The Use of Microbes to Control Petroleum-Based Plastic Pollution

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Introduction

Petroleum based plastics, a versatile invention that is ubiquitous in modern day life, has made thousands of products cheap and easy to produce. However, with this revolutionary material comes a rapidly increasing pollution problem. Ocean pollution is a pressing concern in modern day society, with pollutants damaging ecosystems and harming wildlife. Petroleum based plastics are of particular interest due to their persistence in the environment and the ability to break down into subunits that can act as endocrine disruptors in humans (National Institute of Health [NIH] 2019). This paper reviews how the use of petroleum and plastics has led to the use of plastic digesting microbes as a means to clean up the resulting pollution. The issue of petroleum-based pollution is vitally important to the health of the ocean ecosystems. Plastic pollutants have detrimental effects on the organisms and can cause widespread harm to ecosystems. Additionally, plastics can have harmful effects when digested by wildlife, and the loss of aquatic life as a potential food source harms both people and the industries that rely on these organisms. The overarching STS research question addressed in this paper is how the use of petroleum and plastic has led to the use of plastic digesting microbes as a means to clean up pollution.

Research Questions and Methods

The STS research question this paper covers is how the adoption of plastics as a material has led to the use of plastic digesting microbes to degrade the plastic waste. This paper aims to approach this problem with two major methods, wicked problem framing and historical case studies. The wicked problem-solving method is optimal because it encompasses the technological fix STS theory and examines how the best laid planning efforts fail. When one introduces a new organism into an ecosystem it often creates unforeseen consequences and affects other organisms in surprising ways. The historical case study method is ideal for this research because oil spills have occurred a number of times in the last few decades and bacteria have repeatedly demonstrated the ability to potentially break down petroleum. Additionally, I am examining the shortcomings of the other methods to clean ocean-based plastics and better explain why the use of bacteria is a viable option. The organization for this research separates into historical examples and the effects that these examples have had on the ocean environment.

Background

Pollution and global climate change have been a major concern among the scientific community for years, however, a less talked about issue is the harm that plastic pollutants are having on the ocean ecosystem. Petroleum based plastics are one of the defining inventions of the twentieth century and have led to the mass production of a variety of products. Plastics are an excellent material because they are versatile, relatively cheap to produce, slow to decompose and one can produce massive amounts in a relatively short period of time. This availability has led to plastics becoming a ubiquitous building material in modern day society. However, this success comes at a cost; the properties that make plastics such a good material has led to mountains of floating plastic waste that does not break down through normal biological processes.

Currently, plastics permeate the ecosystem leaving waste, estimated to take a few decades to centuries to break down. Due to the persistence many plastics find their way into the ocean. Plastic straws can take 200 years to decompose naturally, plastic water bottles take approximately 450 years, and plastic fishing line can take up to 600 years to decompose (Mills 2018). This slow decomposition process would not be a pressing concern if discarded plastic products were stored properly where they could be isolated and allowed to break down without infiltrating water systems and ecosystems, however, due to improper disposal procedures, a number of plastics find their way into the ocean. A study in 2015 estimates that 275 million tons of plastics products find their way into the ocean per year (Jambeck 2017). The growing concern with plastics has led to the development of new technologies to help alleviate the pollution problem, including the use of bacteria as a means of metabolizing these compounds.

The stakeholders for ocean pollution are numerous, and the impact of pollution is far-reaching. Ocean-based ecosystems are stakeholders in ocean pollution. Petroleum-based plastics can directly harm the organisms by covering wildlife, catching wildlife in ghost nets, and causing harm when inadvertently consumed by sea life (Wilcox 2018). When plastics decompose into smaller parts, they can also serve as a pollutant for food sources; through biomagnification plastics subunits can build up in the food chain resulting in higher concentrations of plastic in predators and filter feeders (Diepens 2018). These plastics occupy space in the organism's stomach, can damage the digestive system, and are potentially lethal (Wilcox 2018). Finally, plastics subunits can also act as an endocrine disrupter in the human body leading to chemical imbalances and a host of detrimental effects to humans (National Institute for Health 2019). The harmful effects caused by the biomagnification of plastics extends beyond individuals affected by this pollution; it is of vital importance to industries and people that depend on the ocean as a source of food and economic prosperity. Fish stocks already depleted from overfishing can become toxic to humans and put at further risk through the ingestion of plastic. These concerns have led to scientists developing methods of selecting bacteria to breakdown plastics.

STS Framework

The topic of using microorganisms to break down petroleum based plastics relates to the field of Science, Technology, and Society (STS) through the development of a new technology, plastics, which has created the societal and environmental problems of pollution. This problem is multifaceted and pervasive in modern day times; while some efforts are being taken to reduce the amount of pollution, there is still a lack of political support and personal interest to take rapid action to reduce this problem. This problem has a historical background of clean-up efforts and scientists have recently been incorporating microorganisms as a method to solve real-world problems. Due to this fact, this paper uses the historical case study method as one of the primary methods of examining this problem. The historical case study method is optimal for this problem because similar efforts to harness the power of microorganisms have been attempted and problems have been found and learned from different instances. Additionally, one can look at the potential effects of adding an organism to a new ecosystem and the drastic implications that it can have to already established organisms. There are also historical records of bacteria showing promise in metabolizing different forms of waste which can be studied to the effects that they had on different ecosystems. The STS framework for this issue fits within the field of STS through the perspective of the politics of technology. Technology can impact and influence politics, and politics can place regulations or change the way technology is used. Plastics are a distinctly man-made product that has created a problem for society and environmental problems. This framework is viewed through the lense of Wicked Problem Framing. Wicked Problem Framing was inspired by Rittel and Weber’s work and helps look at the failing points of solutions for different societal issues. This framework has general agreement between authors as it is a perspective to view a problem rather than the assertion that an issue is intractable. Wicked Problem Framing provides an excellent way to look forward and hopefully prevent problems from happening in plans from thorough foresight and effective planning. Wicked problem framing is an ideal lense to view this problem because it is a method that views the potential ways that plans, organization, and technological innovation can fail. This method will look at the potential solution of using bacteria to break down plastics and the potential problems that it can cause for ecosystems, communities, and pollution reduction efforts.

Results and Discussion

The research for this paper looked at how petroleum-based plastics and biotechnology have led to the use of plastic digesting microbes as a method to clean up ocean pollution. It specifically looks at the potential issues with using biotechnology in ecosystems and the potential ramifications of using foreign species in clean-up efforts. Through the historical case study method and the wicked problem framing, bacteria are demonstrated to be an effective method of breaking down plastics, however bacteria can have unintended consequences by altering the microbiome of various aquatic ecosystems. Additionally, though this method breaks down the larger polymer chains of plastics, it still fails to eliminate the plastic subunits presence in the water. These subunits are particularly harmful because they can act as endocrine disruptors in humans. While the use of bacteria to breakdown is a potential way to reduce the amount of solid waste accumulated, it still fails to address the overarching problem of proper disposal of plastic waste.

One of the key points that shows the potential for bacteria to break down plastics was the Bonny Light Crude Oil spill (Anita 1990) which used the established biodegradation capability of *Bacillus* and *Pseudomonas* to determine the most effective conditions for bacterial degradation of crude oil. During this oil spill, it was demonstrated that bacteria effectively broke down the crude oil, however, like most microbes, they performed best in specific conditions and required certain temperatures to operate. The capability to digest artificial polymers is also demonstrated through digestion of man-made plastics from the gut bacteria of wax worms. This capability is notable because it demonstrates bacteria's historical adaptability, and ability to adapt to use new food sources. Additionally, according to Urbanek (2018) marine ecosystems have already seen an increasing prevalence of naturally occurring organisms in cold-water aquatic ecosystems with the ability to breakdown several different varieties of polymers. Presently different strains of bacteria already possess some enzymes that can break down plastics; this makes it very possible to edit the genomes of other existing bacteria to be able to metabolize different compounds and potentially produce desired drugs or compounds.

One of the key methods to accelerate the process of plastic degradation is utilizing genetic engineering to augment the genome of an already common bacteria with genes that code for plastic digesting enzymes. Bacteria are excellent organisms to modify for several reasons. Bacteria are ubiquitous throughout the earth; they serve as the foundation for ecosystems and serve in many symbiotic relationships. Bacteria are notable for replicating very quickly, sometimes doubling in a matter of hours. Additionally, they are very adaptable and are capable of surviving in some of the most extreme conditions on earth. They are also desirable for their relatively simple genome which is easily editable through the CRISPR (Clustered Regularly Interspaced Short Palindromic Repeat) method of genetic modification. CRISPR is a class of DNA sequences that are used to defend against bacteriophages that would infect the prokaryote. This defense can be harnessed to precisely split precise areas of DNA and insert desired genes into an organism. This enables one to very carefully select specific genes to enact desirable characteristics in an organism. Additionally, bacteria can use plasmids, or specialized rings of DNA that are able to code for very specific purposes such as drug resistances and different enzyme production. It is notable that this method is already implemented in bacteria to cause bacteria to produce life-saving drugs such as insulin in mass amounts. With this method a majority of the cost would be upfront for editing and testing the new bacterium; in later stages of any project all that would be important is allowing for them to replicate and feed off of the plastic enzymes. This method could be highly effective at reducing the accumulated plastic because it would break down the polymers into smaller parts that the bacteria could use.

One critical issue associated with genetic engineering, however, is the societal side of the STS framework. The U.S. patent system is stringent with the regard to the creation and use of GMOs (Genetically Modified Organism). Historically, the use of GMOs is controversial, according to Zhou (2015), GMO patents typically last 20 years from the expiration of the initial filing for the patent. According to United States law, any genetically modified organism produced to potentially alleviate a plastic pollution problem can be protected under intellectual property laws. Accordingly, funding and use of the formed bacteria would be subject to pricing by for-profit companies and a company with a patent would have exclusive rights to the use of such an organism. Restrictive patents could potentially make a solution more costly and would significantly slow down the use of an organism designed to clean up the environment.

There are also ethical concerns with releasing a new or foreign species into ecosystems. The introduction of a new species, or the increase in the viability of an already present species, can have serious detrimental impacts on an ecosystem and can alter the ecosystem. A common example of invasive species introduction into new environments would be the introduction of bamboo or kudzu that pushes out the native flora or fauna. However, a slightly lesser known issue with invasive species occurs at the microscopic level. According to Rout (2013), invasive organisms can introduce soil microbes that can alter the ecosystem. In a study conducted in 2009 over the course of 4 years, researchers introduced *S. halepense* (a type of invasive grass) to a patch of native soil to assess its effects on an ecosystem and soil nutrients. This introduction resulted in a more favorable soil chemistry for invasive species of plants. The microbiome of the plant invasive species altered the soil chemistry in order to increase the levels of nitrogen, phosphorus and other critical chemicals for the plant growth. Bacterial endophytes found in the rhizomes caused this soil chemistry alteration which enabled spread and increased the favorability of the invasive plant. This case clearly demonstrates the potential issues with introducing new microorganisms into an ecosystem; it can cause a distinctive shift in the microbial ecosystem which can have a ripple effect on the rest of the ecosystem and can alter the environment. The introduction of a plastic digesting bacteria to the ocean ecosystem could cause similar problems by serving as prey, using other nutrients and producing different conditions from their metabolism process.

There are biological concerns associated with the breakdown of polymers of plastics. Polymers structures are a repeating pattern of organic molecules called subunits that forms a complex polymer chain. Polymers can form linear or branching chains, and formed through natural processes or artificially produced, many natural polymers have biological processes that are able to break them down into smaller units. Artificial polymers, however, have few pre-established biological processes in place to take advantage of these structures, which causes plastics longevity and resistance to degradation. This lack of degradation is one of the main advantages of plastics, but this quality also has caused a critical build up of plastics in ecosystems. The ability for bacteria to break down plastics is rare and only recently observed in plastic spills; they accomplish this through the use of enzymes to cleave the linkages between polymer subunits. Different enzymes break down different bonds in polymers. Some organisms possess the ability to break down these polymers naturally, for other organisms, scientists can manipulate their genome to produce these enzymes. The ability to break down plastics for energy or structural support in bacteria could lead to a massive build-up of that specific bacterial population which can significantly alter the structure of the ecosystem. This can occur by the buildup of the subunits in the environments which could still cause problems unless their chemical structure is altered to not act as an endocrine disruptor.

Overall, though specific bacteria can effectively break down plastics, it is a method of attempting to solve a man-made problem, and fails to address the overarching problem. The issue of plastic-based pollution is a symptom of the excessive amount of waste that is produced and the improper disposal of the waste. This solution, while a potential panacea for the plastic pollution, fails to address the overarching problem, improper waste disposal. Despite the efforts of several countries and organizations, a study in 2015 estimates that 275 million tons of plastics products find their way into the ocean per year (Jambeck 2017). Despite primarily affecting the ecosystem, this issue is at its core a human problem, and improper disposal is the problem that will need to be solved in order to prevent the detrimental side effects with other cleaning methods and those associated with letting plastic waste slowly degrade in the ocean. Pollution has caused incredible damage to many ecosystems, and though it is less visible, the ocean is no exception. Plastics are a major cause of several of these problems, and pose both a chemical problem and a physical problem for aquatic life.

Conclusion

The use of plastic digesting microbes presents a unique remedy to the issue of petroleum-based plastics buildup in aquatic ecosystems. Historically, bacteria have demonstrated exceptional adaptability, able to withstand extreme conditions and are susceptible to modification through CRISPR gene editing. The techniques necessary for the modification of bacterial genomes are already in use in several biomedical applications, and the necessary genes for plastic metabolism already present in certain native bacteria. A combination of these traits leads to the potential to use a powerful biological solution to solve the pressing ecological concern of plastic buildup in ocean ecosystems. However, introducing an organism into a new environment can cause drastic and long-lasting unintended effects on the ecosystem. The method of introducing bacteria to metabolize plastics also presents ethical concerns behind introducing foreign and potentially genetically modified organisms into native ecosystems. Though the use of genetic engineering of bacteria is potentially a highly effective, self-propelled way to clean up plastic pollution, it carries many issues and fails to assess the root problem of improper disposal of consumer and industrial waste.

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