighteenth on the list.[6][59]

In a study published by Environmental Science & Technology, Schmidt et al (2017) calculated that 10 rivers: two in Africa (the Nile and the Niger) and eight in Asia (the Ganges, Indus, Yellow, Yangtze, Hai He, Pearl, Mekong and Amur) "transport 88–95% of the global plastics load into the sea.".[66][67][68][69]

The Caribbean Islands are the biggest plastic polluters per capita in the world. Trinidad and Tobago produces 1.5 kilograms of waste per capita per day, is the biggest plastic polluter per capita in the world. At least 0.19 kg per person per day of Trinidad and Tobago's plastic debris end up in the ocean, or for example Saint Lucia which generates more than four times the amount of plastic waste per capita as China and is responsible for 1.2 times more improperly disposed plastic waste per capita than China. Of the top thirty global polluters per capita, ten are from the Caribbean region. These are Trinidad and Tobago, Antigua and Barbuda, Saint Kitts and Nevis, Guyana, Barbados, Saint Lucia, Bahamas, Grenada, Anguilla and Aruba, according to a set of studies summarized by Forbes (2019).[70]

Results

The distribution of plastic debris is highly variable as a result of certain factors such as wind and ocean currents, coastline geography, urban areas, and trade routes. Human population in certain areas also plays a large role in this. Plastics are more likely to be found in enclosed regions such as the Caribbean. It serves as a means of distribution of organisms to remote coasts that are not their native environments. This could potentially increase the variability and dispersal of organisms in specific areas that are less

biologically diverse. Plastics can also be used as vectors for chemical contaminants such as persistent organic pollutants and heavy metals.[33]

Plastic pollution has also greatly negatively affected our environment. "The pollution is significant and widespread, with plastic debris found on even the most remote coastal areas and in every marine habitat".[71] This information tells us about how much of a consequential change plastic pollution has made on the ocean and even the coasts.

In January 2019 a group of scientists defined a planetary boundary for "novel entities" (pollution, including plastic pollution) and found it has already been exceeded. According to co-author Patricia Villarubia-Gómez from the Stockholm Resilience Centre, "There has been a 50-fold increase in the production of chemicals since 1950. This is projected to triple again by 2050". There are at least 350,000 artificial chemicals in the world. They have mostly "negative effects on planetary health". Plastic alone contain more than 10,000 chemicals and create large problems. The researchers are calling for limit on chemical production and shift to circular economy, meaning to products that can be reused and recycled.[72]

The problem of ocean plastic debris is ubiquitous. It is estimated that 1.5–4% of global plastics production ends up in the oceans every year, mainly as a result of poor waste management infrastructure and practices combined with irresponsible attitudes to the use and disposal of plastics. The weathering of plastic debris causes its fragmentation into particles that even small marine invertebrates may ingest hence contaminating the food chain. Their small size renders them untraceable to their source and extremely difficult to remove from open ocean environments.[73] In the marine environment, plastic pollution causes "Entanglement, toxicological effects via ingestion of plastics, suffocation, starvation, dispersal, and rafting of organisms, provision of new habitats, and introduction of invasive species are significant ecological effects with growing threats to biodiversity and trophic relationships. Degradation (changes in the ecosystem state) and modifications of marine systems are associated with loss of ecosystem services and values. Consequently, this emerging contaminant affects the socio-economic aspects through negative impacts on tourism, fishery, shipping, and human health".[74] In 2019 a new report "Plastic and Climate" was published. According to the report, in 2019, production and incineration of plastic will contribute greenhouse gases in the equivalent of 850 million tonnes of carbon dioxide (CO_2) to the atmosphere. In current trend, annual emissions from these sources will grow to 1.34 billion tonnes by 2030. By 2050 plastic could emit 56 billion tonnes of greenhouse gas emissions, as much as 14 percent of the earth's remaining carbon budget.[75] By 2100 it will emit 260 billion tonnes, more than half of the carbon budget. Those are emission from production, transportation, incineration, but there are also releases of methane and effects on phytoplankton.[76] Plastic pollution on land poses a threat to the plants and animals – including humans who are based on the land.[77] Estimates of the amount of plastic concentration on land are between four and twenty three times that of the ocean. The amount of plastic poised on the land is greater and more concentrated than that in the water.[78] Mismanaged plastic waste ranges from 60 percent in East Asia and Pacific to one percent in North America. The percentage of mismanaged plastic waste reaching the ocean annually and thus becoming plastic marine debris is between one third and one half the total mismanaged waste for that year.[79][80]

In 2020 a report conducted by the Food and Agriculture Organization stated that plastic is often used in agriculture. There is more plastic in the soil than in the oceans. The presence of plastic in the environment hurt ecosystems and human health and pose a threat to food safety.[81] Chlorinated plastic can release harmful chemicals into the surrounding soil, which can then seep into groundwater or other surrounding water sources and also the ecosystem of the world.[82] This can cause serious harm to the species that drink the water.

Plastic waste can clog storm drains, and such clogging can increase flood damage, particularly in urban areas.[83] A buildup of plastic garbage at trash cans raises the water level upstream and may enhance the risk of urban flooding.[84] For example, in Bangkok flood risk increases substantially because of plastic waste clogging the already overburdened sewer system.[85] A 2017 study found that 83% of tap water samples taken around the world contained plastic pollutants.[86][87] This was the first study to focus on global drinking water pollution with plastics,[88] and showed that with a contamination rate of 94%, tap water in the United States was the most polluted, followed by Lebanon and India. European countries such as the United Kingdom, Germany and France had the lowest contamination rate, though still as high as 72%.[86] This means that people may be ingesting between 3,000 and 4,000 microparticles of plastic from tap water per year.[88] The analysis found particles of more than 2.5 microns in size, which is 2500 times bigger than a nanometer. It is currently unclear if this contamination is affecting human health, but if the water is also found to contain nano-particle pollutants, there could be adverse impacts on human well-being, according to scientists associated with the study.[89]

However, plastic tap water pollution remains under-studied, as are the links of how pollution transfers between humans, air, water, and soil.[90]

Mismanaged plastic waste leads to plastic directly or indirectly entering terrestrial ecosystems.[91] There has been a significant increase of microplastic pollution due to the poor handling and disposal of plastic materials.[92] In particular, plastic pollution in the form of microplastics now can be found extensively in soil. It enters the soil by settling on the surface and eventually making its way into subsoils.[93] These microplastics find their way into plants and animals.[94]

Effluent and sludge of wastewater contain large amounts of plastics. Wastewater treatment plants don't have a treatment process to remove microplastics which results in plastics being transferred into water and soil when effluent and sludge are applied to land for agricultural purposes.[94] Several researchers have found plastic microfibers that are released when fleece and other polyester textiles are cleaned in washing machines.[95] These fibers can be transferred through effluent to land which pollutes soil environments.[93]

The increase in plastic and microplastic pollution in soils can cause adverse impacts on plants and microorganisms in the soil, which can in turn affect soil fertility. Microplastics affect soil ecosystems that are important for plant growth. Plants are important for the environment and ecosystems so the plastics are damaging to plants and organisms living in these ecosystems.[92]

Microplastics alter soil biophysical properties which affect the quality of the soil. This affects soil biological activity, biodiversity and plant health. Microplastics in the soil alter a plant's growth. It decreases seedling germination, affects the number of leaves, stem diameter and chlorophyll content in these plants.[92]

Microplastics in the soil are a risk not only to soil biodiversity but also food safety and human health. Soil biodiversity is important for plant growth in agricultural industries. Agricultural activities such as plastic mulching and application of municipal wastes contribute to the microplastic pollution in the soil. Human-modified soils are commonly used to improve crop productivity but the effects are more damaging than helpful.[92]

Plastics also release toxic chemicals into the environment and cause physical, chemical harm and biological damage to organisms. Ingestion of plastic doesn't only lead to death in animals through intestinal blockage but it can also travel up the food chain which affects humans.[91]

Marine plastic pollution (or plastic pollution in the ocean) is a type of marine pollution by plastics, ranging in size from large original material such as bottles and bags, down to microplastics formed from

the fragmentation of plastic material. Marine debris is mainly discarded human rubbish which floats on, or is suspended in the ocean. Eighty percent of marine debris is plastic.[96][97] Microplastics and nanoplastics result from the breakdown or photodegradation of plastic waste in surface waters, rivers or oceans. Recently, scientists have uncovered nanoplastics in heavy snow, more specifically about 3,000 tons that cover Switzerland yearly.[98]

It is estimated that there is a stock of 86 million tons of plastic marine debris in the worldwide ocean as of the end of 2013, assuming that 1.4% of global plastics produced from 1950 to 2013 has entered the ocean and has accumulated there.[99] Global "consumption" of plastics is estimated to be 300 million tonnes per year as of 2019, with around 8 million tonnes ending up in the oceans as macroplastics.[100][101] Approximately 1.5 million tonnes of primary microplastics end up in the seas. Around 98% of this volume is created by land-based activities, with the remaining 2% being generated by sea-based activities.[101][102][103] It is estimated that 19–23 million tonnes of plastic leaks into aquatic ecosystems annually.[104] The 2017 United Nations Ocean Conference estimated that the oceans might contain more weight in plastics than fish by the year 2050.[105]

Marine life is one of the most important when one is affected by plastic pollution. Plastic pollution puts animals' lives in danger and is in constant fear of extinction. Marine wildlife such as seabirds, whales, fish and turtles mistake plastic waste for prey; most then die of starvation as their stomachs become filled with plastic. They also suffer from lacerations, infections, reduced ability to swim, and internal injuries.[106] This evidence tells us how damaged marine wildlife is being affected by plastic pollution, they bring up how many animals mistake plastic for prey and eat it without knowing. "Globally, 100,000 marine mammals die every year as a result of plastic pollution. This includes whales, dolphins, porpoises, seals and sea lions".[107] This evidence tells us the statistics of how many marine mammals really are negatively affected enough to die from plastic pollution.

Implications

Research into freshwater plastic pollution has been largely ignored over marine ecosystems, comprising only 13% of published papers on the topic.[108]

Plastics make their way into bodies of freshwater, underground aquifers, and moving freshwaters through runoff and erosion of mismanaged plastic waste (MMPW). In some areas, the direct waste disposal into rivers is a remaining factor of historical practices, and has only been somewhat limited by modern legislation.[109] Rivers are the primary transport of plastics into marine ecosystems, sourcing potentially 80% of the plastic pollution in the oceans.[110] Research on the top ten river catchments ranked by annual amount of MMPW showed that some rivers contribute as high as 88–95% of ocean-bound plastics, the highest being the Yangtze River into the East China Sea.[111] Asian rivers contribute nearly 67% of plastic waste found in the ocean annually, largely influenced by the high density coastal populations all throughout the continent as well as relatively intense bouts of seasonal rainfall.[112]

Impacts on freshwater biodiversity

Invertebrates

A study analyzing ingestion of plastics across a variety of previously published experiments showed that out of the 206 species covered, the majority of papers documented ingestion in fish.[109] This doesn't quite mean that fish ingest plastic more than other organisms, but instead highlights the underrepresentation of plastic effects in equally important organisms, like aquatic plants, amphibians and invertebrates. Despite this disparity, controlled experiments analyzing microplastic impact on aquatic plants like the algae Chlorella spp and common duckweed Lemna minor have yielded significant results. Between microplastics of polypropylene (PP) and polyvinyl chloride (PVC), PVC demonstrated greater toxicity to Chlorella pyrenoidosa, overall negatively impacting their photosynthetic ability. This effect on

photosynthesis is likely due to the 60% reduction of algal chlorophyll a associated with high PVC concentrations found in the same study.[113] When analyzing the effect of polyethylene microbeads (origin: cosmetic exfoliants) on the aquatic macrophyte L. minor, no effect on photosynthetic pigments & productivity was found, but root growth and root cell viability decreased.[114] These results are concerning as plants and algae are integral to nutrient and gas cycling within an aquatic system, and have the capacity to create significant changes in water composition due to their sheer density. Crustaceans have also been analyzed for their response to plastic presence. There is proof that freshwater crustaceans, specifically European crabs and crayfish, suffer entanglement in polyamide ghost nets used in lake fishing.[115] When exposed to plastic nanoparticles of polystyrene, Daphnia galeata (common water flea) experienced reduced survival within 48 hours as well as reproductive issues. Over a span of 5 days, the amount of pregnant Daphnia decreased by nearly 50%, and less than 20% of exposed embryos survived without any immediate repercussions.[116] Other arthropods, like juvenile stages of insects are susceptible to similar plastic exposure as some spend part of their adolescence fully submerged in a freshwater resource. This similarity in lifestyle to other aquatic invertebrates indicates that insects may experience similar side effects of plastic exposure.

Vertebrates

Plastic exposure in amphibians has mostly been studied in adolescent life stages, when the test subjects are still dependent on an aquatic environment where it can be easier to manipulate variables experimentally. Studies on a common South American freshwater frog, Physalaemus cuvieri indicated that plastics may have the potential to induce mutagenic and cytotoxic morphological changes.[117] Much more research needs to be done on amphibian response to plastic pollution, especially since amphibians can serve as initial indicator species of environmental decline.[118] Freshwater mammals and birds have long been known to have negative interactions with plastic pollution, often resulting in entanglement or suffocation/choking after ingesting. While inflammation within the gastrointestinal tract in both groups has been noted, unfortunately there is little to no data on the toxicological effects of plastic pollutants in these organisms.[109] Fish have been studied the most regarding plastic pollution in freshwater organisms, with the majority of studies indicating evidence of plastic ingestion in wild-caught samples and lab specimens.[109] There have been some attempts to look at lethality of plastics in a common freshwater model species, Danio rerio, aka zebrafish. Increased mucus production and inflammation response in the D. rerio GI-tract was noted, but additionally, researchers noted a distinct shift in the microbial communities within the zebrafish intestinal microbiome.[119] This finding is significant, as research within the last few decades has increasingly revealed how much power intestinal microbiomes have regarding their host's nutrient absorption and endocrine systems.[120] Because of this, plastics may have a far more drastic effect on individual organism health than is currently known so far, thus warranting the need for further research as soon as possible. Many of these findings also have been found in a laboratory setting, so more effort needs to be channeled into measuring plastic abundance & toxicology in wild populations.

Effects on humans

Compounds that are used in manufacturing pollute the environment by releasing chemicals into the air and water. Some compounds that are used in plastics, such as phthalates, bisphenol A (BRA), polybrominated diphenyl ether (PBDE), are under close statute and might be very hurtful. Even though these compounds are unsafe, they have been used in the manufacturing of food packaging, medical devices, flooring materials, bottles, perfumes, cosmetics and much more. Inhalation of microplastics (MPs) have been shown to be one of the major contributors to MP uptake in humans. MPs in the form of dust particles are circulated constantly through ventilation and air conditioning systems indoors.[121] The large dosage of these compounds are hazardous to humans, destroying the endocrine system. BRA imitates the female's hormone called estrogen. PBD destroys and causes damage to thyroid hormones,

which are vital hormone glands that play a major role in the metabolism, growth and development of the human body. MPs can also have a detrimental effect on male reproductive success. MPs such as BPA can interfere with steroid biosynthesis in the male endocrine system and with early stages of spermatogenesis.[122] MPs in men can also create oxidative stress and DNA damage in spermatozoa, causing reduced sperm viability.[122] Although the level of exposure to these chemicals varies depending on age and geography, most humans experience simultaneous exposure to many of these chemicals. Average levels of daily exposure are below the levels deemed to be unsafe, but more research needs to be done on the effects of low dose exposure on humans. A lot is unknown on how severely humans are physically affected by these chemicals. Some of the chemicals used in plastic production can cause dermatitis upon contact with human skin. In many plastics, these toxic chemicals are only used in trace amounts, but significant testing is often required to ensure that the toxic elements are contained within the plastic by inert material or polymer. Children and women during their reproduction age are at most at risk and more prone to damaging their immune as well as their reproductive system from these hormone-disrupting chemicals. Pregnancy and nursing products such as baby bottles, pacifiers, and plastic feeding utensils place infants and children at a very high risk of exposure.[121]

Human health has also been negatively impacted by plastic pollution. "Almost a third of groundwater sites in the US contain BPA. BPA is harmful at very low concentrations as it interferes with our hormone and reproductive systems.[123] This quote tells us how much of a percentage of our water is contaminated and should not be drunk on a daily basis. "At every stage of its lifecycle, plastic poses distinct risks to human health, arising from both exposure to plastic particles themselves and associated chemicals".[124] This quote is an intro to numerous points of why plastic is damaging to us, such as the carbon that is released when it is being made and transported which is also related to how plastic pollution harms our environment.

A 2019 study published in Environment International found microplastic in the blood of 80% of people tested in the study, and such microplastic has the potential to become embedded in human organs.[125]

Clinical significance

Due to the pervasiveness of plastic products, most of the human population is constantly exposed to the chemical components of plastics. In the United States, 95% of adults have had detectable levels of BPA in their urine. Exposure to chemicals such as BPA have been correlated with disruptions in fertility, reproduction, sexual maturation, and other health effects.[126] Specific phthalates have also resulted in similar biological effects.

Thyroid hormone axis

Bisphenol A affects gene expression related to the thyroid hormone axis, which affects biological functions such as metabolism and development. BPA can decrease thyroid hormone receptor (TR) activity by increasing TR transcriptional corepressor activity. This then decreases the level of thyroid hormone binding proteins that bind to triiodothyronine. By affecting the thyroid hormone axis, BPA exposure can lead to hypothyroidism.[12]

Sex hormones

BPA can disrupt normal, physiological levels of sex hormones. It does this by binding to globulins that normally bind to sex hormones such as androgens and estrogens, leading to the disruption of the balance between the two. BPA can also affect the metabolism or the catabolism of sex hormones. It often acts as an antiandrogen or as an estrogen, which can cause disruptions in gonadal development and sperm production.[12]

Disease

In 2018, plasticosis, a new disease caused solely by plastics, was discovered in seabirds. The birds identified as having the disease have scarred digestive tracts from ingesting plastic waste.[127] "When birds ingest small pieces of plastic, they found, it inflames the digestive tract. Over time, the persistent inflammation causes tissues to become scarred and disfigured, affecting digestion, growth and survival."[128]

Conclusions

Efforts to reduce the use of plastics, to promote plastic recycling and to reduce mismanaged plastic waste or plastic pollution have occurred or are ongoing. The first scientific review in the professional academic literature about global plastic pollution in general found that the rational response to the "global threat" would be "reductions in consumption of virgin plastic materials, along with internationally coordinated strategies for waste management" – such as banning export of plastic waste unless it leads to better recycling – and describes the state of knowledge about "poorly reversible" impacts which are one of the rationales for its reduction.[129][130]

Some supermarkets charge their customers for plastic bags, and in some places more efficient reusable or biodegradable materials are being used in place of plastics. Some communities and businesses have put a ban on some commonly used plastic items, such as bottled water and plastic bags.[131] Some non-governmental organizations have launched voluntary plastic reduction schemes like certificates that can be adapted by restaurants to be recognized as eco-friendly among customers.[132]

In January 2019 a "Global Alliance to End Plastic Waste" was created by companies in the plastics industry. The alliance aims to clean the environment from existing waste and increase recycling, but it does not mention reduction in plastic production as one of its targets.[133] Moreover, subsequent reporting has suggested the group is a greenwashing initiative.[134][135][136]

On 2 March 2019 in Nairobi, representatives of 175 countries pledged to create a legally binding agreement to end plastic pollution. The agreement should address the full lifecycle of plastic and propose alternatives including reusability. An Intergovernmental Negotiating Committee (INC) that should conceive the agreement by the end of the year 2024 was created. The agreement should facilitate the transition to a circular economy, which will reduce GHG emissions by 25%. Inger Andersen, executive director of UNEP called the decision "a triumph by planet earth over single-use plastics".[20][137]

In the lead up to the Assembly, global public opinion on a plastic treaty was surveyed, analysed and reported by The Plastic Free Foundation in partnership with Ipsos and WWF-International. The report identified that nearly 90% of survey participants – over 20,000 adults across 28 countries – believed that having a global plastics treaty will help to effectively address the plastic pollution crisis.[2] The use of biodegradable plastics has many advantages and disadvantages. Biodegradables are biopolymers that degrade in industrial composters. Biodegradables do not degrade as efficiently in domestic composters, and during this slower process, methane gas may be emitted.[138]

There are also other types of degradable materials that are not considered to be biopolymers, because they are oil-based, similar to other conventional plastics. These plastics are made to be more degradable through the use of different additives, which help them degrade when exposed to UV rays or other physical stressors.[138] yet, biodegradation-promoting additives for polymers have been shown not to significantly increase biodegradation.[139]

Although biodegradable and degradable plastics have helped reduce plastic pollution, there are some drawbacks. One issue concerning both types of plastics is that they do not break down very efficiently in

natural environments. There, degradable plastics that are oil-based may break down into smaller fractions, at which point they do not degrade further.[138]

A parliamentary committee in the United Kingdom also found that compostable and biodegradable plastics could add to marine pollution because there is a lack of infrastructure to deal with these new types of plastic, as well as a lack of understanding about them on the part of consumers.[140] For example, these plastics need to be sent to industrial composting facilities to degrade properly, but no adequate system exists to make sure waste reaches these facilities.[140] The committee thus recommended to reduce the amount of plastic used rather than introducing new types of it to the market.[140]

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