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An Examination of Microplastics: Environmental Impact, Sustainability, and Recyclability Innovation

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ABSTRACT

Microplastics are plastic particles smaller than 5mm and represent a significant environmental and health threat due to their non-degradable nature and increasing accumulation in ecosystems. This scoping literature review provides an overview of plastic consumption patterns, the environmental impact of waste management practices, and emerging biochemical solutions for plastic degradation. Through a multi-phase research approach, key issues such as the ineffectiveness of traditional recycling methods, the environmental hazards posed by microplastics, and the complexities surrounding corporate versus consumer responsibility are examined. This paper also highlights promising advancements in bioplastics and novel recycling techniques, which offer potential pathways for mitigating plastic waste. However, the persistence of plastics in both terrestrial and aquatic environments, coupled with their bioaccumulation in living organisms, underscores the urgency of identifying viable solutions. While various approaches show promise, further research is recommended, particularly in enzyme-assisted bioremediation, which may offer the most effective means of reducing plastic waste and its associated risks to both ecosystems and human health.

Introduction

Microplastics are plastic (synthetic materials with high polymer content) particles that are smaller than 5mm. Some of their unique characteristics are that they are non-degradable, hard to recycle, and insoluble in water (Cole et al., 2011). Although the original purpose of inventing plastics was to benefit humans, by being a cheap material that can also be a sustainable alternative to scarce natural resources, today they are mostly considered more harmful than beneficial due to new recognition of their lasting harm on the environment and living beings. The harm microplastics cause apply both to the environment and most organisms on Earth, whether directly or indirectly. In the process of producing plastics, a significant amount of energy and fossil fuels are used, and their usage usually leads to problems such as environmental pollution, global warming, and a shortage of natural resources. Additionally, not only the production process but also the waste management process of microplastics is considered an issue. As mentioned earlier, microplastics are non-degradable, meaning that they are persistent and will keep accumulating on Earth unless humans come up with a solution that can reduce the amount taking up space in landfills and floating in marine areas. Similarly, many living organisms, including humans, risk microplastic accumulation in their bodies since microplastics are very hard to see or feel. In fact, animals especially face dangers because although they can recognize plastics, they often confuse them as food, such as seeing plastic bags as jellyfish. When microplastics end up entering living organisms' bodies, they accumulate in body tissue and disrupt normal health.

Around the mid-20th century, when the mass production of plastics began, disposable plastic started to become an environmental issue, especially in the aquatic environment (Cole et al., 2011). This is because when more plastics are getting produced and used, more plastics are eventually going to go to oceans and landfills as plastic waste after people are done using them. whole bags and bottle waste have long been considered a problem as larger plastics accumulate and threaten oceans and landfills, but microplastics cause more severe concern in aquatic environments because plastics can spread more easily due to oceanic currents, wave action, and the tides. Recently, microplastics have become the more imminent modern concern with their own unique issues regarding environmental impact and wildlife endangerment.

Today, microplastics are proliferating in greater numbers than ever before. In any environment, plastics do not generally degrade, but they do break apart and become more widespread, meaning that plastics themselves lead to increased microplastic concentrations; moreover, their small size makes them that much harder to filter, especially from wastewater that could be reclaimed to save freshwater. They are now manufactured directly in factories as part of consumer products, joining the smaller particles that result from broken down plastic products . Silva et al. (2018) defines primary microplastics as originally or primarily manufactured microplastics while secondary microplastics are plastic particles that are fragmented from their larger states, due to the continuous weathering of plastic wastes over time. With globalized commerce and the greater scientific realization that the world shares all resources and waterways, it is crucial to better understand the impact of industrial decisions and economic choices to minimize the negative impact of human activity around the globe.

Focus of Inquiry

In this paper, I provide a scoping literature review in which I give an overview of plastic consumption in modern history and discuss the impact of ongoing campaigns, ultimately assessing the potential for innovative solutions that incorporate the latest advancements in biochemistry for use in environmental applications. I also identify societal and environmental threats, such as the tension between corporate and consumer perspectives on recycling, which increases the complexity of the problem even before governments and non-economic organizations are considered. After comparing current methods of plastic waste management and demonstrating the urgency as global awareness of the problem continues to rise in the age of social media, I conclude with a recommendation to further research in the chemical processes that pose the greatest near- and long-term impact in terms of governing recyclability and plastic degradation to reduce plastic waste and its risk to ecosystems and inhabitants' health so that Earth's systems and human sustainability practices will align.

Methodology

To thoroughly investigate the issue of microplastics, I developed my research process in phases, including 1) objectives, 2) guiding questions), 3) scope, 4) screening, and 5) summary and synthesis. The steps taken are further described below. A subsection on terminology was deemed unnecessary because technical and industry-specific terms are provided in the literature and presented within context.

Objectives

The objectives of this paper are to provide information for readers of both casual interest and non-academic expertise to become more familiar through background information so that they can make informed opinions and take a stance on the environmental dangers of plastic waste.

My stated objectives as I began and pursued my research are listed below:

1) To provide a concise yet thorough background of plastic origins
2) Identify knowledge gaps of the general consumer
3) Examine recent discoveries and emerging research
4) Highlight promising research and current efforts to develop into practice
5) Recommend further research to add to the growing body of knowledge in that area

Guiding Questions

I initially began my research on a question I posed in Honors Chemistry for an assignment on linking classroom chemistry to an environmental issue. Originally, my curiosity branched off the topic of catalysts as I wondered how they could be applied to speed up biodegradation. A selection of guiding questions, which informed my search for relevant literature, are shown below:

1) What exactly does non-biodegradable mean?
2) What are the differences between recycling, recovery, and reuse methods?
3) Which solution is currently used the most or considered the most viable?
4) Are any bacteria other than *Ideonella sakaiensis* capable of degrading plastics?
5) On average, how long does plastic take to break down into microplastics?
6) How much plastic has actually been recycled and/or recovered?
7) On average, how much more do industrialized nations use one-time use plastics for convenience?
8) What considerations does it take to start using bacteria such as *Ideonella sakaiensis?*
9) Are landfill areas, locations, capacity, and number related to development level?
10) Why are people hesitant to replace plastics with other materials despite alternatives today?
11) Since plastic is based off petroleum, can oil-eating bacteria play a role in recovery or safe disposal?
12) What solutions or alternatives have been identified, considered, but not implemented in history?

Scope

For this literature review, all information, reports, and journal articles were found online using Google Scholar and Google search engine. Online databases with public search were also used, and no information locked behind paywalls was read or referenced. Only sources written and published in English were collected.

Using a simple focusing outline, example below, I narrowed broader topics into researchable specific topics.

Abridged Outline

I. Plastic waste management
   a. Microplastic degradation
   b. Enzyme-assisted bioremediation
II. Corporate vs. Consumer
   a. Sustainability
   b. Recyclability of plastics
III. Plastics and microplastics
   a. Bioaccumulation and environmental hazards
   b. Wastewater treatment
IV. Environmental hazard areas
   a. Landfills
   b. Marine areas (GPGP and South Pacific Islands)

Screening

To emphasize current research, I prioritized articles within the general date range of the years 2015 to 2024. I screened sources using these dates because the discovery of *Ideonella sakaiensis* was made in 2016. Some sources before my chosen date range are included because they provide useful context.

No sources were used that required paid access or private login information for databases.

Summary and Synthesis

After selecting 40+ sources, I followed these steps to decide which articles to read in greater depth and formulate my research review discussion. Sources were narrowed down through each step.

1) Read abstract and identify key terms
2) Read conclusions
3) Read article and make annotated bibliographies and research summaries to organize information
4) Extract quotes and citation information
5) Synthesize information for sources to dialogue and provide greater relevance

Literature Review

Discussion of Problems

Microplastic proliferation is a dire environmental concern and direct threat to human health. Alongside bulk plastics, microplastics are most likely to accumulate in landfill space because they do not biodegrade if management plans such as degradation or recycling methods are not implemented. In fact, current methods to reduce plastic waste include incineration, or high-temperature heating to force bonds in plastics to release. However, the byproducts of plastic incineration often include persistent organic pollutants (POPs), which the Stockholm Convention on Persistent Organic Pollutants categorizes as "potentially harmful organic compounds that resist environmental degradation through chemical, biological, and photolytic processes" (2019). Fortunately, it is found that plastics actually can be recycled and converted back to simple, valuable molecules under specific technical methods, such as chemical recycling and photothermal catalysts (Eisenreich, 2023). This fact, long known to plastics manufacturers, established a corporate and consumer way of thinking that plastics could keep being produced and used since they are cheap to manufacture, and all types of plastics are able to be recycled at any time, making them feel no guilt about continuing to use plastics (Sullivan, 2020).

In reality, recyclability is unfortunately no guarantee that plastics will be recycled, due to various considerations such as cost, complexity, and limits of recycling specific types of plastics. In fact, many companies ultimately choose to manufacture new plastics every time, partly because new plastics are considered higher quality than recycled plastics, which may not meet requirements for certain applications, such as beverage bottles (Sullivan, 2020). Consequently, the world has not actually recycled much: Only 9% of used plastic has been adequately recycled since 1950, and about half of all plastic has ended up dumped in landfills or in the wild (d'Ambrières, 2019).

While the recycling method has proven to be insufficient so far, another option that remains is incineration, which simply burns up plastic waste, converting solids to invisible gas. The reason this method was suggested in the past and has continued to be used is that it is significantly less costly and much simpler compared to other possible solutions without sacrificing quality (Sullivan, 2020). Nevertheless, plastic materials have long been known to release harmful gasses when incinerated and leave residues that are known to be toxic to human health (Rist et al., 2018). The known science demonstrates that plastic materials can technically be incinerated and degraded, but at the risk of creating other environmental pollutants as well, with such outputs of this method adversely affecting human health. Additionally, humans should also consider the extra fossil fuel combustion that is needed for the incineration process, which means that air pollution is produced in multiple phases during incineration without even producing a usable product. In the interest of saving space, incineration leaves the Earth worse off through burning fossil fuels and releasing harmful gasses and residues, contributing to global warming and pollution of the air, sea, and land.

Beyond accumulating in spaces, a growing concern about microplastics is that they can easily accumulate in living organisms and cause health problems. As plastic products are increasingly produced and used by humans, plastic waste in the natural environment also has been rapidly collecting. After they are initially thrown away as larger plastic particles/products, plastics naturally break down through mechanical weathering, similar to erosion, into smaller particles over time, which spread further by wind and water currents; worse, they may be small enough or irregularly shaped that they are not easily recognized. Consequently, small plastic particles are found almost everywhere we look, including aquatic and terrestrial environments and other food products and beverages (Rist et al., 2018).

Examples of the global scale regarding marine plastics include the Great Pacific Garbage Patch (GPGP) and the South Pacific Islands. In the GPGP, discovered in 1997, at least 79 thousand tons of ocean plastic are predicted to float inside an area of 1.6 million km^2 and microplastics accounted for 8% of the total mass and 94% of the estimated 1.8 trillion pieces floating in the area (Lebreton et al., 2018). More recent estimates double that approximation (Teague, 2024). South Pacific Islands, eastern Australia, and New Zealand are experiencing similar problems, where "discarded plastics are a significant pollutant of shorelines and adjacent coastal and oceanic waters" (Gregory, 1999). Contradicting people's thoughts that expect the low severity of the situation due to the low amount of people inhabiting those areas, "Estimates suggest that between 8 million and 11 million tons of plastic waste enter the ocean each year" (Main, 2023).

The situation gets worse especially in those environments since the likelihood of consuming microplastics is much higher. In aquatic and terrestrial environments, most animals fail to recognize microplastics but confuse them with their foods. Similarly, when microplastics are contained in food products and beverages, even humans rarely realize that microplastics are contained, due to their minute size, and they unconsciously end up allowing microplastics to enter their bodies. Some people might think it is not a big deal, but the effect is much worse than previously considered. Unlike many other materials that pass through the body when ingested, microplastics are harder to detoxify from living organisms' bodies since they absorb into body tissue. They are also carriers of toxins, meaning that if too much microplastic accumulates in living bodies, health issues that are yet to be identified can follow (Underwood et al., 2017).

Those difficulties in recycling/degrading proves that plastic is a material that is hard to "close the loop," which is the process that uses the recycled raw material for the same product and fully replaces the virgin material (Li et al., 2022). If humans fail to close the loop of the plastics by not taking meaningful actions, more plastics will be produced and will accumulate. Without changing this situation, an overflow of plastics will disrupt the Earth's systems and inhabitants. In contrast, if people succeed in closing the plastic loop, significantly less plastic can be made, reducing energy consumption and materials extraction. Unfortunately, the current situation/trend shows that humans are failing in closing the loop of the plastics and the amount of plastics is increasing every day.

Solution Analysis and Identification

To resolve the harms microplastics have caused, humans must expand on current solutions to optimize plastic consumption and manufacturing sustainability along with its waste management. The preferred solutions will be able to reduce, perhaps even reverse landfill dumping, which will provide a sustainable plastic production and use lifecycle. If the plastic wastes that are dumped all over the world are properly managed and recovered for reuse rather than disposal, the lifecycle of plastics would be extended, potentially even forming a closed loop that makes efficient use possible, reducing the amount of energy needed to maintain the current wasteful cycle of manufacture, consumption, and disposal. Just as important as economic concerns, reducing plastic waste that pollute waterways and marine environments would improve upon existing bioenvironmental issues. Doing so would not only mitigate plastic pollution in the marine environments but also reduce the danger to living organisms across global food webs.

Since people are the root cause of the issue, they should also be the ones to take responsibility for cleanup and advocacy solutions. Since plastics started to become a major global issue, various campaigns and awareness programs have come to influence consumers, corporations, and governments to some effect. For example, since the 1980s, plastic corporations have campaigned and lobbied, spending millions to convince the public through ad campaigns for recycling, yet at the same time pushing responsibility onto consumers while building a positive image of plastic consumption and ignoring what they had already known about its potential for environmental harm (Sullivan, 2020).

These efforts of the companies since then continued, but the impact on actual recycling was nowhere near what was needed to prevent widespread accumulation.

Into the 2000s in line with technological advancements, the impact individuals around the world made on the situation through social media became significantly larger. Online communication made spreading every environmental issue or event in a wider range possible. Unlike news outlets that were primarily used as a tool to spread information—typically as objectively as possible—social media allows individuals to share as much information as they feel is necessary to push people toward action, with the added benefit of not requiring a profession in traditional journalism (Puentes, 2021). Rapada et al. (2023) found that "the concern on plastic pollution has gained traction wherein the global pro-sustainability community has initiated advocacies and measures to control the indiscriminate usage of plastics," establishing the potential for individuals' ability to promote change. In response to the public mandate for change, corporations have come to see the consumers' changing perspective and have taken environmental impact into account, with many businesses taking action to rebrand through positive global mission statements. Such companies are called Benefit Corporations (B Corps). Adding positive environmental impact and sustainability to their original goals of making profit, they adhere to the principles of serving the people, making profit, and protecting the Earth by doing less or no harm, integrating a sustainability aspect to "provide products and services to help address the climate crisis and shape more resilient supply chains" in addition to "rethinking design to reduce waste and reuse materials" ("2022 best for the world environment," 2022).

In the current century, people's efforts to mitigate or resolve the plastic waste issue are leading to advancement beyond cultural attitude changes. Approaching the issue from multiple directions, scientific developments are being made to improve on plastic design, recycling, and recovery. The advancement in technologies has allowed scientists to consider numerous possibilities. Against plastic companies' lobbying efforts, other producers are succeeding in alternative materials, such as bamboo and paper products, but these substitutions do not change the concept of plastic waste itself. Beyond replacing plastics with other materials, science is allowing manufacturers to look at innovative recycling options and recovery—plastic breakdown into its base molecules—to minimize the use of fossil fuels and energy in new plastic production. Mimicking the ideal characteristics of plastics, such as its cheap, light, and durable nature, scientists and researchers in 1926 discovered bio-plastics, a near-perfect substitute "derived from plant sources such as sweet potatoes, soya bean oil, sugarcane, hemp oil, and cornstarch" (Fridovich-Keil, 2008; Reddy et al., 2013). The main benefits of using this material is that while it functions similar to normal plastics, its carbon footprint is much lower and the product itself is highly biodegradable compared to normal plastics (Lamberti et al., 2020). This unique latter characteristic is significant for reducing plastic wastes around the world because when normal petroleum-based plastics are used, the main reason for the uncountable amount of plastic wastes was their difficulty in naturally biodegrading. Further research could identify in more detail why this viable alternative is not currently normalized, suspected reasons including cost efficiency and convenience for manufacturers already invested in typical plastics. For bio-plastics' main application in the future, recent researches have predicted their potential in replacing petroleum-based plastics in fields such as automobiles and biomedical applications (Nanda et al., 2021). Instead of completely replacing the material that has been familiar to humans for a long time, there are also possible methods that still deal with normal petroleum-based plastics, which continue to dominate plastic manufacturing.

In dealing with traditional plastics, the current methods of recycling are considered costly despite how familiar consumers are with recycling in industrialized societies. With advances in chemistry, new versions of recycling have appeared and grabbed scientists' attention. For example, compared to standard bottle crushing and melting, which results in materials that can be reused for non-food and beverage containers, scientists have discovered ideal conditions to allow plastics to "undergo thermal degradation to produce a liquid known as pyrolysis oil" of more basic organic molecules and can separate constituent molecules through "hydrogenolysis to produce lubricants and oils, functionalization of plastics, and the creation of plastic alloys" (Li et al., 2022). Unlike other methods of waste disposal, like incineration which produces harmful substances throughout the process, advanced recycling methods like thermal degradation and hydrogenolysis not only reduce plastic waste safely but also lead to usable ingredients that can lower the amount of extraction involved in making new plastics. Still, energy and carbon footprint concerns are barriers that must be addressed because both processes inherently utilize high heat, which involves fossil fuels to generate sufficient energy.

Perhaps one of the most striking of recent breakthroughs in plastics chemistry is a finding that may make the term non-biodegradable obsolete. As of 2016, plastic biodegradation is no longer just a hypothetical dream. At the frontier of biochemistry and environmental science is the concept of environmental bioremediation. This refers to the use of organisms to reverse the harm done on the environment, such as the use of modified bacteria that consume oil spills. For plastics, the technique of enzyme-assisted bioremediation is currently in development since the 2016 discovery of *Ideonella sakaiensis*, a wild-type bacteria, in a plastic bottling plant in Sakai City, Japan. Researchers found that the isolated bacteria could reduce polyethylene terephthalate (PET), the film-like plastic used to make most clear plastic bottles, into the two molecules that make it (Palm et al., 2019). Laboratory experiments have confirmed the bacterium's ability to integrate the enzymes PETase and MHETase, which break down PET into terephthalic acid (TPA) and ethylene glycol (EG), allowing these molecules to yield new PET that can be used in all bottling (Palm et al., 2019). Thus, instead of pushing recycled plastics down the chain to create inferior recycled plastics, a full recovery of original plastics that does not use new petroleum or fossil fuel energy is theoretically possible. By outputting simple building blocks that are used for a new reaction, scientists can successfully close one of the largest waste chains into a sustainable loop.

Conclusion

The abundant presence of microplastics in marine environments and human waste yard pose a growing ongoing threat to environmental and public health. Current consumption rates and the lack of environmental cleanup required persistent attention, making plastic waste management an urgent area of human concern. With plastic waste continuing to accumulate on land and sea, its resistance to natural chemical breakdown endangers the Earth's carbon cycle and the planet's inhabitants. Scientific innovations must be applied to engineer the optimal solution because plastics will not break down fast enough, creating complex waste management problems in the future. Traditional methods, such as recycling campaigns and incineration, are clearly insufficient and mask the environmental harm caused by plastic production and disposal. Moreover, the bioaccumulation of microplastics in living organisms, including humans, may no longer be ignored.

Therefore, it is essential to continue research to expand the body of knowledge on microplastics, sustainability, and environmental protection. Advancements in biochemistry, particularly in enzyme-assisted bioremediation and the partial degradation of plastics to reuse intermediate molecules, show promise in decreasing plastic waste and pollution. However, these scientific breakthroughs must be responsibly applied and integrated into comprehensive waste management strategies that can be financially sustainable while prioritizing environmental and human health.

Limitations

This paper acknowledges several limitations that generally occur when researching for and writing scoping literature reviews. Only sources published in English were used, potentially limiting valuable information and testing conducted in the global scientific community. Furthermore, the use of primarily peer-reviewed articles tended to lead to more technical discussions, requiring more explanation to bring the content to non-academic and casual readers.

Compared to a systematic literature review, which I also considered, the broad range of topics made a scoping literature review more appropriate, but at the cost of formally categorizing data or ranking them according to criteria. Moreover, this review prioritized general awareness and information on a broad range of topics in the history and timeline of plastics, rather than examining any one topic with full depth.

As a high school researcher, my own judgment may be lacking in judging the quality of sources I select, though I tried to minimize bias and maximize credibility by avoiding gray literature and instead, prioritizing peer-reviewed academic journals.

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References

2022 best for the World Environment: B Corps lead the way toward a sustainable, regenerative economy. (2022, August 17). B Lab United States & Canada. https://usca.bcorporation.net/zbtcz08z22zbftwz2022-best-for-the-world-environment-b-corps-lead-the-way-toward-a-sustainable-regenerative-economy/

Cole, M., Lindeque, P., Halsband, C., & Galloway, T. S. (2011). Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin, 62(12), 2588–2597. https://doi.org/10.1016/j.marpolbul.2011.09.025

d'Ambrières, W. (2019). Plastics recycling worldwide: Current overview and desirable changes. Field Actions Science Reports, (19), 12–21. https://journals.openedition.org/factsreports/5102

Eisenreich, F. (2023). Photocatalysis as an effective tool for upcycling polymers into value-added molecules. Angewandte Chemie, 135(29). https://doi.org/10.1002/ange.202301303

Fridovich-Keil , J. L. (2008, December 31). Bioplastic. Encyclopædia Britannica. https://www.britannica.com/technology/bioplastic

Gregory, M. R. (1999). Plastics and south pacific island shores: Environmental implications. Ocean & Coastal Management, 42(6–7), 603–615. https://doi.org/10.1016/s0964-5691(99)00036-8

Lamberti, F. M., Román-Ramírez, L. A., & Wood, J. (2020). Recycling of bioplastics: Routes and benefits. Journal of polymers and the environment, 28(10), 2551–2571. https://doi.org/10.1007/s10924-020-01795-8

Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., Hajbane, S., Cunsolo, S., Schwarz, A., Levivier, A., Noble, K., Debeljak, P., Maral, H., Schoeneich-Argent, R., Brambini, R., & Reisser, J. (2018a). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific Reports, 8(1). https://doi.org/10.1038/s41598-018-22939-w

Li, H., Aguirre-Villegas, H. A., Allen, R. D., Bai, X., Benson, C. H., Beckham, G. T., Bradshaw, S. L., Brown, J. L., Brown, R. C., Sanchez Castillo, M. A., Cecon, V. S., Curley, J. B., Curtzwiler, G. W., Dong, S., Gaddameedi, S., Garcia, J. E., Hermans, I., Kim, M. S., Ma, J., & Huber, G. W. (2022). Expanding plastics recycling technologies: Chemical aspects, technology status and challenges. Green Chemistry, 8899–9002. https://doi.org/10.26434/chemrxiv-2022-9wqz0

Main, D. (2023, October 22). Think that your plastic is being recycled? Think again. MIT Technology Review. https://www.technologyreview.com/2023/10/12/1081129/plastic-recycling-climate-change-microplastics/

Nanda, S., Patra, B. R., Patel, R., Bakos, J., & Dalai, A. K. (2021). Innovations in applications and prospects of bioplastics and biopolymers: A review. Environmental Chemistry Letters, 20(1), 379–395. https://doi.org/10.1007/s10311-021-01334-4

Palm, G. J., Reisky, L., Böttcher, D., Müller, H., Michels, E. A., Walczak, M. C., Berndt, L., Weiss, M. S., Bornscheuer, U. T., & Weber, G. (2019). Structure of the plastic-degrading Ideonella sakaiensis MHETase bound to a substrate. Nature Communications, 10(1). https://doi.org/10.1038/s41467-019-09326-3

Puentes, C. (18AD). Social media and environmental activism: An evolving relationship. School of Marine and Environmental Affairs. https://smea.uw.edu/currents/social-media-and-environmental-activism-an-evolving-relationship/

Rapada, M. Z., Yu, D. E., Janairo, J. I., & Yu, K. D. (2023). Impact of online-based information and interaction to proenvironmental behavior on plastic pollution. Cleaner and Responsible Consumption, 9, 100126. https://doi.org/10.1016/j.clrc.2023.100126

Reddy, L. R., Reddy, S. V., & Gupta, A. G. (2013). Study of bio-plastics as green & sustainable alternative to plastics. International Journal of Emerging Technology and Advanced Engineering, 3(5). https://www.academia.edu/39166666/Study_of_Bio_plastics_As_Green_and_Sustainable_Alternative_to_Plastics

Rist, S., Carney Almroth, B., Hartmann, N. B., & Karlsson, T. M. (2018). A critical perspective on early communications concerning human health aspects of microplastics. Science of the Total Environment, 626, 720–726. https://doi.org/10.1016/j.scitotenv.2018.01.092

Silva, A. B., Bastos, A. S., Justino, C. I. L., da Costa, J. P., Duarte, A. C., & Rocha-Santos, T. A. P. (2018). Microplastics in the environment: Challenges in analytical chemistry - A review. Analytica Chimica Acta, 1017, 1–19. https://doi.org/10.1016/j.aca.2018.02.043

Stockholm Convention on persistent organic pollutants (POPs). Text of the convention. (2019). https://www.pops.int/TheConvention/Overview/TextoftheConvention/tabid/2232/Default.aspx

Sullivan, L. (2020, September 11). How big oil misled the public into believing plastic would be recycled. NPR. https://www.npr.org/2020/09/11/897692090/how-big-oil-misled-the-public-into-believing-plastic-would-be-recycled

Teague, K. (2024, April 11). The Great Pacific Garbage Patch: The floating islands of trash three times the size of France. CNET. https://www.cnet.com/science/the-great-pacific-garbage-patch-the-floating-islands-of-trash-three-times-the-size-of-france/

Underwood, A. J., Chapman, M. G., & Browne, M. A. (2016). Some problems and practicalities in design and interpretation of samples of microplastic waste. Analytical Methods, 9(9), 1332–1345. https://doi.org/10.1039/c6ay02641a