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Observing the Effects of Marine Debris Bioaccumulation and Biomagnification

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ABSTRACT

Marine debris in the ocean is a complex problem to tackle due to its multifaceted nature. Amongst the various forms of marine debris, microplastics, and heavy metals are often the focus of research due to their pervasive and toxic nature within the marine environment. Plastics, being lightweight, are frequently carried around by the ocean currents on the ocean surface. During transit, plastics often break down into smaller forms known as microplastics. These microplastics, small enough to be digested by marine wildlife, often attract toxic chemicals and are introduced into the food web. On the other hand, heavy metals are water soluble, toxic, and dense. As such, they don't travel far from their source of origin unless subject to a strong water current. Due to their soluble nature, they are easily introduced into the biological systems of marine wildlife. Once inside, they stubbornly remain in the body and accumulate until they reach lethal levels or their host is consumed by a predator. Both microplastics and heavy metals pose a serious threat to not only the marine ecosystem but also to other systems that interact with the ocean in any form. An understanding of microplastic and heavy metal marine debris and their effects on the trophic chain is essential in fixing this waste problem.

Introduction

Marine debris is classified as any artificial object that is disposed of on coastlines and in the marine ocean. More specifically, marine debris can be identified as any human-made plastic, metal, or polymer; materials that do not decompose naturally or have a long half-life. In terms of marine debris composition, plastic waste by itself is nearly 70% percent of all marine debris (Kühn and van Franeker, 2020. The lightness of the plastic material, its innate resistance to decomposition, and its widespread usage, all contribute to the number one title of marine debris king. Such characteristics have ensured that plastic is found in not only all the seven seas, but also in the global poles.

Although plastic composes a significant amount of marine debris, the remaining 30% is nothing to scoff at. Metals, polymer textiles, and even everyday waste threaten marine wildlife. In the case of metals, highly toxic trace metals from shipwrecks or waste thrown overboard from ships, industrial waste flows downstream from the river to the ocean and harms the immediate marine environment and ecosystem. In addition to the metal frame itself polluting the environment, the cargo of the shipwreck is more often than not the main source of marine debris. Ceramics, glass, and metal aboard the ship of the cargo often share the same fate as its ship, and the oil from the wreck itself is extremely fatal. Although an argument can be made to the encrustation process that accompanies metal shipwrecks, more often than not a shipwreck becomes a giant source of marine debris that toxifies the ocean.

Paper and glass also constitute marine debris. In the case of glass, the ocean, nor nature in general, does not have a natural way of decaying glass; glass may persevere up to 4000 thousand years. Glass may eventually accumulate the same way as microplastics in the ecosystem. The marine will cause the glass to fracture into small particles, which in turn will be consumed by primary consumers. This toxic accumulation will travel up the food chain until it returns back to human society on a dinner plate.

The ocean currents have a tendency to drag marine debris through a tremendous journey. For example, waste from the 2011 Fukushima Tsunami started turning up on the West Coast of the United States of America. City waste from inland North American cities flows downward to the bay and enters the ocean to travel along whatever ocean current is the strongest. The Great Pacific Garbage Patch in the Pacific Ocean serves as a heavy reminder of the awe-inspiring amount of marine debris in the ocean in the 21st century. Multiple research groups have been trying to map the global flow of marine debris, and even NASA's Cyclone Global Navigation Satellite System has been utilized to precisely track the flow of microplastics. Additionally, artificial intelligence has been collecting data to augment the current library of plastic flow. Other research groups focus on wind-based ocean circulation or Gyres. As mentioned before, the light nature of plastics causes them to flow to the top of the ocean surface, where they are suspected to wind-influenced factors.

The beforehand mentioned Great Pacific Garbage Patch is mostly composed of floating microplastics, while the shipwrecks from the initial part of the manuscript are sunken. As such, marine debris is classified based on its density. Marine debris which has a heavier density than the ocean sinks to the bottom of the ocean and is not subject to ocean currents, while light-density marine debris can be influenced by both the ocean current and the wind current on the surface. However, that is not to say that microplastics are not found on the bottom of the ocean. Complex biofouling processes bring the light plastic down to the ocean floor upon which it decomposes and travels again, this time, as food sources for unaware organisms. The bioaccumulation that results from traveling up the energy pyramid is therefore the last portion of interest in this manuscript.

Radical instances of toxic bioaccumulation, such as the Itai-Itai disease, highlighted the alarming effects of bioaccumulation on the human body (Shuto, 2005). The toxic cadmium metal flowed from the wastewater of various mines in the Toyama prefecture in Japan. This cadmium was initially taken up by river algae and phytoplankton and then introduced through the natural passageway in the food web. One of the ways the Japanese population of the Toyama prefecture became affected by cadmium poisoning was through the consumption of fish in the Jinzu River.

Such instances of water-carried pollution helped bring about action regarding the adverse effects of marine-based bioaccumulation. Toxic metal bioaccumulation is mostly common and localized in locations where a water body such as a lake or river is in close contact with industrial human activity (Li et al., 202). On the other hand, plastic bioaccumulation is mostly concerned with the presence of microplastics and how they enter the human body, and the detrimental effects on the human body.

This manuscript will be divided into two main portions. An introduction of various marine debris and then a detailed study regarding the overall effect of marine debris in the environment and in organisms. This initial portion will help categorize the plastic marine debris and metal marine debris. The manuscript will then follow up with a section of how marine debris interacts with organisms. The bioaccumulation will be organized with emphasis on marine debris type, source, accumulation location, and adverse health effects.

What Constitutes Marine Debris

Plastic

Plastics are a group of versatile synthetic materials that can be modeled into solid objects of different shapes and sizes (Al-Zawaidah et al. 2021). Zawaidah and his colleagues suggest that plastics cover a diverse range of materials with their respective usages and densities: polystyrene, with a density ranging between 0.91 and 0.97 g cm3, usually serving for packaging applications, and polyvinylchloride, with density ranging from 1.16 and 1.58 g cm3, applied for building and construction. Plastics are structured to be lightweight, resistant, and durable, enabling their application in diverse and various fields. Being diverse and versatile, plastics are used in numerous applications that enhance our daily lives. From a material science perspective, according to the Journal of Environmental Analytical Chemistry, plastic refers to “polymeric material that may contain other substances to improve performance and/or reduce costs” (Rafey and Siddiqui, 2021).

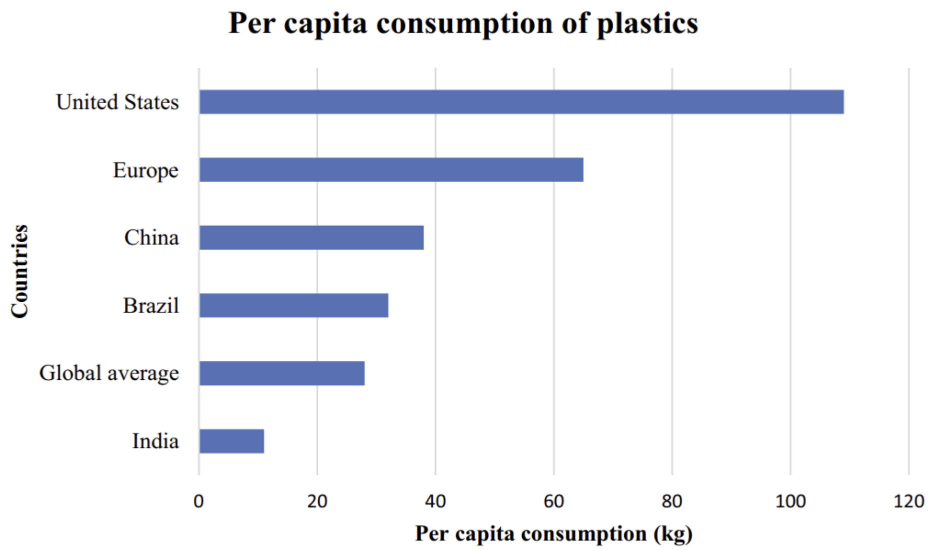

Figure 1. Per capita consumption of plastics in developed and developing countries. (FICCI, 2014)

While the global production of plastic generated only 2 million tons of plastic during the 1950s, eventually, the full potential of plastic was recognized, and global production of plastic rose to 348 million tons by 2017. Furthermore, an analysis of such production suggests that plastic consumption drastically rose alongside its production, with a consumption increase of approximately 18000%. Subsequently, the rapid increase in the use of plastics is projected to increase by two times by 2040 and 2050, with an estimated production of 1600 million tons. The per capita consumption of plastic in major countries is illustrated in Figure 1 with the United States having the most amount of per capita consumption of plastic by approximately 110 kg.

Plastics are classified according to their diameter. Although not internationally standardized, microplastic is defined as a plastic particle with a diameter < 5 mm while macroplastics are defined as particles with a diameter ≥ 5 mm.

Macroplastic

As defined previously above, macroplastic refers to plastics with a diameter that is greater than or equal to 5mm. However, differing definitions of macroplastics have also been published: for instance, a research article by Barnes and his colleagues referred to macroplastic as artificial debris with a diameter > 20 mm. Meanwhile, other studies and organizations suggest a classification of macroplastic that ranges from a diameter greater than 20mm, 25mm, or even 1cm (van Emmerik et al., 2018). Nevertheless, from an international standpoint, the classification of plastic with a diameter bigger than 5mm is generally considered as the standard definition of a macroplastic.

Microplastic

Microplastics are plastics that are comprised of small plastic debris usually 1µm to 5 mm. However, current research shows that there has been an increase in the concentration of microplastic in marine ecosystems throughout the world. Microplastics have a wide range of size, variable shapes, distinct biochemical properties, and composition that ultimately contribute to the degradation of the environment and ecosystem. It is depicted by several researches that

Microplastic particles are known to wash ashore, sink to the seafloor, get ingested by organisms, be contained in ocean ice, or be both airborne and/or waterborne. (Everaert et al., 2020)

Figure 2. A visual comparison of different plastic sizes. (Loganathan and Kizhakedathil, 2022) https://doi.org/10.33263/briac132.126

Metal Marine Debris (Heavy metal)

Metal marine debris is a unique marine debris as the metal itself is not toxic to the environment. Additionally, unlike plastic, due to the heavy and dense nature of metal composites, metals are unlikely to wander far from their original source. If metal marine debris was classified by size, it would be divided by its ability to be detected by the naked human eye. As mentioned before, shipwrecks, trash thrown overboard, fishing nets, and other equipment can be classified as macro metal marine debris. While fishing nets entangle and kill marine wildlife, such macro metal marine debris poses as much of a threat as a plastic bag: deadly under certain circumstances but also avoidable.

The truly dangerous metal marine debris is unseen. Heavy metals on a molecular level are capable of traveling the water routes of the river and ocean and causing pollution and toxic interactions with the environment and wildlife. Consequently, traveling upward a river usually sheds insight on the source of the heavy metal pollution. Wastewater from industrial factories and domestic sewage water is often the cited main culprits (Ntengwe, 2006). Surprisingly enough, wastewater from agriculture was also classified as a contributor to heavy metal pollution (Wei and Yang, 2010).

From a chemical perspective, heavy metals have earned their namesake because of their high density compared to water and are known to induce toxicity in small amounts and become carcinogens at higher concentrations (Martin, 1991; Kim et al., 2015; Duffus, 2016).

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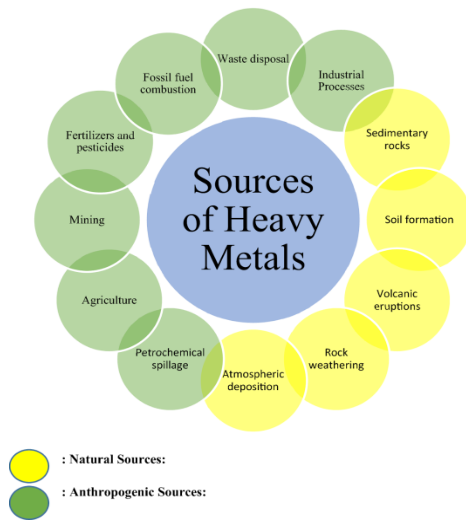

Figure 3. Sources of heavy metal. Note that heavy metals are also found in natural sources. (Nnaji et al., 2023) https://doi.org/10.1007/s42452-023-05351-6

Noteworthy heavy metals include Zn, Pb, Cd, Cu, Sn, and Hg. These heavy metals are not biodegradable, and when they flow toward the coast, they often fall to the bottom of the shore where they melt into the ocean sediment. These metals are then unconsciously consumed by benthic organisms. Antifouling copper paints are also a source of marine metal debris and contribute to the direct distribution of heavy metal in the middle of the ocean (Brennecke et al., 2016).

Marine Debris and Its Effects on Human Health

In the previous sections of this manuscript, marine debris had been divided and classified by type. For the identification of marine-based toxic content, the detrimental bioaccumulation and biomagnification of microplastics, will be considered alongside toxic metal bioaccumulation and biomagnification. This is because compared to other marine debris, plastic debris has a greater degree of biomagnification over the various trophic levels while toxic metals amplify up through the marine trophic levels at an alarming rate.

Before pressing on, it is important to note the difference in bioaccumulation and biomagnification. Bioaccumulation can be thought to be individual organism-based, while biomagnification travels up a trophic level. More specifically, bioaccumulation can be thought of as a toxic pile-up on the body (Wang et al., 2016). Biomagnification will always be used in the same content as the food web or trophic levels and is classified as a chemical concentration that increases when traveling up the food chain (Maher et al., 2016).

Marine bioaccumulation and biomagnification were thought to function in the same method as the figure below, plastic seems to enter the food chain from a different route. It was initially thought that plastic accumulation could start at the primary consumer level, the zooplankton, and it will biomagnify as it goes up the trophic level pyramid. However, measured readings regarding microplastic content in zooplankton proved otherwise. While controlled experiments yielded results that are in accordance with academic trophic level data, real samples did not produce the same results; zooplankton may not be the primary culprit of plastic bioaccumulation. (Miller et al., 2020).

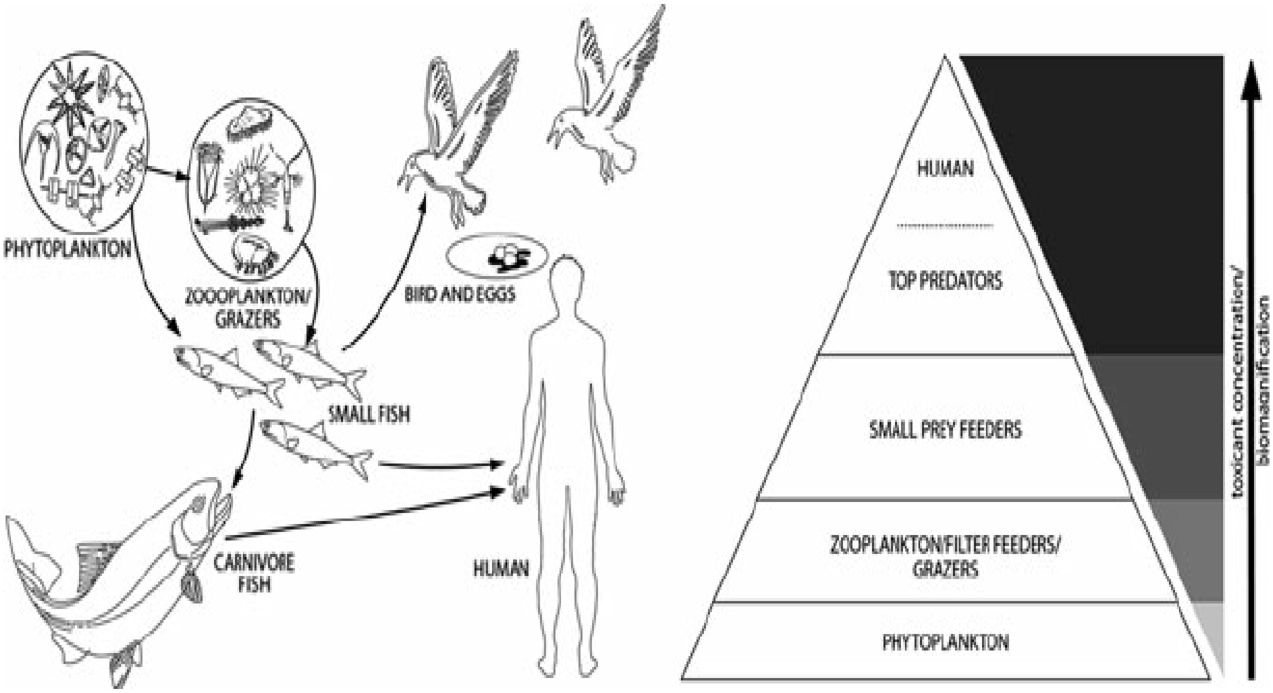

Figure 4. A simplified diagram of biomagnification throughout the marine trophic levels. (Sharifuzzaman et al., 2016) https://doi.org/10.1007/978-4-431-55759-3_2

An on-site study that tried to identify the microplastic uptake of the zooplankton found that although zooplankton did indeed consume microplastic in marine environments, the amount was not as significant as previously proposed (Gunaalan et al., 2023). Rather, it seemed that microplastic uptake occurred more frequently and in greater amounts in other marine animals such as turtles, fish, whales, dolphins, porpoises, and even seabirds (Duncan et al., 2019; Kühn and van Franeker, 2020). Nevertheless, in the general scheme of energy and material flow, bioaccumulation at lower trophic levels may result in biomagnification of the same chemical compound at higher trophic levels (Kelly et al., 2007).

Plastic Bioaccumulation

In a controlled environmental setting, bioaccumulation and its subsequent biomagnification could be observed (Cole and Galloway, 2015). However, in a natural environment, the same clear-cut processes were rarely observed. Plastic bioaccumulation occurred frequently at an individual trophic level through either direct or indirect ingestion, albeit with small effects from indirect trophic transfer (Hammer et al. 2016; Chae et al. 2018). Direct ingestion refers to the direct and immediate consumption of plastic matter, and indirect ingestion refers to the consumption of prey that has already consumed plastic matter.

In summary, bioaccumulation depends on the physiology of the animal. The size of the prey and predator amongst the trophic levels gives support to this theory. Small plankton are capable of consuming only microplastics, while larger consumers are capable of entertaining larger-sized plastic morsels. Some animals, such as certain seabirds) have unique gastrointestinal tracts that are capable of eliminating microplastics that they may have consumed (Provencher et al. 2018).

More often than not, animals are not capable of eliminating microplastics from their biological systems, and in the case of smaller-sized microplastics (microplastics smaller than 0.150 millimeters) and their related chemical additives, they are retained in the bloodstream of the consumer in question. It is this small microplastic that travels up the trophic level and causes biomagnification. In the case of seabirds, although they could eliminate the microplastic from their system, they could not eliminate the chemical pollutants that were on the microplastics they consumed (Ryan et al., 1988).

Plastic Biomagnification in Marine Life

Plastic biomagnification has been found consistently in controlled laboratory environments. However, on-site ocean analysis sometimes shows different results; sometimes biomagnification is very stark and trackable, while other times the theory encounters serious empirical evidence as a counterargument. In the midst of such variation, plastic biomagnification results near human activity have yielded results that are similar to those found in controlled laboratory environments

Biomagnification test readings in the Tokyo Bay area have shown biomagnification across several trophic levels. When in a polluted environment, the degree of biomagnification is very apparent and can be seen to increase as it goes up the food web. In this particular case, mollusks in the Tokyo Bay area were found to have a higher concentration of polychlorinated biphenyls (PCBs) than their water environment. Crabs and fish which prey upon these mollusks showed a higher concentration of PCBs, with mollusks having PCB concentrations several degrees (2x~3x) higher than fish (Takeuchi et al., 2009)

	reported concentration of PCBs (ppb)
water	0.93−1.02
mollusks	23.3−73
crabs and fish	113−367

Figure 5. An example of localized biomagnification in Tokyo Bay. PCB reading data obtained by Takeuchi et al. (2009). Data and table organized by Engler (2012). https://pubs.acs.org/doi/abs/10.1021/es3027105

Biomagnification was also identified in the Arctic, far from human activity (Borgå et al, 2004). In this particular case, the subject of interest, the arctic cod, was part of a significantly lengthy food chain that was lacking in diversity. This meant that there were fewer competitors on a single trophic level, of which there were many. The arctic cod showed a higher degree of PCB bioaccumulation when compared to other organisms on trophic levels lower than it. This PCB accumulation could not have come from the environment as the Arctic marine environment is relatively clean compared to other bodies of water. Borgå et al., have found that nearly 90% of all PCB accumulation came from direct inception from food sources.

Countries that have marine produce as a large portion of their daily diet have also shown toxic microplastic biomagnification. The chemicals that coat the microplastic are persistent, exhibit bioaccumulation tendencies, and are toxic, are classified as PBTs. Japan especially, has shown large concentrations of PBTs. An average Japanese person has been recorded to consume 3.22 pg toxic equivalent/kg body weight/day. This meant that the average Japanese person obtained 35% of PBTs from shellfish and fish (Tsutsumi et al., 2001.) In contrast, the United States of America, a country that does not have a marine-heavy diet, only reported .4 pg toxic equivalent/kg body weight/day (Schecter et al., 2001). and the World Health Organization has stated the safe range of daily PBT consumption as 1~4 pg toxic equivalent/kg body weight/day (van Leeuwen et al. 2000). Japan may be going over the limit as 65% of their PBT exposure may be coming from other sources.

Plastic Health Effects

After plastics enter the marine environment, they float to the surface of the ocean and are assaulted by the elements. These battered plastics are eventually downsized into microplastics, plastics smaller than 0.5 millimeters where they are affected by a variety of elements, both living and nonliving. The additional interaction causes even smaller and more deadly chemical pollutants to attach to the plastic like a life tube.

Polychlorinated biphenyls, dioxins, perfluorinated carboxylic acids, and perfluoroalkyl acids are some specific examples of PBTs that are found to be sorbed on plastic. When discussing the health effects of microplastics, it is specifically the PBTs sorbed on the microplastic that cause health issues. As such, for this particular subunit, the PBTs on the microplastic will be the main focus.

PBTs, due to their hydrophobic tendencies, and therefore, are found to congregate on the ocean surface to minimize exposure to the ocean water. Plastic, being light, floats to the surface, and being hydrophobic attracts the previously mentioned chemicals. As mentioned before, the light nature of the plastic makes it subject to movements on the ocean surface and wind currents. This also implies that plastic is capable of transporting toxic chemicals across a significant distance. Indeed, toxic chemicals were found in high concentrations in certain gyres around the world.

The previously mentioned PBTs are known to cause hepatotoxicity or liver damage. The PBTs induce cytochrome P450 monooxygenase isoenzyme 1A (CYP1A) activity (Tian et al, 2014). In ordinary circumstances, the liver conducts its detoxification duties. The CYP1A is found in phase 1 of the detoxification process, and when expressed in normal amounts it aids the liver. However, polychlorinated biphenyls, polychlorinated dibenzofurans, and polynuclear aromatic hydrocarbons have been known to cause the *CYP1A* to be overexpressed, and thus produce excess amounts of the CYP1A enzyme in marine organisms. When produced in excess, the CYP1A enzyme is a carcinogen and will bring about tumor development (Michel and Vincent-Hubert, 2015). In the event that the marine organism does survive phase 1, the damage done to the liver will eventually kill the organism as it will be unable to detoxify itself in the toxic seawater environment (Smital and Kurelec, 1998)

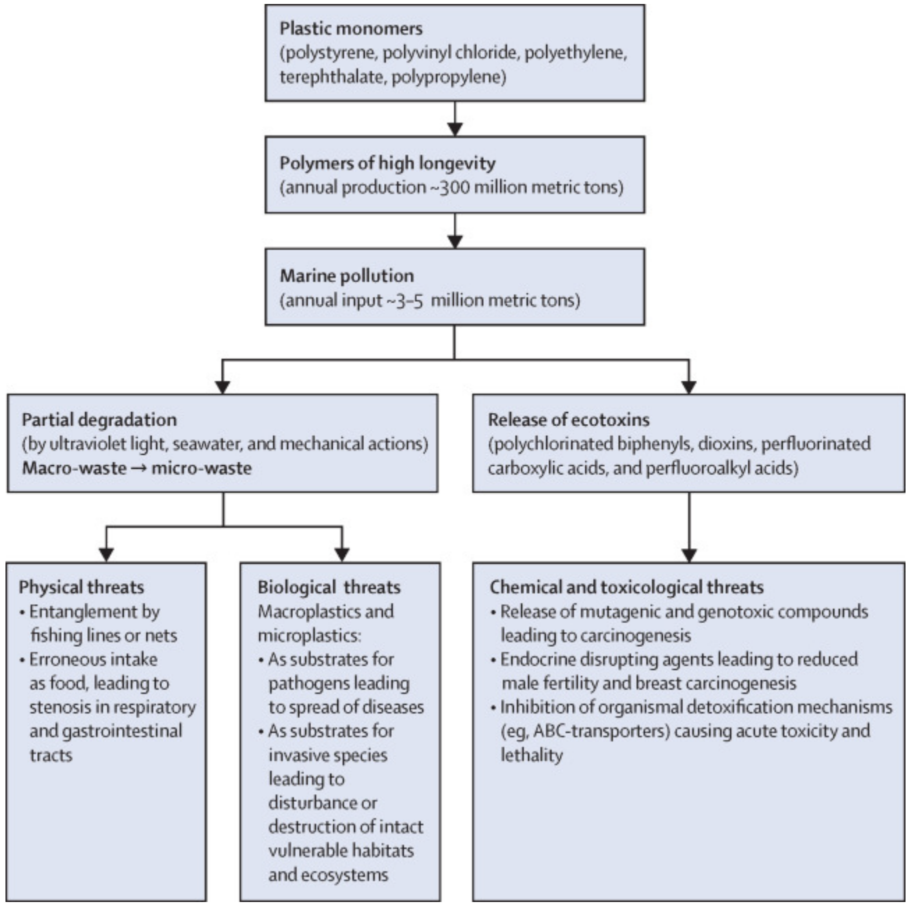

Figure 6. Summary of the detrimental effects caused by marine debris. (Efferth and Paul, 2017) https://doi.org/10.1016/S2542-5196(17)30140-7

Regarding specific chemicals, Bisphenol A (2,2-bis(4-hyddroxyphenyl)propane), is produced in astonishing amounts by volume and affects both marine life and human health well accumulated in the body. Bisphenol A, an endocrine disrupting chemical, binds to oestergone receptors and interferes with the reproductive system of human females while also poisoning marine male organisms' reproductive system (Bonefeld-Jørgensen et al., 2007). Phthalate, a plasticizer and also another endocrine disrupting chemical, has been known to decrease sperm quantity and quality. They have been known to cause DNA damage in germ cells and induce abnormal sperm cells. Phthalate accumulation concentration levels of 0.08-1.32 mg/kg were seen to negatively affect male fertility (Dobrzyńska, 2016).

Heavy Metal Bioaccumulation

Metal bioaccumulation is unlike plastic bioaccumulation as it occurs on the bottom of the ocean, in comparison to plastic's place at the ocean surface. The location of the heavy metals means that it is often absorbed by benthic sea life, which then are consumed by other marine forms that are placed on a trophic level above them. The sediments are ripe with heavy metals, and mussels, clams, oysters, crustaceans and even sea turtles are exposed to heavy metals (Altindağ and Yiğit, 2005; Abdallah, 2023).

Not all heavy metal bioaccumulation occurs at the seabed. In seawater, chromium is known to exist in the soluble oxyanion chromate (CrO_4^{2-}) state (Pettine and Millero, 1990). Due to it being in a soluble state, it can be ingested by phytoplankton. Although the phytoplankton is capable of naturally ejecting the heavy metal from its system, continuous prolonged exposure (a heavily chromium-polluted environment) will cause chromium to accumulate within the phytoplankton (Semeniuk et al., 2016). This outcome is alarming as phytoplankton is the primary producer in a marine environment and thus, a possible patient zero for chromium biomagnification.

An alarming characteristic of heavy metal bioaccumulation is its ability to be sorbed onto the surface of microplastics. Yellow seahorses subject to microplastics that were exposed to heavy metals showed stunted growth, and zebrafish that proved resilient to microplastic had cellular damage in the liver cells when they were fed heavy metal-laced microplastics. (Rainieri et al., 2018; Jinhui et al., 2019).

Heavy Metal Biomagnification

Aside from direct consumption, the soluble nature of heavy metals allows them to be easily introduced into the biological system of fish through the gills. Additionally, as mentioned before heavy metal accumulation occurred in the primary producer, the phytoplankton. Compared to plastic biomagnification, metal biomagnification is observed with greater frequency and magnitude. Dissolved heavy metal ingestion and direct food consumption make sure marine organisms are subject to continuous and prolonged heavy metal poisoning.

As heavy metal biomagnification occurs up the trophic level, secondhand heavy metal poisoning naturally follows. Mercury is the foremost example of biomagnification of heavy metals in a marine environment and is found in high concentrations in large fish that are positioned up in the upper echelons of the trophic level. Sharks and tuna are two examples of large fish that consume smaller fish, but research regarding the biomagnification in sharks is lacking compared to tuna. The fact that tuna appears as a staple in a human's diet while the shark is considered an exotic delicacy may contribute to the difference in research output.

Heavy Metal Health Effects

Metal bioaccumulation has been studied for an even longer period of time than plastic bioaccumulation. This is because the often lethal effects of metal bioaccumulation could be traced back to areas in close proximity to industrial activities. Toxic metal runoffs entered the river and flowed downward to the coast. The same river was sometimes used as the source of water by the human population down the river.

Compared to the past, industrial complexes are far more numerous, and each complex faces different degrees of waste disposal. Although certain companies are striving to neutralize their factory's waste, more often than not, heavy metal can be found at the opening of a bay. Additionally, heavy metals are innately resistant to biodegradation and have a tendency to build up inside the muscles of organisms (Li et al, 2020). A period of prolonged exposure to minute amounts of heavy metal will eventually induce carcinogen expression (Tchounwou et al., 2012).

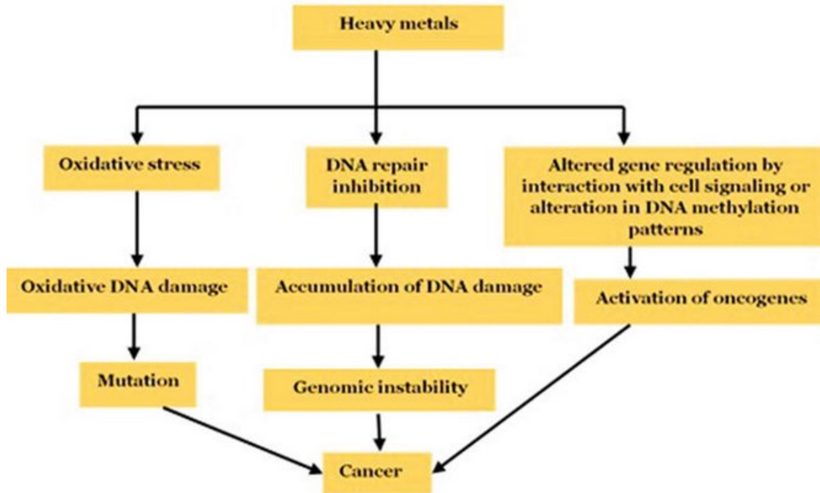

Figure 7. A flow chart of how heavy metals induce cancer. Different heavy metals induce different biological responses. (Hartwig, 2000) https://doi.org/10.1351/pac200072061007

Heavy metal poison in organisms often induces renal damage, liver damage, DNA damage, consequently a decrease in body weight, and ultimately a premature death from cell damage. Although heavy metals may be removed from the body depending on the heavy metal type, removal depends on whether the organism has been subject to continuous and prolonged exposure. If the body is not given time to eject to heavy metal from its system, the heavy metal integration rate will overcome the excretion rate, and thus, heavy metal accumulation will result.

Cadmium, also infamous as the main offender of the Itai-Itai disease, induced renal tubular dysfunction, severe osteomalacia, pseudo-fractures, and anemia (Shuto, 2005). As a result of renal tubular dysfunction essential nutrients such as calcium, phosphorus, and vitamin D could not be absorbed back into the bloodstream at the kidney. Additionally, the kidney failure was the start of a chain reaction that eventually led to excessive phosphate excretion and hypophosphatemia. Calcium excretion was another characteristic of cadmium bioaccumulation/biomagnification, and accumulating cadmium eventually induced osteomalacia.

Chromium also performs similarly to cadmium. Renal damage was found in rats exposed to chromium. Hepatic mitochondrial and microsomal lipid peroxidation were observed as was an increase in overall excretion activity (Sahu et al., 2014). Cell damage was also found near the nucleus of the renal cells, and kidney damage-associated diseases soon manifested.

Conclusion

An argument made to minimize the dangers in the Earth’s ocean is that the oceans constitute a high surface of the Earth compared to terrain land. This argument states that since the amount of ocean water is so vast, it can dilute itself, and the effects that come back to society can be ignored or treated. Unfortunately, that is not the case. The waste that enters the ocean eventually comes back in multiple ways, of which food was studied extensively in this manuscript. Other than bioaccumulation and biomagnification, marine debris comes back to human society in a number of ways. For microplastics, and in some cases, nanoplastics, the plastics enter the water cycle and come back to society not as food on the table, but through the air which we breathe. In the case of heavy metals, the toxic heavy metals seep through pores near the land in the river and infiltrate agricultural land. Carefully planning around toxic metals in a fish-based diet will not work if the common cabbage has is full of cadmium.

The solution to solving this predicament is unfortunately undoable by a single country. Although certain countries do produce more marine debris compared to other countries, due to the water-based nature and scale of the situation, an international approach is suggested. Additionally, trying to suddenly cut down usage of either plastic or industrial metal may cause unwanted collateral damage to the environment as governments and businesses try to scramble to find appropriate replacements. Nevertheless, replacement products will eventually have to manifest or the world may slowly poison itself to death. A gradual decrease of specific products is suggested, alongside neutralization reactions which seek to minimize the environmental damage of the marine debris may be the optimal solution. Finally, as hard as it may sound, nations will have to agree on how to properly contribute to cleaning the ocean; such efforts may start from their shores to international efforts in various plastic gyres, they have to come together.

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Reference

Abdallah, M. A. (2023). Bioaccumulation and biomagnifications of toxic metals in tissues of loggerhead turtles (Caretta caretta) from the Mediterranean Sea coast, Egypt. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-33972-9

Al-Zawaidah, H., Ravazzolo, D., & Friedrich, H. (2021). Macroplastics in rivers: Present knowledge, issues and challenges. *Environmental Science: Processes & Impacts*, *23*(4), 535–552. https://doi.org/10.1039/d0em00517g

Altindağ, A., & Yiğit, S. (2005). Assessment of heavy metal concentrations in the food web of lake Beyşehir, Turkey. Chemosphere, 60(4), 552–556. https://doi.org/10.1016/j.chemosphere.2005.01.009

Bonefeld-Jørgensen, E. C., Long, M., Hofmeister, M. V., & Vinggaard, A. M. (2007). Endocrine-disrupting potential of bisphenol A, bisphenol A dimethacrylate, 4-n-nonylphenol, and 4-n-octylphenol in vitro : New Data and A brief review. Environmental Health Perspectives, 115(Suppl 1), 69–76. https://doi.org/10.1289/ehp.9368

Borgå, K., Fisk, A. T., Hoekstra, P. F., & Muir, D. C. (2004). Biological and chemical factors of importance in the bioaccumulation and trophic transfer of persistent organochlorine contaminants in Arctic marine food webs. Environmental Toxicology and Chemistry, 23(10), 2367–2385. https://doi.org/10.1897/03-518

Brennecke, D., Duarte, B., Paiva, F., Caçador, I., & Canning-Clode, J. (2016). Microplastics as vector for heavy metal contamination from the Marine Environment. Estuarine, Coastal and Shelf Science, 178, 189–195. https://doi.org/10.1016/j.ecss.2015.12.003

Chae, Y., Kim, D., Kim, S. W., & An, Y.-J. (2018). Trophic transfer and individual impact of nano-sized polystyrene in a four-species freshwater food chain. *Scientific Reports*, *8*(1). https://doi.org/10.1038/s41598-017-18849-y

Cole, M., & Galloway, T. S. (2015). Ingestion of nanoplastics and microplastics by Pacific oyster larvae. *Environmental Science & Technology*, *49*(24), 14625–14632. https://doi.org/10.1021/acs.est.5b04099

Dobrzyńska M. M. (2016). Phthalates - widespread occurrence and the effect on male gametes. Part 2. The effects of phthalates on male gametes and on the offspring. Roczniki Panstwowego Zakladu Higieny, 67(3), 209–221.

Duffus, J. H. (2016). “heavy metals”—a meaningless term? IUPAC Standards Online. https://doi.org/10.1515/iupac.74.0076

Duncan, E. M.; Broderick, A. C.; Fuller, W. J.; Galloway, T. S.; Godfrey, M. H.; Hamann, M.; Limpus, C. J.; Lindeque, P. K.; Mayes, A. G.; Omeyer, L. C. M.; Santillo, D.; Snape, R. T. E.; Godley, B. J. Microplastic Ingestion Ubiquitous in Marine Turtles. *Glob. Change Biol.* **2019**, *25* (2), 744– 752, DOI: 10.1111/gcb.14519

Efferth, T., & Paul, N. W. (2017). Threats to human health by Great Ocean Garbage Patches. The Lancet Planetary Health, 1(8). https://doi.org/10.1016/s2542-5196(17)30140-7

Engler, R. E. (2012). The complex interaction between marine debris and toxic chemicals in the Ocean. Environmental Science & Technology, 46(22), 12302–12315. https://doi.org/10.1021/es3027105

Everaert, G., De Rijcke, M., Lonneville, B., Janssen, C. R., Backhaus, T., Mees, J., van Sebille, E., Koelmans, A. A., Catarino, A. I., & Vandegehuchte, M. B. (2020). Risks of floating microplastic in the Global Ocean. *Environmental Pollution*, *267*, 115499. https://doi.org/10.1016/j.envpol.2020.115499

FICCI, Potential of Plastics Industry in Northern India with Sepacial Focus on Pasticulture and Food Processing - 2014: A Report on Plastic Inudstry, 2014

Gunaalan, K., Nielsen, T. G., Rodríguez Torres, R., Lorenz, C., Vianello, A., Andersen, C. A., Vollertsen, J., & Almeda, R. (2023). Is zooplankton an entry point of microplastics into the Marine Food Web? *Environmental Science & Technology*, *57*(31), 11643–11655. https://doi.org/10.1021/acs.est.3c02575

Hammer, S., Nager, R. G., Johnson, P. C. D., Furness, R. W., & Provencher, J. F. (2016). Plastic debris in great skua (stercorarius skua) pellets corresponds to seabird prey species. *Marine Pollution Bulletin*, *103*(1–2), 206–210. https://doi.org/10.1016/j.marpolbul.2015.12.018

Hartwig, A. (2000). Recent advances in metal carcinogenicity. Pure and Applied Chemistry, 72(6), 1007–1014. https://doi.org/10.1351/pac200072061007

Jinhui, S., Sudong, X., Yan, N., Xia, P., Jiahao, Q., & Yongjian, X. (2019). Effects of microplastics and attached heavy metals on growth, immunity, and heavy metal accumulation in the yellow seahorse, Hippocampus Kuda Bleeker. Marine Pollution Bulletin, 149, 110510. https://doi.org/10.1016/j.marpolbul.2019.110510

Kelly BC, Ikonomou MG, Blair JD, Morin AE, Gobas FA. Food web–specific biomagnification of persistent organic pollutants. Science. 2007;317(5835):236–9. 10.1126/science.1138275

Kim, H. S., Kim, Y. J., & Seo, Y. R. (2015). An overview of carcinogenic heavy metal: Molecular toxicity mechanism and prevention. Journal of Cancer Prevention, 20(4), 232–240. https://doi.org/10.15430/jcp.2015.20.4.232

Kühn, S.; van Franeker, J. A. Quantitative Overview of Marine Debris Ingested by Marine Megafauna. *Mar. Pollut. Bull.* **2020**, *151*, 110858 DOI: 10.1016/j.marpolbul.2019.110858

Li, L., Wang, S., Shen, X., & Jiang, M. (2020). Ecological risk assessment of heavy metal pollution in the water of China's coastal shellfish culture areas. Environmental Science and Pollution Research, 27(15), 18392–18402. https://doi.org/10.1007/s11356-020-08173-w

Loganathan, Y., & Kizhakedathil, M. P. J. (2022). A review on microplastics – an indelible ubiquitous pollutant. *Biointerface Research in Applied Chemistry*, *13*(2), 126. https://doi.org/10.33263/briac132.126

Maher B, Taylor A, Batley G, Simpson S. Bioaccumulation. Sediment quality assessment: a practical guide: CSIRO Publishing; 2016. p. 123–56.

Martin, M. H. (1991). The heavy elements—chemistry, environmental impact and health effects. Environmental Pollution, 69(4), 354–356. https://doi.org/10.1016/0269-7491(91)90124-f

Michel, C., & Vincent-Hubert, F. (2015). DNA oxidation and DNA repair in gills of zebra mussels exposed to cadmium and benzo(a)pyrene. Ecotoxicology, 24(9), 2009–2016. https://doi.org/10.1007/s10646-015-1536-3

Miller, M. E., Hamann, M., & Kroon, F. J. (2020). Bioaccumulation and biomagnification of microplastics in marine organisms: A review and meta-analysis of current data. *PLOS ONE*, *15*(10). https://doi.org/10.1371/journal.pone.0240792

Nnaji, N. D., Onyeaka, H., Miri, T., & Ugwa, C. (2023). Bioaccumulation for Heavy Metal Removal: A Review. SN Applied Sciences, 5(5). https://doi.org/10.1007/s42452-023-05351-6

Ntengwe, F. W. (2006). Pollutant loads and water quality in streams of heavily populated and industrialised towns. Physics and Chemistry of the Earth, Parts A/B/C, 31(15–16), 832–839. https://doi.org/10.1016/j.pce.2006.08.025

Pettine, M., & Millero, F. J. (1990). Chromium speciation in seawater: The probable role of hydrogen peroxide. Limnology and Oceanography, 35(3), 730–736. https://doi.org/10.4319/lo.1990.35.3.0730

Provencher, J. F., Vermaire, J. C., Avery-Gomm, S., Braune, B. M., & Mallory, M. L. (2018). Garbage in guano? microplastic debris found in faecal precursors of seabirds known to ingest plastics. Science of The Total Environment, 644, 1477–1484. https://doi.org/10.1016/j.scitotenv.2018.07.101
Rainieri, S., Conlledo, N., Larsen, B. K., Granby, K., & Barranco, A. (2018). Combined effects of microplastics and chemical contaminants on the organ toxicity of zebrafish (Danio rerio). Environmental research, 162, 135–143. https://doi.org/10.1016/j.envres.2017.12.019
Rafey, A., & Siddiqui, F. Z. (2021). A review of Plastic Waste Management in India – challenges and opportunities. *International Journal of Environmental Analytical Chemistry*, *103*(16), 3971–3987. https://doi.org/10.1080/03067319.2021.1917560
Ryan, P. G., Connell, A. D., & Gardner, B. D. (1988). Plastic ingestion and PCBS in seabirds: Is there a relationship? Marine Pollution Bulletin, 19(4), 174–176. https://doi.org/10.1016/0025-326x(88)90674-1
Sahu, B. D., Koneru, M., Bijargi, S. R., Kota, A., & Sistla, R. (2014). Chromium-induced nephrotoxicity and ameliorative effect of carvedilol in rats: Involvement of oxidative stress, apoptosis and inflammation. Chemico-biological interactions, 223, 69–79. https://doi.org/10.1016/j.cbi.2014.09.009
Schecter, A., Cramer, P., Boggess, K., Stanley, J., Päpke, O., Olson, J., Silver, A., & Schmitz, M. (2001). Intake of dioxins and related compounds from food in the U.S. population. Journal of Toxicology and Environmental Health, Part A, 63(1), 1–18. https://doi.org/10.1080/152873901750128326
Semeniuk, D. M., Maldonado, M. T., & Jaccard, S. L. (2016). Chromium uptake and adsorption in marine phytoplankton – implications for the marine chromium cycle. Geochimica et Cosmochimica Acta, 184, 41–54. https://doi.org/10.1016/j.gca.2016.04.021
Sharifuzzaman, S. M., Rahman, H., Ashekuzzaman, S. M., Islam, M. M., Chowdhury, S. R., & Hossain, M. S. (2016). Heavy metals accumulation in coastal sediments. *Environmental Remediation Technologies for Metal-Contaminated Soils*, 21–42. https://doi.org/10.1007/978-4-431-55759-3_2
Smital, T., & Kurelec, B. (1998). The chemosensitizers of multixenobiotic resistance mechanism in aquatic invertebrates: A new class of pollutants. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis, 399(1), 43–53. https://doi.org/10.1016/s0027-5107(97)00265-0
Shuto, R. (2005). Itai-itai. Encyclopedia of Toxicology, 655–656. https://doi.org/10.1016/b0-12-369400-0/01038-3
Takeuchi, I., Miyoshi, N., Mizukawa, K., Takada, H., Ikemoto, T., Omori, K., & Tsuchiya, K. (2009). Biomagnification profiles of polycyclic aromatic hydrocarbons, alkylphenols and polychlorinated biphenyls in Tokyo Bay elucidated by Δ13C and Δ15N isotope ratios as guides to trophic web structure. Marine Pollution Bulletin, 58(5), 663–671. https://doi.org/10.1016/j.marpolbul.2008.12.022
Tian, S., Pan, L., & Zhang, H. (2014). Identification of a CYP3A-like gene and cyps mrna expression modulation following exposure to benzo[a]pyrene in the bivalve mollusk chlamys farreri. Marine Environmental Research, 94, 7–15. https://doi.org/10.1016/j.marenvres.2013.11.001
Tsutsumi, T., Yanagi, T., Nakamura, M., Kono, Y., Uchibe, H., Iida, T., Hori, T., Nakagawa, R., Tobiishi, K., Matsuda, R., Sasaki, K., & Toyoda, M. (2001). Update of daily intake of pcdds, pcdfs, and dioxin-like PCBS from food in Japan. Chemosphere, 45(8), 1129–1137. https://doi.org/10.1016/s0045-6535(01)00151-5
Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. Experientia supplementum (2012), 101, 133–164. https://doi.org/10.1007/978-3-7643-8340-4_6
van Emmerik, T., Kieu-Le, T.-C., Loozen, M., van Oeveren, K., Strady, E., Bui, X.-T., Egger, M., Gasperi, J., Lebreton, L., Nguyen, P.-D., Schwarz, A., Slat, B., & Tassin, B. (2018b). A methodology to characterize riverine macroplastic emission into the Ocean. *Frontiers in Marine Science*, *5*. https://doi.org/10.3389/fmars.2018.00372
van Leeuwen, F. X. R., Feeley, M., Schrenk, D., Larsen, J. C., Farland, W., & Younes, M. (2000). Dioxins: Who's Tolerable daily intake (TDI) revisited. Chemosphere, 40(9–11), 1095–1101. https://doi.org/10.1016/s0045-6535(99)00358-6
Wang JD, Tan Z, Peng JP, Qiu QX, Li MM. The behaviors of microplastics in the marine environment. Mar Environ Res. 2016;113:7–17. 10.1016/j.marenvres.2015.10.014

Wei, B., & Yang, L. (2010). A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. Microchemical Journal, 94(2), 99–107. https://doi.org/10.1016/j.microc.2009.09.014