Suffocated in plastic.
The future of green alternatives

Research project

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I’d like to thank many people for all they’ve done for me and this project. My parents for all the help and support they have given me during all these months. My tutor and my English teacher for solving all my doubts and assisting me in everything I’ve needed. My best friend, Nara Gómez and my international friends for all their emotional support and love. And finally, my academy teacher, Yago Garcia, for helping me improve my English language so much that I’ve been able to get my C1 and make this project.

Without you this project wouldn't have been possible.

Thank you.

RESUM

Aquest treball revisa els efectes que la producció massiva de plàstics i la seva mala gestió a l'hora de desfer-nos d'ells té sobre el planeta i en concret la hidrosfera. També s'explica la diferència entre els bioplàstics i els biodegradables, i com aquests no sempre son beneficiosos pel nostre medi i com això fa que no poguem analitzar bé la realitat d'aquest problema. A més a més, s'estudien les solucions per a millorar la situació en la qual hem deixat el planeta i es recullen un seguit de nous plàstics més respectuosos per al medi ambient que poden servir per substituir els plàstics convencionals. A la part pràctica analitzo les possibilitats que hi ha de produir plàstics a partir de materials alternatius al petroli, que a llarg termini resultin menys perjudicials per al planeta, i he fet l'experiment a base de caseina, maizena, gelatina i agar-agar. Tot i que hi hagi un llarg camí abans de que els bioplàstics puguin substituir els actuals, els quatre que he fet m'han demostrat que hi ha moltes vies per explorar.

RESUMEN

Este trabajo revisa los efectos que la producción masiva de plásticos y su mala gestión en el momento de deshacernos de estos tiene sobre el planeta y en concreto la hidrosfera. También se explica la diferencia entre los bioplásticos y los biodegradables y como estos no son siempre beneficiosos para nuestro medio y como esto hace que no podamos analizar bien la realidad de este problema. Además, se estudian las soluciones para mejorar la situación en la cual hemos dejado el planeta y se recogen un seguido de nuevos plásticos más respetuosos para el medio ambiente que pueden servir para sustituir los plásticos convencionales. En la parte práctica analizo las posibilidades que hay de producir plásticos a partir de materiales alternativos al petróleo, que a largo plazo resulten menos perjudiciales para el planeta y he hecho el experimento a base de caseína, Maizena, gelatina y agar-agar. Aunque haya un largo camino antes de que los bioplásticos puedan sustituir los actuales, los cuatro que he hecho me han demostrado que hay muchas vías para explorar.

1. INTRODUCTION

1.1 Motivation

Since I was a child, I've always been concerned about our planet's situation. Every now and then, someone would come to school to explain how we should recycle, how we should avoid using certain materials and how our planet is threatened by these materials called plastics that take forever to decompose. The obvious question came to my mind almost instantly: why are we using a material that is so bad to our home? In a child's mind that did not make any sense. What's more, it still doesn't.

With time, I've learnt that most humans do what's more beneficial to them, and not to what surrounds them. That saddened me, of course. I was disappointed in our kind. However, I was delighted to find out that there's tons of people, from scientists through students to regular people, trying to fix all the wrongdoing we've done during our existence on Earth, and create new alternatives so as to not repeat the same mistakes. That gave me hope, even if it was just a little, so I've always been invested in learning more about this really important matter of great scientific relevance.

The deciding factor that led me to choose this topic was an article from the BBC called *Why biodegradables won't solve the plastic crisis,* which I consulted after a bizarre dream that I had where plastics were involved, that claimed that there is a common misconception about whether "green alternatives" are truly beneficial to our planet. I was shocked and mad at myself, because I had never given a second thought to it. This is why I decided to do this research project: I want to learn more about our planet's situation with plastic pollution and comprehend it.

1.2 Objectives

The main objective of this project is to observe and to study the decomposition of biodegradable plastics and their effects on our biosphere and to determine if they would be truly suitable to replace conventional plastics.

At the same time, the project is aimed to know the current situation of plastic waste on Earth and its solutions and to find out whether bioplastics and biodegradable plastics are truly beneficial for our planet or not.

1.3 Hypotheses

Before starting the project, I’ve considered two different hypotheses:

- Perhaps the public's understanding of plastics is biassed, and it prevents us from correctly assessing the problem that plastics, whether traditional or ostensibly "biodegradable," cause today -and for our future.

- Perhaps, with a simple experiment, albeit restricted in scope, I will be able to produce plastic goods with a more suited behaviour for the development of new polymers that break down in the environment on a scale acceptable to the biosphere.

1.4 Methodology

To achieve the three goals, I've been conducting extensive search across the Internet and media. This included reading papers from reputable scientific journals, learning about NGO initiatives, examining data compilations, and checking up information in encyclopaedias, inter alia.

All of this was aimed to learn more about the basics of plastic, the current state of plastic in our world, the difference between biodegradable plastics and bioplastic, and the future of green alternatives to these polymers.

What’s more, as a result of all of this study, I've come across an assortment of experiments from a variety of individuals, which I've altered to create my own, based on my own possibilities and techniques. To assess their biodegradability, I planned to build four distinct bioplastics and test their features and characteristics, as well as observe their breakdown process in three different artificially generated settings.The experiment hasn't been simple, if not challenging, to carry out, but the results have been quite satisfying.

THEORETICAL FRAMEWORK

2. FUNDAMENTALS OF PLASTIC

2.1 What are plastics?

Plastics are materials composed of enormous, natural, carbon-containing, chainlike particles that can be framed into an assortment of items. The atoms that create plastics are long carbon chains, called polymers, that give plastics a considerable lot of their valuable properties. The word *plastic* comes from the words *plasticus* (Latin for “capable of moulding”) and *plastikos* (Greek “to mould,” or “fit for moulding”). Plastics can be malleable, translucent, tough, lightweight, shatterproof, smooth, durable… it fairly bears most of the qualities other materials have. Moreover, plastics are lightweight, waterproof, chemical resistant, and created in practically any tone. These materials are moldable, synthetic materials derived mostly from fossil fuels, such as oil, coal, or natural gas, as well as cellulose, or other renewable biological resources. Since they are made up of organic molecules that can be formed into a variety of products, compared to metal and paper, plastics provide a number of advantages. They are widely used due to their low energy requirements in production, low maintenance, corrosion resistance, lightweight, and durability. Therefore, it’s massively worldwide used everywhere. More than 50 groups of plastics have been created, and new sorts are as of now a work in progress. [1,2]

2.1.1 Structure

Plastics may also be classified into two different groups based on their chemical makeup. Plastics composed of polymers with exclusively aliphatic (linear) carbon atoms in their backbone chains fall under this group. The structure of polypropylene can be used as an example; a pendant methyl group (CH3) is connected to every other carbon atom:

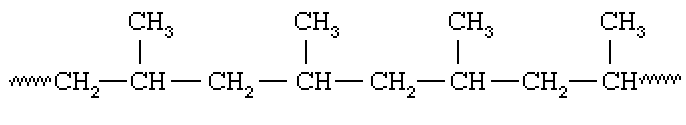

Figure 1: structure of polypropylene

[1] (“Plastics”, 2009)
[2] Filiciotto, L., & Rothenberg, G. , *Biodegradable Plastics: Standards, Policies, and Impacts*, p.56–72

Heterochain polymers, on the other hand, are a kind of plastic. In addition to carbon, some compounds have elements like oxygen, nitrogen, or sulphur in their backbone chains. Polycarbonate, for example, has two aromatic (benzene) rings in its molecules:

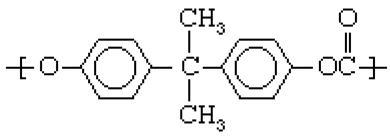

Figure 2: structure of polycarbonate

Carbon-chain and heterochain polymers are defined as either thermoplastic resins or thermosetting resins.

2.1.2 Properties

A polymer's physical state and shape have a significant impact on its mechanical characteristics. The elongation that happens when a plastic is loaded (stressed) under tension is a basic measure of the variations in mechanical behaviour. A glassy polymer like polystyrene is quite stiff, with a high initial stress-to-elongation ratio. Polyethylene and polypropylene, two highly crystalline polymers, on the other hand, may be used as films and moulded items since their amorphous portions are considerably above their glass transition temperatures at ambient temperature.

Stiffness and breaking stress are two of the most often stated mechanical characteristics of polymers. Toughness, which is the energy absorbed by a polymer before failure—often as a result of a rapid impact—is another essential characteristic. Fatigue failure can occur when a plastic is repeatedly stressed below its tensile strength. Moreover, most plastics are poor heat conductors; but, by introducing a gas (typically air) into the material, conductivity can be further lowered. Unless specifically engineered for conductivity, plastics are also electrical insulators. Dielectric strength and dielectric loss are significant electrical characteristics in addition to conductivity.[3]

[3] Rodriguez, F. , *Plastic*.

2.1.3 The history of plastic

The first synthetic plastic ever created was a phenol-formaldehyde resin called Bakelite, made by the chemist Leo Hendrik Baekeland in 1907.[4] It was made to substitute celluloid and hard rubber. Bakelite can be moulded, making it superior to celluloid in this sense while also being less expensive to produce. Furthermore, it could be shaped relatively fast, which is a huge benefit in mass production. Bakelite is a thermosetting resin, which means that once formed, it will keep its shape even when heated or exposed to certain solvents. Not only that, but also has extremely high resistance to heat and electricity. Due to Bakelite's fragility and need to be filled, colours did not come out pleasingly to one's eye. It was eventually superseded by newer polymers that had similar properties but could also accept vivid colours. It did, however, herald the start of the worldwide plastics industry. Nevertheless, it was not until the 1950s that worldwide plastic manufacturing grew at a rapid pace.[5] Plastics manufacturing rose approximately 200-fold during the following 65 years, reaching 381 million tonnes in 2015.[6]

Figure 3: Bakelite plastic

2.2 Types of plastic

When we talk about plastics, we can distinguish a huge diversity of them. Nevertheless, there are seven types[7] that are more commonly used than the others:

[4] ("Bakelite", 2009)
[5] American Chemical Society, *Bakelite First Synthetic Plastic - National Historic Chemical Landmark*.
[6] Ritchie, H., & Roser, M. , *Plastic Pollution*.
[7] A&C Plastics, *7 Different Types of Plastic*

- Polyethylene (PE)

The most prevalent plastic on the planet comes in a variety of densities. The resulting plastic has varying physical qualities depending on the density of polyethylene used. There are four types: Low-Density Polyethylene, Medium-Density Polyethylene, High-Density Polyethylene and Ultra High Molecular Weight Polyethylene.[8]

Figure 4: PE bottles

- Polyvinyl Chloride (PVC)

PVC can be made rigid or flexible, depending on the application. Its propensity to mix with different materials is well-known. PVC in its rigid form is widely used in construction materials, doors, windows, bottles... Whereas plumbing items, electrical cable insulation, clothes, medical tubing, and other related products use the softer and more flexible version of PVC.[9]

Figure 5: PVC pipes

- Polypropylene (PP)

PP is one of the world's most flexible thermoplastics. Under repeated tension, it will not crack. Polypropylene sheets are used to produce laboratory equipment, automotive parts, medical gadgets, and food containers because they are durable, flexible, heat resistant, acid resistant, and inexpensive.[10]

[8] (“Polyethylene”, 2019)
[9] Bierwagen, G.P. , Gent, A. N. , Preston, J. , Rodriguez, F. , Kauffman, G.B. and Stevens, M. P. , *Major industrial polymers-Polyvinyl Chloride (PVC)*
[10] (“Polypropylene”, 2017)

Figure 6: PP lids

- Polymethyl Methacrylate (PMMA)

Acrylic is a clear thermoplastic that is used as a lightweight, shatter-resistant substitute for glass. Abrasion-resistant, bullet-resistant, UV-tolerant, non-glare, anti-static, and other properties can be added to clear plastic.[11]

Figure 7: PMMA tubes

- Polycarbonate (PC)

Polycarbonate is a tough, stable, and transparent technical plastic that is as clear as glass. Polycarbonate plastic is incredibly durable and impact-resistant, yet it also has a lot of design versatility. Polycarbonate plastic can be found in a wide range of products, including greenhouses, DVDs, sunglasses, and police riot gear.[12]

Figure 8: PC sheet

- Polyethylene Terephthalate (PETE or PET)

Polyethylene Terephthalate is easily recyclable and has strong chemical resistance to organic compounds and water. It's almost shatterproof and has a remarkable strength-to-weight ratio. This plastic is found in textile fibres, food and drink containers, glass fibre for engineering resins, carbon

[11] (“Polymethyl Methacrylate”, 2018)
[12] (“Polycarbonate”, 2017)

nanotubes, and a variety of other things that we use every day. [13]

Figure 9: PET bottles

- Acrylonitrile-Butadiene-Styrene (ABS)

ABS is a strong, flexible, glossy, highly processable, and impact-resistant material. It is commonly found in the automotive and refrigeration industries, as well as in boxes, gauges, protective equipment, luggage, and toys.[14]

Figure 10: ABS lego bricks

2.3 Environmental effects of plastic

Even though plastics are one of the most valuable (in terms of usefulness) materials available today, one simply cannot overlook the massive problem that we have created as a result of the large amount of pollution that this material generates. Toxic chemicals released by plastic pollution damage humans, animals, and plants. It has an impact on all creatures in the food chain, from microscopic plankton to whales. Unfortunately, this is just the tip of the iceberg. Not only does plastic pollute the environment, but also does all of this damage on a lifelong basis.

As explained previously, plastic is a polymeric substance, which means it has very big molecules that resemble lengthy chains made up of an apparently endless sequence of linked connections. Natural polymers like rubber and silk are abundant, but because they do not remain in the environment, nature's "plastics" have not been linked to pollution. Today, however, the ordinary consumer is exposed to a variety of plastic materials that were created expressly to combat natural decay processes—materials derived mostly from petroleum that may be moulded, cast, spun, or coated as a coating.

[13] (“Polyethylene Terephthalate”, 2020)
[14] (“Acrylonitrile-butadiene-styrene copolymer”, 2019)

Synthetic plastics tend to survive in natural environments because they are mainly nonbiodegradable. Plastic takes hundreds, if not thousands, of years to degrade, thus the environmental impact is long-lasting. Furthermore, many lightweight single-use plastic goods and packaging materials, which make up about half of all plastics manufactured, are not deposited in containers. Instead, they are inappropriately disposed of at or around the point where their utility to the customer has expired. They damage the environment as soon as they are heaped into an already full trash bin, tossed out of a car window, dropped on the ground or unintentionally blown away by a gust of wind. In many areas of the globe, landscapes strewn with plastic packaging have become the norm. Despite the fact that population centres create the most trash, studies from throughout the world have found no single country or demographic group to be the most guilty. Plastic pollution's sources and consequences are precisely worldwide.[15]

Figure 11: landfill full of wasted plastic

3. PLANET EARTH AND PLASTIC WASTE

3.1 The journey of plastic

As it has been mentioned before, the 1950s were the decade where the production of plastics grew exponentially. From 1950 to 2015, 8300 million tonnes of polymers, synthetic fibres, and additives were produced in total. Out of the 8300 million tonnes produced since 1950, in 2015, 2500 million tonnes of basic plastics were still in use,

[15] Moore, C. , *Plastic pollution*

whereas 4600 million tonnes were disposed of in landfills or discarded, 700 million tonnes were burned, and 500 million tonnes were recycled. Out of the 500 million tonnes that have been recycled, 100 million tonnes of recycled plastic remained in use, 100 million tonnes were incinerated, and 300 million tonnes were eventually thrown or dumped, meaning that since 1950, just 9% of the 5800 million tonnes of primary plastic that is no longer in use has been recycled.[16]

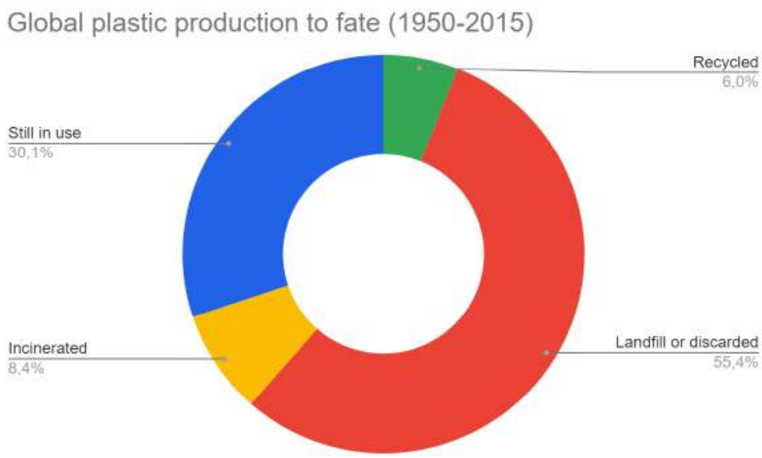

Figure 12. Global plastic production to fate (1950-2015)

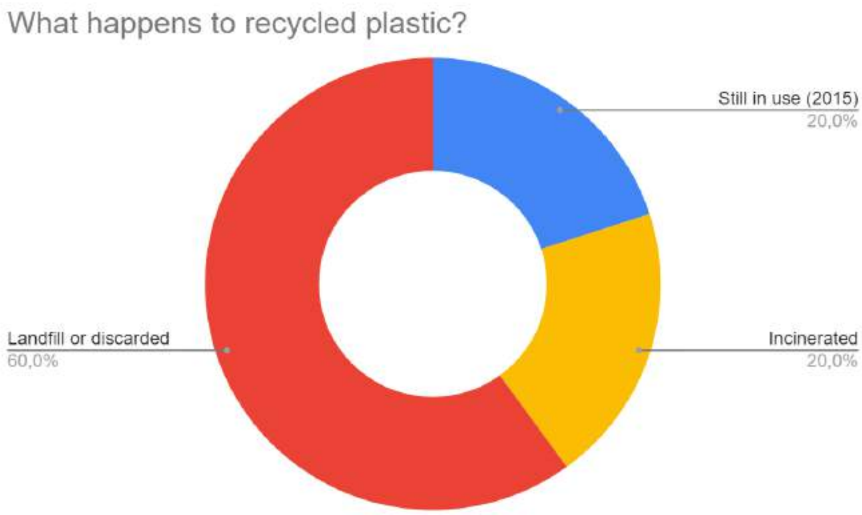

Figure 13. What happens to recycled plastic?

[16] Ritchie, H., & Roser, M

3.1.1 Plastic production

In 1950, the world's annual production was barely 2 million tonnes. Annual output has expanded nearly 200-fold since then, hitting 381 million tonnes in 2015. Cumulatively speaking, by 2015, the globe has generated 7.8 billion tonnes of plastic, or more than one tonne for every person on the planet.

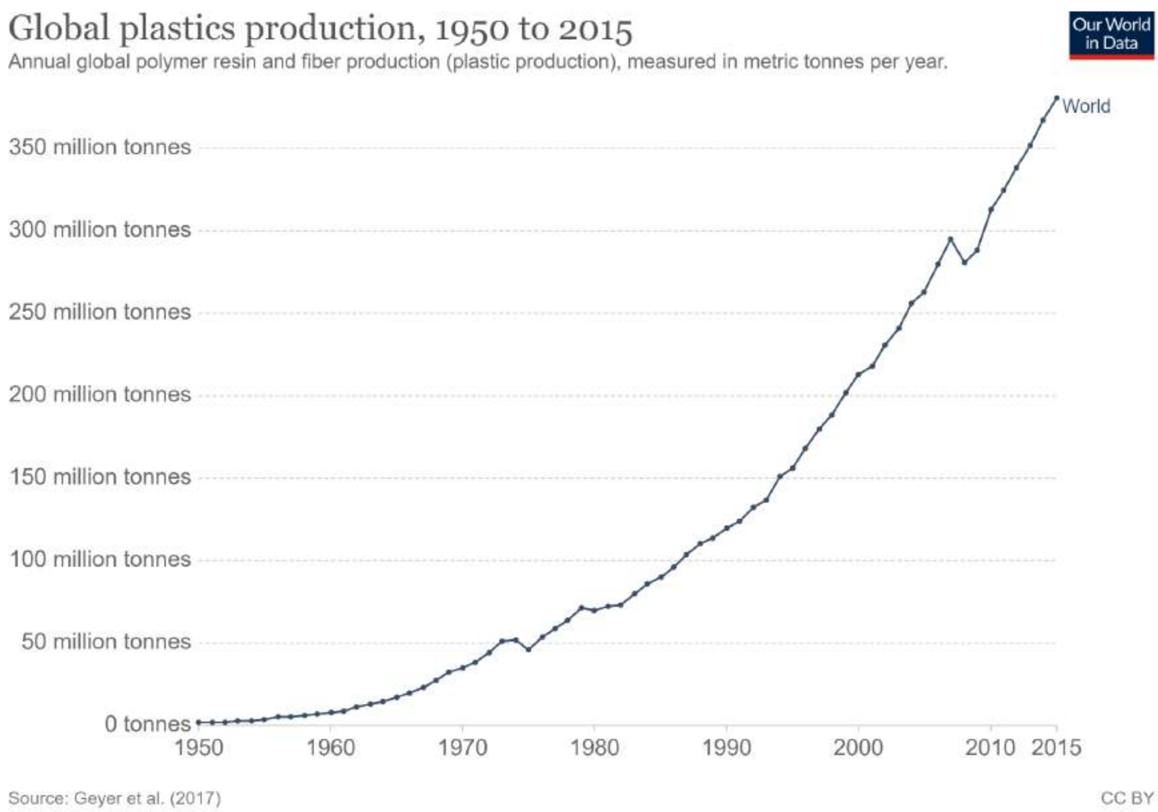

Figure 14. Global plastics production, 1950 to 2015

If we take a closer look at which sectors produce this massive amount of plastic nowadays, packaging was the most common application of primary plastics, accounting for 42 percent of all plastics used. Building and construction was the second-largest industry, accounting for 19% of total output. Plastic waste creation is impacted by the polymer type and lifetime of the end product, therefore primary plastic manufacturing does not immediately represent plastic trash generation (as illustrated in the second graph).

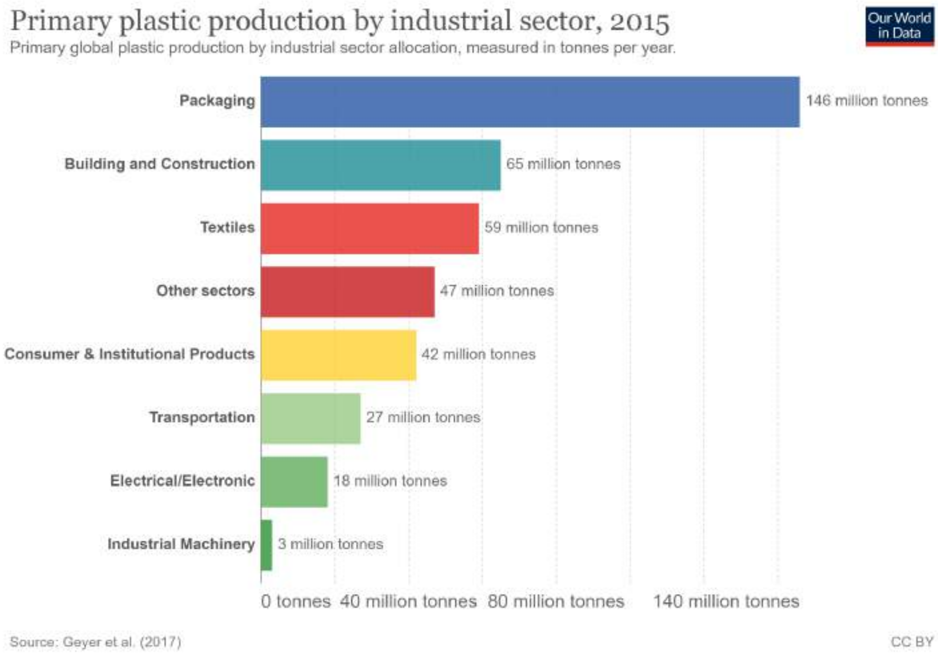

Figure 15. Primary plastic production by industrial sector, 2015

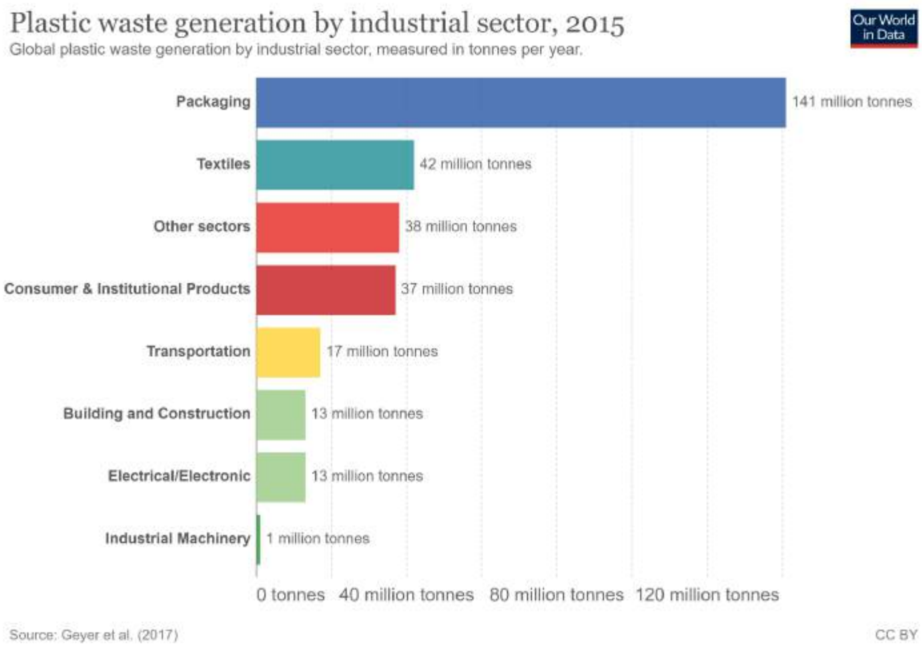

Figure 16. Plastic waste generation by industrial sector, 2015

For example, packaging has a relatively limited 'in-use' lifespan (typically around 6 months or less). This is in contrast to the usage of plastic in architecture and construction, which has a 35-year average lifespan. As a result, packaging is the leading source of plastic trash, accounting for over half of the global total.[17]

3.1.2 Mismanaged and wasted plastic

As it has been disclosed before, in 2015, 407 million tonnes of primary plastics were produced. However, about three-quarters (302 million tonnes) ended up as trash.

The study “Plastic waste inputs from land into the ocean” by Jambeck et al. (2015) based on 2010 data, gives us a variety of information that may be useful to understand the problem with mismanagement.

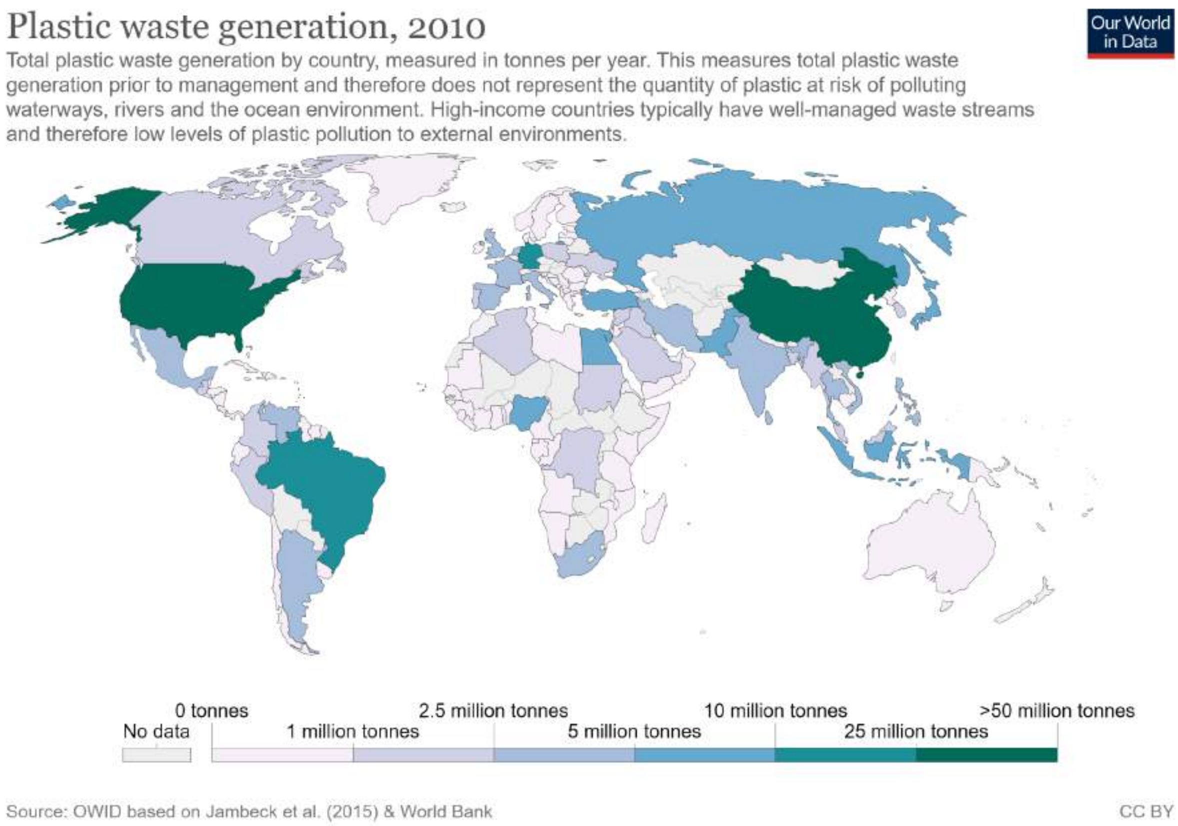

Figure 17. Plastic waste generation, 2010

China, with the world's largest population, generated the most plastic, over 60 million tonnes. The United States came in second with 38 million people. Spain ranked 13th in the world, with 4,71 million tonnes, similar to other neighbouring countries. This research looked at total plastic waste and didn't take into consideration trash

[17] Ibidem

management, recycling, or incinerator practises. As a result, they don't represent the amount of plastic that might end up in the ocean or other rivers.

Estimates of the percentage of plastic trash that is regarded as insufficiently managed and hence at danger of entering the seas and other ecosystems are shown on the globe map below. We observe huge disparities in waste management efficacy throughout the world:

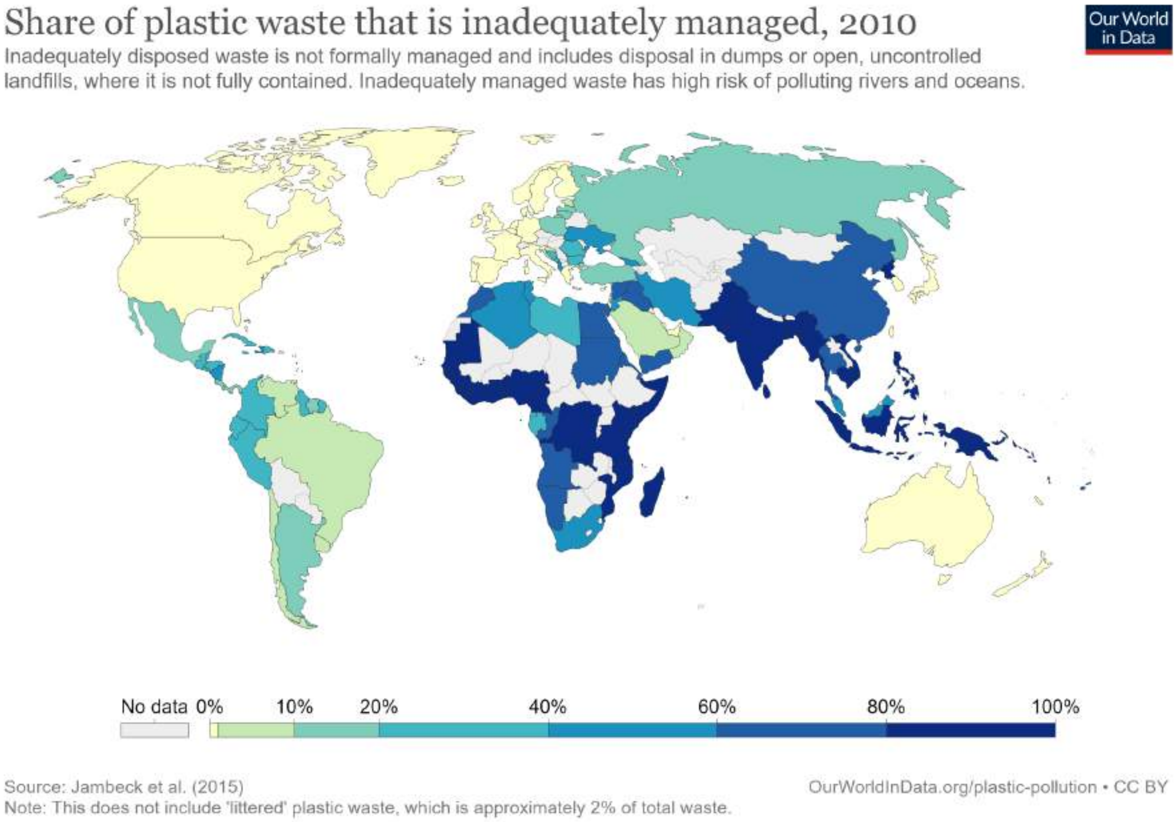

Figure 18. Share of plastic waste that is inadequately managed, 2010

On the one hand, most of Europe, North America, Australia, New Zealand, Japan, and South Korea have very effective waste management infrastructure and procedures. Almost little plastic trash is deemed badly managed in these nations. On the other hand, in many low-to-middle-income nations, improperly discarded garbage is common; in several countries in South Asia and Sub-Saharan Africa, 80-90 percent of plastic waste is improperly disposed of, putting rivers and seas at danger of pollution.

Understanding the global picture is critical if we are to address the ocean plastic problem. It emphasises the critical importance of waste management in mitigating ocean contamination; while North America and Europe create large amounts of plastic trash, well-managed waste streams ensure that relatively little of it ends up in the ocean. Indeed, if North America and Europe totally stopped using plastic, worldwide unmanaged plastic would drop by less than 5%, the study concluded.[18]

3.2 Plastic in our hydrosphere

Plastic pollution, of course, affects not just the oceans, but also the seas, lakes, and rivers of the entire planet; moreover, the plastic particles ingested by the many living forms in these settings enter the food chain, eventually reaching us humans.

Only plastic waste that is mismanaged poses a significant risk of leakage to the environment; in 2010, this totaled 31.9 million tonnes, with 8 million tonnes – or 3% of global annual plastic waste – generated within 50 kilometres of the coastline. Plastics in the ocean's surface waters are hundreds of times less than yearly ocean plastic imports.The amount of plastic in surface waters is unknown; estimates range from tens of thousands to tens of millions of tonnes.[19]

Because most of the plastics we make are less thick than water, they should float on the ocean's surface. However, the quantity of plastic afloat at sea, according to our best estimates, is orders of magnitude less than the amount of plastic that enters our seas in a single year. So, why are there at least 100 times fewer plastics in our surface waters? The *missing plastic problem* is a term used to describe this disparity.[20]

There are numerous theories that may be used to explain this. It's possible that it's due to erroneous measurement. Another prevalent theory is that big pieces of plastic are broken into smaller pieces by ultraviolet light (UV) and mechanical wave forces. Deep-sea sediments were one suggested ‘sink' for ocean plastics, however they

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[18] Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. , *Plastic waste inputs from land into the ocean*, p. 768–771
[19] Ibidem
[20] 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. , *Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic*

were abandoned owing to microplastic being up to four orders of magnitude more prevalent. However, new study suggests that plastics in the water degrade at a slower rate than previously assumed, and that most of the missing plastic gets washed ashore or buried along our shorelines.[21]

Figure 19: Plastic debris on a beach shore

3.2.1 Plastic in rivers

There are several ways for plastic to infiltrate the ocean ecosystem. River systems are one important source of input. This has the potential to carry plastic garbage from further interior to coastal locations, where it might end up in the ocean.

Two-thirds of worldwide yearly river intake (67 percent) was accounted for by the top 20 polluted rivers. Geographically, we can observe that Asia has the bulk of the most polluted rivers. In 2015, the Yangtze River, the world's most polluted river, injected roughly 333,000 tonnes of plastic into the ocean, accounting for almost 4% of annual ocean plastic pollution.[22]

[21] Lebreton, L., Egger, M., & Slat, B. , *A global mass budget for positively buoyant macroplastic debris in the ocean*.

[22] Lebreton, L. C. M., van der Zwet, J., Damsteeg, J. W., Slat, B., Andrady, A., & Reisser, J. , *River plastic emissions to the world’s oceans.*

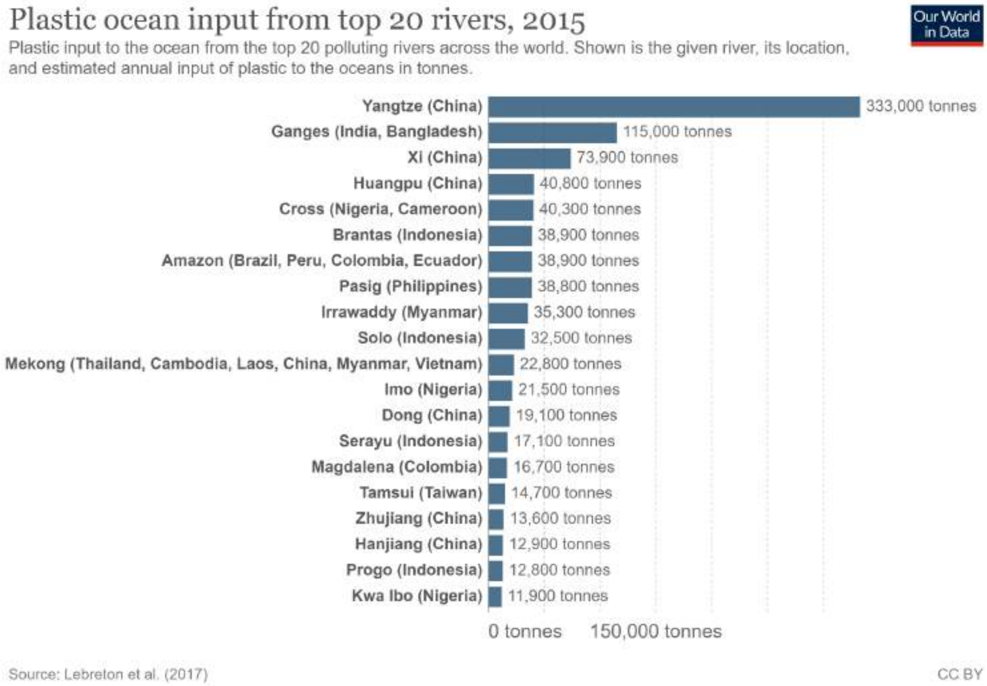

Figure 20. Plastic ocean input from top 20 rivers, 2015

3.2.2 Plastic in oceans

As mentioned above, plastic is washed into the oceans by rivers, tides, and other marine sources. Oceanic surface currents and wind patterns have a significant impact on the dispersion and accumulation of ocean plastics. Plastics are buoyant, which means they float on the surface of the water, allowing them to be carried by wind and surface currents. Consequently, plastics tend to collect in marine gyres[23], with large concentrations of plastics in the centre of the basins and considerably lower amounts at the edges.

[23] Gyre: Caused by the Coriolis Effect, is a system of circular currents in an ocean.

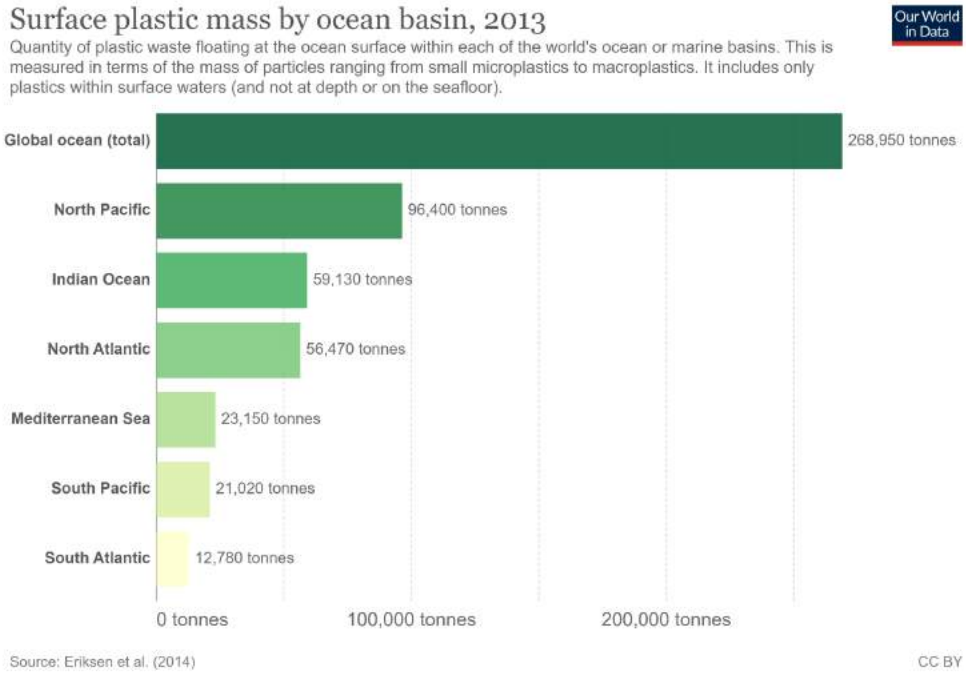

Figure 21. Surface plastic mass by ocean basin, 2013

Between 2013 and 2014, the amount of plastic in surface waterways throughout the world was projected to be over 269,000 tonnes. Plastics were found in the greatest quantities in basins in the Northern Hemisphere. This is to be expected, given that the Northern Hemisphere is home to the bulk of the world's population, particularly coastal people. Nonetheless, given the amount of plastic that has accumulated in the Southern oceans, the results were unforeseen. This was an unexpected conclusion given the absence of coastal people and plastic inputs in the Southern Hemisphere. This is thought to indicate that plastic pollution may travel considerably more easily between marine gyres and basins than previously thought.

At the same time, more than 5 trillion plastic particles are believed to be in the world's surface waterways.

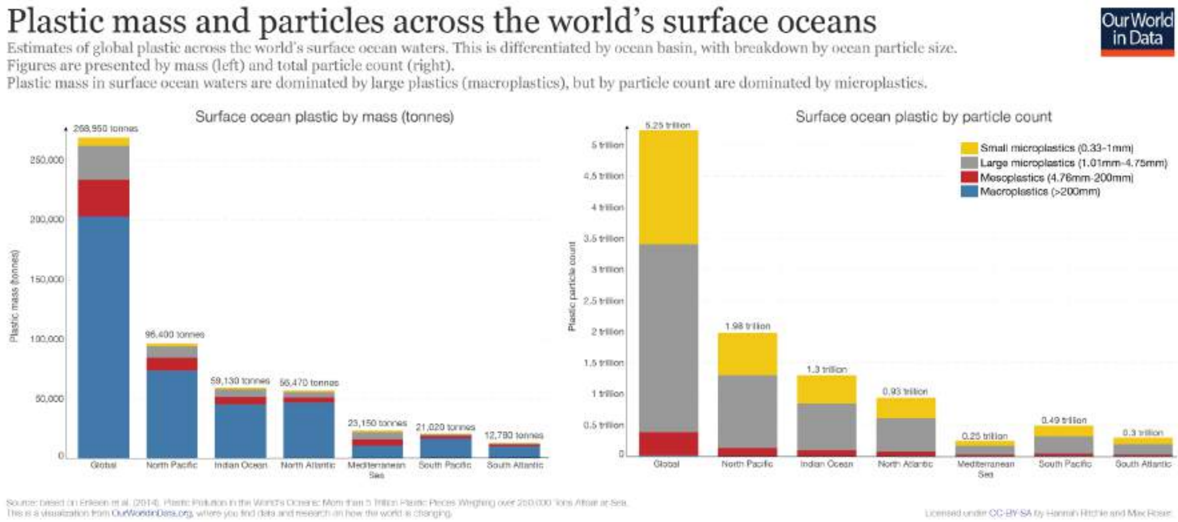

Figure 22. Plastic mass and particles across the world's surface oceans

As demonstrated, macroplastics (big particles) make up the majority of plastics by mass, whereas microplastics make up the majority by particle count (small particles).[24] This illustrates that the need of making plastics that actually decompose and disappear is really huge, since all of these tiny particles that are floating around our ocean are a result of plastic that broke down in a thousand little pieces instead of actually decomposing.[25]

3.2.3 Great Pacific Garbage Patch

In the North Pacific Ocean, the Great Pacific Garbage Patch, also known as the Pacific trash vortex, is an accumulation of marine debris.[26] The patch was first reported in a study by the National Oceanic and Atmospheric Administration in 1988. (NOAA). The description was based on studies conducted in 1988 by a group of Alaskan researchers who tested

[24] Eriksen, M., Lebreton, L. C. M., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., Galgani, F., Ryan, P. G., & Reisser, J. , *Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea.*
[25] More information about difference between decomposing and breaking down in BIODEGRADABLE PLASTICS AND BIOPLASTICS
[26] Marine debris: litter that winds up in oceans, seas, and other big bodies of water.

neustonic[27] plastic in the North Pacific Ocean.

Figure 23: Great Pacific Garbage Patch

Researchers discovered rather large quantities of marine debris collecting in ocean current-controlled areas. The researchers anticipated that comparable conditions would exist in other regions of the Pacific where prevailing currents were favourable to the formation of reasonably stable waters based on their results in the Sea of Japan. The North Pacific Gyre was particularly mentioned. In 1997, Charles J. Moore claimed to have discovered a massive swath of floating trash. Moore notified oceanographer Curtis Ebbesmeyer, who coined the term "Eastern Garbage Patch" to describe the area (EGP).

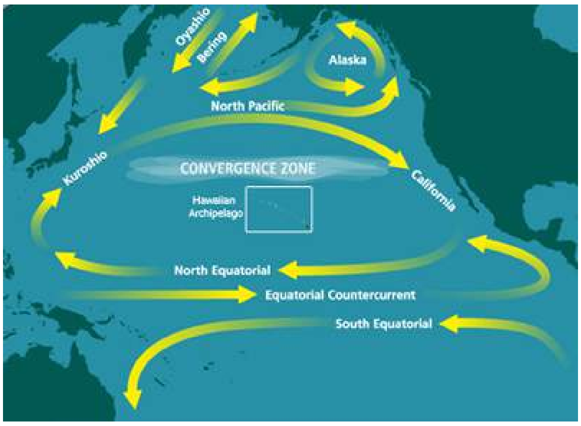

Figure 24: How is the patch created

Ocean or marine pollution collected by ocean currents progressively produced the Great Pacific trash patch. The gyre is split by the enormous North Pacific Subtropical Gyre into two regions: the "Eastern Garbage Patch" between Hawaii and California, and the "Western Garbage Patch" stretching eastward from Japan to the Hawaiian Islands.

The zone functions like a highway, transporting trash from one patch to the next and traps it. Because conventional plastic and contemporary bioplastics do not biodegrade in the marine environment, the majority of the plastic waste in the Garbage Patch comes from land-based sources and survives the lengthy journey there. All existing plastics can only photodegrade in the ocean, which means they can only break down into smaller pieces as they are exposed to UV light. Plastics can be discovered not only on the ocean's surface but the seafloor beneath the Great Pacific Garbage Patch. Oceanographers and ecologists have revealed that around 70% of marine trash falls to the ocean's bottom.

[27] Neustonic: A collection of tiny and small creatures that live on or just beneath the surface of a body of water.

Nowadays, it lies between 135°W and 155°W, and 35°N and 42°N, respectively. The patch, according to researchers from The Ocean Cleanup project, encompasses 1.6 million square kilometres. According to research, the patch is quickly growing.

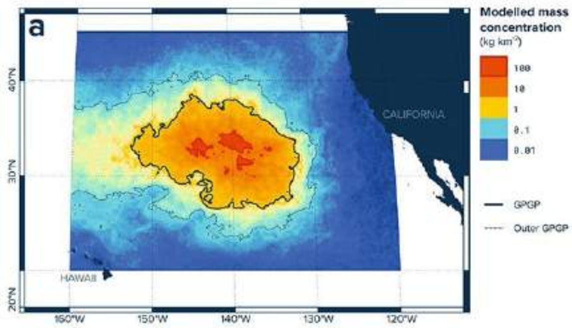

Figure 25: Location of the GPGP

Since 1945, the patch is said to have grown "ten-fold per decade." Nobody knows with accuracy how big the Great Pacific Garbage Patch is or how much garbage it contains. Scientists can't comb the North Pacific Subtropical Gyre because it's too big. Furthermore, as it has been mentioned above, not all garbage floats on the surface. Denser material can sink centimetres or even metres beneath the surface, making determining the size of the vortex virtually difficult. [28] And this garbage patch is not the only one on our planet. That's how grave the problem is.

3.3 Impact on wildlife and human health

There have been several recorded cases of plastic's influence on ecosystems and wildlife. Plastic effects have been published in journals since the 1980s.

There are three main ways that plastic waste may harm animals: Entanglement (Plastic trash entangling, surrounding, or strangling marine creatures), ingestion and interaction (Collisions, obstacles, abrasions, and usage as a substrate are all examples). Plastics can interact with or impact animals in a variety of ways. In the case of microplastics, the main worry is ingestion, as shown on the table in the annex section, which summarises evidence on the impact of marine plastic on animal life[29] Despite several recorded examples, it is commonly accepted that the entire degree of ecological effects is unknown.

[28] National Geographic Society, *Great Pacific Garbage Patch*.
[29] Our World in Data, *Ecological impacts of marine plastic debris.*

Surprisingly enough, many species do not modify their eating habits after ingesting microplastics. Microplastics have little effect on a variety of species, including suspension feeders[30] and detritivores[31]. Overall, however, the presence of microplastic particles in the stomach is likely to have detrimental biological consequences for certain species.

Regarding human health, the tiniest particles (micro and nanoparticles) that are tiny enough to be swallowed – are the most dangerous to human health. However, there is now very little proof of microplastics' potential impact on humans. Orally through water, ingestion of marine items containing microplastics, through the skin via cosmetics (listed as very improbable but conceivable), or inhalation of particles in the air are all ways that plastic particles might be consumed.[32]

Microplastics have the potential to go up the food chain to greater levels. This can happen when a species eats lower-level food-chain creatures with microplastics in their guts or tissues. It has been proven that microplastics may be found at higher levels of the food chain (in fish). Microplastics in fish tend to be found in the stomach and digestive tract, portions of the fish that are not normally eaten, which might restrict human dietary absorption. Microplastics and nanoplastics have also been discovered in bivalves grown for human consumption. Human exposure and possible danger, on the other hand, have yet to be discovered or measured.[33,34] Plastic fibres have been found in a variety of foods, such as honey and table salt. Then again, some of the authors claimed that this exposure posed no significant health concerns.[35,36]

Microplastics can sorb environmental pollutants because they are hydrophobic and have a large surface area-to-volume ratio. If there is a substantial buildup of environmental pollutants, these concentrations may be able to 'biomagnify' their way

[30] Suspension feeders: an aquatic animal which feeds on particles of organic matter suspended in the water, especially a bottom-dwelling filter feeder.
[31] Detritivores: an animal which feeds on dead organic material, especially plant debris.
[32] Revel, M., Châtel, A., & Mouneyrac, C. , *Micro(nano)plastics: A threat to human health?*, p.17–23
[33] Galloway, T. S. , *Micro- and Nano-plastics and Human Health*, p.343–366
[34] Güven, O., Gökdağ, K., Jovanović, B., & Kıdeyş, A. E. , *Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish*, p.286–294
[35] Liebezeit, G., & Liebezeit, E. , *Non-pollen particulates in honey and sugar*, p.2136–2140
[36] Navarro Bernuz, A. , *Microplàstics. L'amenaça invisible*

up the food chain to greater levels. There has been no clear evidence of persistent organic contaminants or leached plastic additives accumulating in people to date. Continued study in this field is necessary to have a better understanding of the role of plastic in larger ecosystems as well as the threat it poses to human health.[37]

3.4 Solutions for plastic waste problem

Attempting to repair all of the harm we have caused is a genuine task, but it is also important. Many efforts are currently underway to remove as much plastic as possible from our seas and to develop ways to degrade it.

Take the Ocean Cleanup, for instance. A non-profit organisation that was formed in 2013 to develop innovative technology for removing plastic from the oceans. They want to clean up 90 percent of the plastic pollution in the world's oceans. To do so, they have created the Interceptor and the Artificial CoastLine.[38]

The Interceptor is an autonomous solar-powered machine that is set up on rivers so as to reduce the input that will end on oceans. The barrier directs river waste flowing with the stream towards the Interceptor's entrance. The water flow route is designed to travel through the system, transporting the plastic onto the conveyor belt, thanks to the Interceptor's catamaran architecture. The trash is moved onto a conveyor belt by the current, which constantly collects the debris from the water and transports it to the shuttle. The trash is mechanically distributed between six bins by a shuttle. The containers are filled evenly using sensor data until they reach full capacity. The garbage may be stored in the Interceptor for up to 50m3 before it has to be emptied. This implies it can function in even the most contaminated rivers throughout the world. When the interceptor is nearly full, it sends a text message to the local operators, instructing them to come collect the garbage. The barge is then removed from the InterceptorTM, moved to the side of the river, the dumpsters are emptied, the trash is sent to local waste management facilities, and the barge is returned to the InterceptorTM.[39]

[37] Wang, J., Tan, Z., Peng, J., Qiu, Q., & Li, M., *The behaviours of microplastics in the marine environment*, p. 7–17
[38] The Ocean Cleanup, *About*.
[39] The Ocean Cleanup, *Rivers*.

Figure 26: The Interceptor from The Ocean Cleanup

The Artificial CoastLine is made out of a long U-shaped barrier that uses active propulsion to steer plastic into a retention zone at the far end. The waste patch's circulation currents shift the plastic around, resulting in natural hotspots of increased concentration. By generating a relative speed difference with the cleanup system, it will be positioned and guided to collect incoming plastics. The device is guided to the waste patch's greatest concentration locations, collecting and holding plastic in the retention zone. The boats adjust and maintain the wingspan and direction of the birds. The rear of the retention zone is carried aboard, sealed up, disconnected from the system, and dumped on board the vessel once the system is full. The retention zone is then reinstalled, and the cleanup process begins. They carry their containers back to shore for recycling and making recycled items once they are full of plastic aboard.[40]

Figure 27: The Artificial CoastLine from the Ocean Cleanup

On the scientific research side, there's a lot of studies related to using bacteria to degrade this highly resistant material. Nobel winner of Chemistry 2018 Frances H.Harold affirmed in an interview that bacteria are beginning to discover how to

[40] The Ocean Cleanup, *Oceans*.

degrade plastics and that we can help them accelerate this evolution through bioengineering.[41]

What’s more, a group of German researchers identified the first of its type bacterium strain capable of degrading the toxic chemicals found in polyurethane goods, a step toward decreasing plastic pollution in the environment. The research was published in the journal Frontiers in Microbiology last week. With the soil of a location coated in plastic trash, they discovered the bacteria *Pseudomonas putida*. It ate polyurethane diol, which is commonly used to protect objects against corrosion. These molecules can be used as a single source of carbon, nitrogen, and energy by the bacteria.[42]

Additionally, it has been discovered that Posidonia meadows, which are at risk of extinction due to irresponsible maritime tourism and water pollution, are capable of capturing plastic inside the so-called Neptune balls that the plant creates when the leaves fall off. If we were to plant and protect the meadows of this herb, they would not only clean up microplastics located at the sea's bottom, but they would also create enormous amounts of oxygen and offer food, shelter, and a space for reproduction for diverse species.[43]

These, and a slew of others, might be the key to repairing all of the harm.

4. GREEN ALTERNATIVES AND THE FUTURE

4.1 Biodegradable plastic and bioplastic

When it comes to alternative plastics, two terms are frequently misunderstood or used interchangeably when they shouldn't: bioplastics and biodegradable plastics. The terms "bioplastic" and "biodegradable plastic" are similar but not interchangeable. Not all bioplastics are biodegradable, contrary to what most people are led to believe.[44,45]

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[41] This interview can be found inside the annex section.
[42] Andrew, S. C., *Researchers identified bacteria that can degrade plastic*.
[43] Duran, X., *La posidònia, en perill d’extinció, pot capturar i extreure plàstics abocats a l’oceà.*
[44] Vert, M., Doi, Y., Hellwich, K. H., Hess, M., Hodge, P., Kubisa, P., Rinaudo, M., & Schué, F., *Terminology for biorelated polymers and applications (IUPAC Recommendations 2012)*, p.377–410
[45] Krieger, A. E., *Are bioplastics better for the environment than conventional plastics?*

Biodegradable plastics are those that can be decomposed into water, carbon dioxide, and biomass by living creatures, mainly microorganisms. Renewable raw materials, microorganisms, petrochemicals, or a combination of all three are widely used to make biodegradable polymers.[46]

On the other hand, bioplastics are the ones made from renewable biomass sources including vegetable fats and oils, maize starch, straw, woodchips, sawdust, and recovered food waste, among others. Some bioplastics are made by processing natural biopolymers such as polysaccharides (e.g. starch, cellulose, chitosan, and alginate) and proteins (e.g. soy protein, gluten, and gelatin), while others are made chemically from sugar derivatives (e.g. lactic acid) and lipids (oils and fats) from plants and animals, or biologically by fermentation of sugars or lipids.[47]

4.2 The issue with biodegradability

Not only the misconception between biodegradable and bioplastic is a problem, but it is also worth mentioning that contrary to popular belief, biodegradable isn't necessarily something good for the environment, as the name may suggest. To make it easier to understand, see the following experiment led by Imogen Napper at the University of Plymouth.

Napper gathered carrier bags with varied claims regarding biodegradability and placed them in three distinct natural habitats over the course of three years: buried in soil, abandoned in the sea, and hanging up in the open air. She put biodegradable, compostable, and oxo-biodegradable bags to the test, as well as standard high-density polyethylene (HDPE) bags. (Because of concerns that oxo-biodegradable polymers may break down into microplastics, the European Commission has proposed that they are banned.)

When kept in seawater for three months, the bag labelled "compostable" vanished completely, according to Napper's experiment. It lasted two years in the soil before disintegrating when the researchers loaded it with groceries. After three years, the

[46] Harris, W., *How Long Does It Take for Plastics to Biodegrade?*
[47] Vert, M., Doi, Y., Hellwich, K. H., Hess, M., Hodge, P., Kubisa, P., Rinaudo, M., & Schué, F., p.377–410

rest of the bags (including the one labelled "biodegradable") were still present in soil and sea water, and could still contain groceries. All of the bags had dissolved or were beginning to disintegrate after nine months in the open air, primarily breaking down into microplastics. This is because sunshine aids in the decomposition of plastics through a process known as photo-oxidation, in which the plastic becomes worn and brittle, fragmenting rather than breaking down to its organic components.[48]

“That doesn't actually mean it's breaking down into its most natural counterparts of carbon and hydrogen, it just means they're becoming smaller pieces,” explained Napper. “Which you could argue is more problematic because you can't clean up. People need to be aware that putting it in the recycling or trying to compost it, or putting it in the general waste bin won't necessarily get them the results that they're being advertised for” says Napper.[49]

Figure 28: Dr Napper testing the plastic bags used in the experiment

This and many other studies have revealed that indeed, biodegradable plastic breaks down, but only on the right conditions set by the manufacturer. This is why, if left in the wrong place, such as the ocean, biodegradable plastics won’t degrade but will break down into the tiny pieces we most fear, microplastics, by the process mentioned above, photo-oxidation. Therefore, this is something that must be known by everybody and rectified in future generations of biodegradable plastics.

[48] Napper, I. E., & Thompson, R. C., *Environmental Deterioration of Biodegradable, Oxo-biodegradable, Compostable, and Conventional Plastic Carrier Bags in the Sea, Soil, and Open-Air Over a 3-Year Period*, p. 4775–4783

[49] Oakes, K., *Why biodegradables won’t solve the plastic crisis*.

4.3 New projects for plastics

It's no secret that since the science field became aware of the massive problem of plastic we found ourselves in, tons of research have been invested in finding new ways to create this all-useful material so that it is not a hazard to our planet. The following are just a glimpse of what awaits us in the near future.

4.3.1 Animal shell plastic

The Wyss Institute for Biologically Inspired Engineering at Harvard University has developed a novel bioplastic made from shrimp shells. Likewise Aagje Hoekstra created the Coleoptera bioplastic from the armour of dead Darkling Beetles employed in insect farms in the Netherlands for the animal food business and discarded after their deaths. And similarly, Jeongwon Ji, a Royal College of Art graduate, has created Crustic, a bioplastic manufactured from Chinese mitten crab shells, which are an invasive species in the UK.

The three plastics are constructed of chitosan, a kind of chitin that's the world's second-most prevalent organic substance. Chitin, a strong polysaccharide, is the primary component of crustacean shells, insect armour like cuticles, and even butterfly wings. Shrilk decomposes in just a few weeks after being thrown, releasing rich nutrients that aid plant development.[50,51,52]

Figure 29: Crustic plastic

[50] Harvard Gazette, *Promising solution to plastic pollution*.
[51] Howarth, D., *Coleoptera plastic made of beetles by Aagje Hoekstra*.
[52] Etherington, R., *BioElectric by Jeongwon Ji.*

4.3.2 Algae plastic

Ari Jónsson, an Iceland Academy of the Arts student, mixed red algae powder with water to produce a biodegradable container that would begin to degrade as soon as it is empty. In the same way, using raw material derived from algae, Margarita Talep, a Chilean designer, has produced a sustainable, biodegradable alternative to single-use packaging.

Agar is used to make these two polymers. When agar powder is mixed with water, it produces a jelly-like substance that can keep its shape for as long as it is hydrated or it can be dried to create different types of products. By combining it with a plasticiser and adjusting the quantities of the ingredients, a variety of goods may be created, all of which will disintegrate in two to three months with no problems.[53,54]

Figure 30: Ari Jónsson algae bottle

4.3.3 Plant-based plastic

Reolivar, by Naifactory lab, is a plastic produced from olive pits, resistant to ordinary circumstances but decomposes in a matter of weeks when placed in a compost bin or even in nature. [55]

Additionally, plant-based plastics have been used in the products of well-known firms such as Reebok and Lego. The former has created a pair of sneakers with a bioplastic sole dubbed "Cotton + Corn," which features a sole produced from corn, an insole made from castor bean oil, and a 100% cotton top. The latter has created a

[53] Morby, A., *Ari Jónsson uses algae to create biodegradable water bottles.*
[54] Hitti, N., *Margarita Talep develops algae-based alternative to single-use plastic packaging*.
[55] Sader, M., *El plástico de huesos de aceituna hecho en España que revolucionará el mundo.*

new range of toys manufactured from sugar cane, with the eventual objective of utilising the bioplastic to make all of its bricks by 2030.[56,57]

Figure 31: Reolivar plastic

4.3.4 Using bacteria to make plastic

One of the resources expected to be utilised in the future to manufacture eco-friendly plastics is bacteria, which has already been attempted by a handful.

Emma Sicher, an Italian designer, devised the From Peel to Peel project, which mixed food waste with bacteria and yeasts to make disposable packaging as a sustainable alternative to plastic.[58]

Moreover, an article published in the prestigious journal Nature compiles the results of a study that used Escherichia coli to create a biodegradable bioplastic. The bacterium was genetically modified to generate protein-based hydrogels, which are then cast and dried at room temperature to produce aqua plastic, which can tolerate strong acids and bases as well as organic solvents.[59] Venvirotech Biotechnology has also done a similar experiment with pleasant results.[60]

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[56] Aouf, R. S., *Reebok launches plant-based Cotton + Corn sneaker*.
[57] Morris, A., *Lego to launch sustainable bricks made from sugar cane.*
[58] Hitti, N., *Emma Sicher makes eco-friendly food packaging from fermented bacteria and yeast.*
[59] Duraj-Thatte, A. M., Manjula-Basavanna, A., Courchesne, N. M. D., Cannici, G. I., Sánchez-Ferrer, A., Frank, B. P., Van't Hag, L., Cotts, S. K., Fairbrother, D. H., Mezzenga, R., & Joshi, N. S., Water-processable*, biodegradable and coatable aquaplastic from engineered biofilms*, p.732–738
[60] Gencat: Departament de Recerca i Universitats, *Venvirotech Biotechnology crea un nou plàstic biodegradable a partir de residus orgànics.*

Figure 32: Peel to Peel plastic

4.3.5 New combinations

As can be seen in the field of research on the most sustainable alternatives to current plastics, there are many open lines of research. This includes the possibility of producing materials based on plastics of habitual use but that are able to degrade in the conditions and periods of time that are acceptable for the protection of the environment.

For instance, the novel biodegradable material that has been developed by scientists at the BEACON bioeconomy research centre and the AMBER materials science research centre. They discovered that by mixing polycaprolactone (PCL) with polylactic acid (PLA), which typically requires high temperatures to break down, the material totally degrades in a home composter-like environment.[61,62]

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[61] Goodbody, W., *New biodegradable plastic developed by Irish based scientists.*
[62] DelRe, C., Jiang, Y., Kang, P., Kwon, J., Hall, A., Jayapurna, I., Ruan, Z., Ma, L., Zolkin, K., Li, T., Scown, C. D., Ritchie, R. O., Russell, T. P., & Xu, T., *Near-complete depolymerization of polyesters with nano-dispersed enzymes*, p.558–563

LABORATORY RESEARCH

5. PLASTIC EXPERIMENTS

Three experiments will be conducted as part of the project's experimental component. The first will include developing four distinct types of bioplastics and assessing their qualities and characteristics, while the second will entail watching how these plastics disintegrate to see if they are appropriate to replace traditional plastics in the future, in my opinion.

5.1 Plastic making

5.1.1 Objectives

The main goal of this experiment is to create four distinct types of bioplastics and test them to see what properties they have.

5.1.2 Materials

The following items will be required to complete the experiment:

- Water
- Food colouring (four different colours)
- Glycerin
- Agar-Agar
- Cornstarch
- Gelatin
- Milk
- White vinegar

Figure 33: Water

Figure 34: Food colouring and glycerin

Figure 35: Agar-Agar

Figure 36: Cornstarch

Figure 37: Gelatin

Figure 38: Milk

Figure 39: White vinegar

And the supplies listed below will be needed:

Plastics 1,2,3 materials	Plastic 4 materials
Beaker Saucepan Rubber spatula Measuring spoons Digital scale Moulds	Beaker Filter paper/Cheesecloth Saucepan Rubber Spatula Wax paper Moulds

Figure 40: Beaker

Figure 41: Saucepan

Figure 42: Moulds

Figure 43: Rubber Spatula and measuring spoons

Figure 44: Digital Scale

Figure 45: Filter paper and wax paper

5.1.3 Procedure

This table illustrates the proportion of ingredients used to make the four different plastics:

Plastic 1 (Plant base)	Green food colouring	50 ml Water	0,25 ml Glycerin	9 gr cornstarch
Plastic 2 (Algae base)	Blue Food colouring	50 ml Water	0,125 ml Glycerin	3 gr Agar-Agar
Plastic 3 (Animal base)	Yellow Food colouring	50 ml Water	0,25 ml Glycerin	12 gr animal gelatin
Plastic 4 (Casein base)	Red Food colouring	250 ml low-fat milk	50 ml vinegar	-

Just like the ingredients, the process to make plastic one, two and three is nearly the same, whereas plastic four, the casein based plastic, has a different process too.

Procedure to make plastics 1,2 and 3.[63]

- Measure 50 ml of water with a 100 ml beaker and pour it into the saucepan.
- Measure with the digital scale and add the substrate (cornstarch, Agar-Agar or gelatin*) to the mixture and add a few drops of the respective food colouring.
- Use the measuring spoons to calculate the amount of glycerin needed and aggregate it into the mixture.
- Put the saucepan on the stove, at medium-low heat
- Stir thoroughly until it starts to thicken and stop when there are no clumps**.

[63] Original experiment instructions can be found in the annex section.

- Pour the mixture into the moulds, which have been previously greased with oil. Try to pour the plastic to a similar thickness (1 cm)
- Let the mixture cool down in a warm place so as to avoid any cracks or fissures, up to three days. Do not wait more days, due to the fact that the plastic may start to decompose.

*Before using gelatin, make sure to follow the instructions in the package
**Gelatin won't thicken. Just melt the gelatin, and before bringing it to a boil, continue the procedure

Procedure to make plastic 4.[64]
- Use a 500 ml beaker to measure out 250 ml of milk, add a few drops of red food colouring and stir.
- Use a 100 ml beaker to measure out 50 ml of white vinegar.
- Pour the milk into the saucepan and turn the stove on to medium-high
- Bring the milk to a boil and remove it immediately from the stove.
- Place the saucepan on the counter and aggregate the vinegar slowly while stirring constantly during 1 minute, until lumps begin to form.
- Place the filter paper/cheesecloth over the empty 500 ml beaker and pour the lumpy mixture through the filter paper/cheesecloth.
- Since it's very hot, wait a couple of minutes to cool down before handling the mixture. Once the casein has cooled down, you may squeeze the remaining liquid with your hand and place it on a wax paper. After a few minutes, press the casein into the mould and wait for at least 24 hours to dry.

Once we have all four types of plastic, we have tested the plastics to determine the different characteristics of each type of plastic. The test are the following:

- Opacity
- Flexibility (bend the plastic)
- Freezing (put the plastic inside the freezer for 24 hours and let it unfreeze)
- Heat (put the plastic in the oven at 60 degrees for 1 hour)
- Stain Resistance: Place a drop of coffee and mustard on the plastic.

[64] Original experiment instructions can be found in the annex section

5.1.4 Results

These are the four plastics that have come as a result of the experiment:

Figure 46: Algae Plastic

Figure 47: Animal plastic

Figure 48: Plant plastic

Figure 49: Milk plastic

To test their characteristics, we have used multiple samples of each type of plastic and we have applied a different set of tests mentioned above. The results have been recorded in the following table:

CHARACTERISTICS	CORNSTARCH	AGAR-AGAR	GELATIN	CASEIN
Colour & Opacity	Waxy colour Can't see through	Kind of transparent	Transparent	Opaque
Flexibility	Not solid enough to be flexible	Somewhat stiff	Pretty flexible	Hard Breaks when bent
Freezing	Has become solid enough but resembles a sponge	More flexible but slowly melts	Quite stiff but pretty flexible	Breaks down. Does not hold together

Heat	Even creamier than it already was, holds no particular form	Sweated a litte. Became way more flexible	Completely melted	Breaks down
Stain resistance	Substances melted the plastic	Both substances left some stain, but nothing too noticeable	Unaffected by mustard, coffee left a stain	Both substances left an intense stain

As you may see, we have obtained a variety of results.

To begin with the cornstarch plastic didn't have enough solidness to be used in any particular context, due to its creamy texture. It resembles rubber when it dries up, even though it quickly cracked. When frozen, it did gain this rigidness that it was lacking but it also soaked up water. It wasn't resistant to heat and even less resistant to acids.

The algae plastic was a big surprise, since it reminded me of silicone items. It was fairly resistant to all the tests with the exception of the cold temperatures since it slowly leaked water.

Similarly to the Agar-Agar plastic, the gelatin plastic was a decent result. However, it wouldn't be suitable to use in products that are meant to keep hot products due to the fact that it is pretty weak to heat.

And lastly, the casein plastic resembled a hard plastic such as polystyrene. Really hard and resistant to be bent, but didn't pass any of the tests regarding heat, cold and acidity resistance.

Figure 50: Plastic freezing test

Figure 51: Plastic heating test

Figure 52: Plastic stain resistance test

5.2 Plastic decomposition experiment

5.2.1 Objectives

The prime aim of this second experiment is to monitor how these four polymers deteriorate in order to determine whether they are suitable to replace traditional plastics in the future, taking into account the characteristics previously mentioned.

5.2.2 Materials

To do the experiment we will need: three samples of each plastic, three trays, salt water (which can be from the beach or tap water mixed with 38 parts of salt per thousand), earth for growing plants, and water (which can be from the tap or from a nearby river). During the visits, a thermometer will also be required.

5.2.3 Procedure

To observe the decomposition of bioplastic we have made this second experiment. Three trays must be placed in a place where the sun hits between 10 and 12 hours a day in summer. Each tray represents an environment where plastic pollution can be found at.

Tray Earth is filled with 750/1000 grams of dirt. At the same time, Tray River is filled with one litre and a half of water, whereas Tray Ocean is filled with one litre and a half of salt water. In my case, I used water from the tap for Tray River and salt water from El Prat’s beach for Tray Ocean.

The four types of plastic must be placed in each tray and need to be visited each day to see the progress in the process of decomposition. At the same time, outside temperature, weather, time and temperature of each environment has to be noted down each day.

5.2.4 Results

I started the first try of the experiment on the 25th of July at 1 PM on my building's rooftop. I placed three trays with each of the set environments.

Figure 53: The set environments on the first try

Due to the casein plastic fragility, it was the only one to break once placed in the Earth Tray. At the same time, the plant and the casein plastic immediately started to break once it was placed in the water trays (plant base owing to biodegradability and casein owing to fragility), whereas the animal and the algae plastic did not change at all.

Figure 54: Ocean tray 1st try, day 1

Figure 55: Earth tray 1st try, day 1

Figure 56: River tray 1st try, day 1

24 hours later I realised that the experiment would be way shorter than I had expected and that I would have to repeat it. The major problem I found was that the food colouring used had tinted both of the water environments and it was little transparent so it was hard to see the plastic. Throughout day 2 and 3, I ended up deciding to cancel the experiment since the plastics were practically melting instead of decomposing in the Earth tray and I couldn't evaluate both of the water trays due to the lack of transparency mentioned in day 1. Moreover, the water had been evaporating so it was clear that the location was too hot to carry out the experiment.

1st try (cancelled)	Day 0	Day 1	Day 2	Day 3
Time	13:20	13:37	16:33	16:37
Temperature	28 ºC	27 ºC	28 ºC	27 ºC
Weather	Sunny day with few clouds	Cloudy day	Sunny day	Sunny day
Ocean	29,1 ºC	25,5 ºC	31,7 ºC	35,1 ºC
Earth	47,6 ºC	36,2 ºC	55,3 ºC	60,8 ºC
River	28,2 ºC	25,3 ºC	31,3 ºC	33,4 ºC

Figure 57: Ocean tray 1st try, day 3

Figure 58: Earth tray 1st try, day 3

Figure 59: River tray 1st try, day 3

The second try was carried out on the 29th of July on my flat's balcony. This time, I didn't use any food colouring, and added half a litre more to the water trays, as well as burying the plastics in the Earth Tray. Moreover, I let the casein plastic to dry up a few more hours so it would gain hardness, which it did. The plastics were a little hard to spot in both water trays but it was way better than the colour mix in the first try. I analysed the evolution of the experiment during the span of 10 days.

Figure 60: The set environments 2nd try

2nd try	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Time	11:00	11:05	9:12	12:48	12:05	13:19	12:11	14:00	13:45	12:06	11:15
Temperature	28 ºC	28 ºC	27 ºC	27 ºC	27 ºC	27 ºC	28ºC	28 ºC	27 ºC	28 ºC	27ºC
Weather	Sunny day	Sunny day with few clouds	Cloudy day	sunny day	Sunny day with few clouds	Sunny day with few clouds	Cloudy day	Rained and hailed	Sunny day with few clouds	Sunny day with few clouds	Cloudy day
Ocean	27,5 ºC	30,2ºC	23,4ºC	28,9ºC	27,6ºC	26,7ºC	25,8ºC	24,9ºC	22,8ºC	26,5ºC	23,1ºC
Earth	45,0 ºC	52,9ºC	28,7ºC	57,1ºC	55,7ºC	33,4ºC	36,1ºC	23,9ºC	24,4ºC	29,5ºC	30,6ºC
River	27,2 ºC	30,1ºC	22,5ºC	28,6ºC	28,0ºC	26,8ºC	25,2ºC	24,5ºC	21,9ºC	25,9ºC	22,9ºC

The gelatin plastic became a gooey substance during the first two days of the experiment and diluted completely in both water trays. Additionally, on day two, the gelatin plastic on the dirt tray was completely absorbed in the dirt, so it came out as a complete success in decomposition, but rather weak to the set conditions.

Otherwise, the creamy consistency of the plant plastic was quite a nuisance to the experiment, especially in the water trays. It slowly broke in tinier pieces but it left the water milky and hard to see through. Furthermore, on the dirt tray it quickly dried up and broke into tiny pieces, but hadn't disappeared for the time being.

On the other hand, the casein and algae plastics reacted extremely differently to the pair mentioned above on the water trays. Neither of them changed much. What's more, the algae plastic was unfazed by the water, so I assumed that this plastic wouldn't decompose as long as it was hydrated. This was confirmed by the plastic on the Earth Tray, which had shrunk considerably and had lost it's flexibility. The casein plastic just lost it's rigidness but it maintained it's shape all the way through in the water environments and remained completely intact on the Earth Tray.

After the 10 day period of daily visits, I left the plastics that hadn't decomposed yet on my balcony without checking on them for a month and a half.

Figure 61: Algae plastic from the Ocean tray 2nd try, day 10

Figure 62: Casein plastic from the Ocean tray 2nd try, day 10

Figure 63: Cornstarch plastic from the Ocean tray 2nd try, day 10

Figure 64: Earth tray second try, day 10

Figure 65: Algae plastic from the River tray 2nd try, day 10

Figure 66: Casein plastic from the River tray 2nd try, day 10

Figure 67: Cornstarch plastic from the River tray 2nd try, day 10

In closing, the cornstarch plastic ended up disappearing from the three trays completely. Similarly, the algae plastic completely decomposed in the dirt tray and became significantly thinner in the water trays. I believe that in another month, it would have completely disappeared. Lastly, the casein plastic just broke into minuscular pieces in both water environments, but didn't seem to decompose. However, the sample inside the Earth tray started becoming a filamentous mass, and would've probably decomposed in a few more months.

Figure 68: Algae plastic after a month in the Ocean Tray (with little water)

Figure 69: Algae plastic after a month in the Ocean Tray (with little water)

Figure 70: Casein plastic after a month in the Earth Tray

6. CONCLUSIONS

The situation with regard to plastic is considerably worse than I had anticipated. The amount of plastics and garbage littering our biosphere yields enormous figures that are causing much more harm than good. On the other side, there are a slew of active initiatives and individuals striving to clean up the massive mess we've made, so there's still reason to be optimistic.

At the same time, it is true that there is a significant misunderstanding about the differences between biodegradable and bioplastic, as well as their impacts, like I had previously speculated. Contrary to popular belief, just because something includes the prefix bio doesn't imply it won't have an impact on the environment. Not all bioplastics are biodegradable, and even if a plastic is, it doesn't guarantee they will degrade in every scenario. Most current biodegradable plastics only breakdown under the circumstances set by the manufacturer, which means that if they are left in an environment that does not meet those parameters, they will break like any other plastic and create microplastics, as evidenced by numerous studies and I feel that everyone should be aware of this. Fortunately, it appears that in the not-too-distant future, we will have access to a plethora of new polymers that will not only perform similarly to current plastics, but will also degrade safely.

In terms of the experiment, I got a wide range of outcomes. The gelatin plastic was a full success in terms of decomposition, but it was quite poor in terms of the set circumstances, as it dissolved in just two days, thus it wasn't likely helpful in any context. Aside from that, the cornstarch plastic gradually dissolved in both water trays, so I wouldn't call it deteriorating. Furthermore, it rapidly dried out and fragmented into little bits on the dirt tray, lasting around 20 days before vanishing from sight. It was unsuitable for use in anything due to its breakdown and initial consistency. Casein and agar plastic, on the other hand, lasted far longer than the other two. In the water trays, the casein plastic did break down but did not decompose, therefore I concluded that it was not biodegradable in water. It did, however, develop a filamentous mass in the soil tray, which would have degraded in a few months. Finally, the agar plastic decomposed without issue in the Earth Tray and grew noticeably thinner in the water trays, indicating that it would have decomposed completely in another month or two.

Even if some of the bioplastics that I've created haven’t resulted in success, they have shown me that, while there is still a long way to go before they can replace traditional plastics, some of them can be helpful and their components would be readily available plus not difficult to manufacture. In fact, the algae plastic has had the most surprising outcome and I believe that it is a promising material that will be used in the near future due to the fact that it had a good consistency and was fairly resistant to the three tests that it was put through, not to mention that it degraded safely in all conditions and it’s already being developed by other individuals who want to help the environment.

All in all, I'm pleased I picked this topic, since I now feel more conscious of our position and how it will evolve, as well as capable of contributing and helping. Never had I expected to learn so much from such a specific subject. I reckon we really need great minds to come up with new ideas, and I encourage anyone to seek new paths in this complicated situation, in order to get a free non-degradable plastic future, where our planet won’t be suffocated by plastic anymore.

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- Figure 33 to figure 70: Photograph taken by author

8. ANNEX

Annex 1: Table of marine plastic impact on animal life

Study	Animal	Encounter type	Predominant debris type	Impact (response)
Allen et al. 2012	Grey seals	Entanglement	MF line, net, rope	Constriction
Beck & Barros, 1991	Manatees	Entanglement	MF line, bags, other debris	Death
Campagna et al. 2007	Elephant seals	Entanglement	MF line, fishing jigs	Dermal wound
Croxall et al. 1990	Fur seals	Entanglement	Packing band, fishing gear, other debris	Dermal wound
Dau et al. 2009	Seabirds, pinnipeds	Entanglement	Fishing gear	External wound
Fowler 1987	Fur seals	Entanglement	Trawl netting, packing bands	Death
Fowler 1987 (correlative evidence only)	Fur seals	Entanglement	Trawl netting, packing bands	Reduced population size
Good et al. 2010	Invertebrates, fish, seabirds, marine mammals	Entanglement	Derelict gillnets	Death
Moore et al. 2009	Seabirds, marine mammals	Entanglement	Plastic, fishing line	Death
Pham et al. 2013	Gorgonians	Entanglement	Fishing line	Damage/breakage
Velez-Rubio et al. 2013	Sea turtles	Entanglement	Fishing gear	Death
Winn et al. 2008	Whales	Entanglement	Plastic line	Dermal wound
Woodward et al. 2006	Whales	Entanglement	Plastic line	Dermal wound
Beck & Barros 1991	Manatees	Ingestion	MF line, bags, other debris	Death
Bjorndal et al. 1994	Sea turtles	Ingestion	MF line, fish hooks, other debris	Intestinal blockage, death
Brandao et al. 2011	Penguins	Ingestion	Plastic, fishing gear, other debris	
Browne et al. 2013	Lugworms (laboratory)	Ingestion	Microplastics	Biochemical/cellular, death
Bugoni et al. 2001	Sea turtles	Ingestion	Plastic bags, ropes	Gut obstruction, death
Carey 2011	Seabirds	Ingestion	Plastic particles, pellets	Perforated gut
Cedervall et al. 2012	Fish (laboratory)	Ingestion	Nanoparticles	Biochemical/cellular
Connors & Smith 1982 (correlative evidence only)	Seabirds	Ingestion	Plastic pellets, foam	Biochemical/cellular
Dau et al. 2009	Seabirds, pinnipeds	Ingestion	Fishing hooks	Internal wound
de Stephanis et al. 2013	Sperm whale	Ingestion	Identifiable litter items	Gastric rupture, death
Fry et al. 1987	Seabirds	Ingestion	Plastic fragments, pellets, identifiable litter	Gut impaction, ulcerative lesions
Jacobsen et al. 2010	Sperm whales	Ingestion	Fishing gear, other debris	Gastric rupture, gut impaction, death
Lee et al. 2013	Copepods (laboratory)	Ingestion	Micro- and nanoplastics	Death
Oliveira et al. 2013	Fish (laboratory)	Ingestion	Microplastics	Biochemical/cellular
Rochman et al. 2013a-c	Fish (laboratory)	Ingestion	Microplastics	Biochemical/cellular
Ryan 1988	Birds (laboratory)	Ingestion	Microplastics	Reduced organ size
Velez-Rubio et al. 2013	Sea turtles	Ingestion	Marine debris	Gut obstruction
Wright et al. 2013	Lugworms (laboratory)	Ingestion	Microplastics	Biochemical/cellular
Von Moos et al. 2012	Mussels (laboratory)	Ingestion and gill uptake	Microplastics	Biochemical/cellular
Katsanevakis et al. 2007	Epibenthic megafauna	Interaction (contact)	Plastic bottles, glass jars	Altered assemblage
Lewis et al. 2009	Sessile invertebrates (coral reef)	Interaction (contact)	Lobster traps	Altered assemblage
Uneputty & Evans 1997 (correlative evidence only)	Assemblage on sediment	Interaction (contact)	Plastic litter	Altered assemblage
Chiappone et al. 2002	Sessile invertebrates (coral reef)	Interaction (contact)	MF line, lobster trap, hook and line gear	Tissue abrasion
Chiappone et al. 2005	Sessile invertebrates (coral reef)	Interaction (contact)	Hook and line gear	Tissue abrasion
Uhrin & Schellinger 2011	Seagrass	Interaction (contact)	Crab pots, tires, wood	Breakage, suffocation, death
Ozdilek et al. 2006 (correlative evidence only)	Sea turtles	Interaction (obstruction)	Waste, medical waste	Reduced population size
Widmer & Hennemann 2010 (correlative evidence only)	Ghost crabs	Interaction (obstruction)	Beach litter, mostly plastic	Reduced population size
Widmer & Hennemann 2010 (correlative evidence only)	Ghost crabs	Interaction (substrate)	Beach litter, mostly plastic	Altered assemblage
Goldstein et al. 2012 (correlative evidence only)	Marine insects	Interaction (substrate)	Microplastics	Increased population size

Annex 2: Interview with Frances H.Harold in La Vanguardia

ANA JIMÉNEZ

Arnold participa en los actos de los premios de la Fundación Princesa de Girona

ENTREVISTA

ANTONIO CERRILLO
Barcelona

"Las bacterias nos ayudarán a degradar los plásticos"

Frances H. Arnold

Catedrática de Bioingeniería, Nobel de Química en el 2018

Frances H. Arnold (Pittsburgh, EE.UU., 1956) obtuvo en el 2018 el Nobel de Química por sus investigaciones sobre evolución dirigida. Sus métodos para producir enzimas (catalizadores de todas las reacciones bioquímicas de los organismos vivos) permiten seleccionarlas y mejorarlas, hasta dotarlas de propiedades que no se dan en la naturaleza. Arnold es catedrática de Ingeniería Química, Bioingeniería y Bioquímica en el Instituto de Tecnología de California. Con motivo de la entrega de los premios de la Fundación Princesa de Girona (FPdGi), mantendrá hoy un diálogo con la ingeniera química María Escudero, premio de Investigación Científica de la FPdGi en el 2018.

¿En qué áreas puede ser útil su investigación?
Mis métodos se utilizan en todo el mundo para mejorar el rendimiento de las enzimas en todo, desde detergentes para ropa, cosméticos, tratamiento de enfermedades o fabricación de combustible para aviones a partir de recursos renovables. Imagino un mundo en el que la química limpia y eficiente de la naturaleza reemplace los sucios procesos de fabricación humanos. ¿No sería maravilloso fabricar nuestros productos farmacéuticos, cosméticos, combustibles y productos químicos de la misma manera como hacemos la cerveza? ¿No sería maravilloso que los microbios se comieran nuestros desechos plásticos y los convirtieran en nuevos materiales valiosos?

La proliferación de plástico es un enorme problema medioambiental en todo el mundo. ¿Podemos sustituirlos por materiales que se degraden? ¿Podremos crear bacterias que se los coman?
La respuesta es sí. Los plásticos solo llevan en el planeta unos 100 años. Sin embargo, las bacterias ya están empezando a descubrir cómo los pueden degradar. Y podemos ayudarlas acelerando esa evolución. También podemos reciclar estos materiales e inventar nuevos materiales que se degraden más fácilmente.

Microbios que se alimentan de compuestos tóxicos. ¿Debemos buscar en la naturaleza las claves para descontaminar el mundo?
Los microbios tienen muchísima inventiva y han ideado formas de vivir en todo tipo de entornos. Sin embargo, no necesariamente resuelven los mismos problemas que los humanos necesitan resolver. Me gusta la idea de que podemos recurrir al método de innovación de la naturaleza, que es la evolución, para convertir la naturaleza en nuestro socio. Los seres humanos aún tenemos que resolver nuestros propios problemas, pero la naturaleza puede ser parte de esa solución. Podemos ayudar a orientar la naturaleza hacia soluciones que nos beneficien a todos respetando la biodiversidad.

El petróleo y sus derivados están en todas partes. ¿Hay alternativas al petróleo?
Tenemos que hacer la transición hacia un balance de cero emisiones netas de carbono lo antes posible si queremos evitar las peores consecuencias del cambio climático. Por lo tanto, si continuamos extrayendo combustibles fósiles, debemos compensar las emisiones secuestrando carbono. Esto significa bombearlo de nuevo al suelo, mantenerlo en forma de material orgánico en el suelo, convertirlo en productos químicos o incluso fabricar cemento secuestrador de carbono. Hay mucho campo para mejorar la tecnología para secuestrar carbono, así como también para dejar de usar combustibles fósiles. Espero que los científicos jóvenes sigan inventando estos métodos mejorados. California, que es similar en muchos aspectos a España, se está alejando de los recursos fósiles hacia la electricidad libre de carbono (eólica y solar, por ejemplo) y el transporte. Un gran beneficio de esta transición es la menor contaminación del aire de los automóviles y las plantas de energía.

Química verde y plagas
"Elaboramos feromonas, un producto natural, para reemplazar a los insecticidas"

¿Pueden los productos químicos alternativos reemplazar el uso de insecticidas?
Cofundé Provivi con dos exalumnos en el 2014. Inventamos procesos para elaborar feromonas sexuales complejas a muy bajo coste, para que puedan ser rociadas en campos de maíz, algodón, arroz y soja donde las larvas hacen un daño tremendo. Nuestros productos son naturales y no tóxicos, no dañan a los insectos beneficiosos y no dejan residuos tóxicos que dañen a los humanos. Ya los proporcionamos en Kenia, Indonesia, Sudamérica y México, donde los agricultores disfrutan de cultivos de mejor calidad y más rendimiento usando menos insecticidas.

Preocupa la ubicuidad de los plaguicidas. ¿Qué soluciones puede aportar la química verde?
Las feromonas ayudan a los agricultores ecológicos a combatir las plagas por mediación de los compuestos naturales; sirven para reemplazar a los pesticidas. Producimos feromonas utilizando una química mucho más eficiente, incluidos nuevos procesos biológicos. Muchas naciones no pueden comprar productos orgánicos (ecológicos). Los agricultores de los países más pobres causan un enorme daño ambiental con los pesticidas y me gustaría que tuvieran alternativas viables, incluidas las feromonas, y que ejecutaran mejores prácticas agrícolas.●

Annex 3: Instructions to create the algae, gelatin and the cornstarch bioplastics

Creating Biodegradable Plastic

Set Up:

In this activity you will develop fork handle molds out of aluminum foil, create different types of bioplastic to pour into your molds, and then test the materials' strength and flexibility.

Directions:

Part 1: Building the Molds

1. Create three molds in the shape of a fork handle for each substrate type using aluminum foil. Make three molds for each substrate types for a total of nine molds. The molds can be as simple as a small container about 1 cm wide, 2 cm deep and 10 cm long. Multiple samples are needed to test and evaluate the characteristics of the different types of bioplastic. The molds should be designed so they won't leak.
2. Number the outside of each mold with a Sharpie marker to keep track of the substrate samples.
3. Spray the molds with non-stick spray.

SOURCE TYPE	WATER	SUBSTRATE	SUBSTRATE AMOUNT	GLYCERIN
Animal	50 ml (¼ cup)	Gelatin	12 g (3 tsp.)	5 drops
Algae	50 ml (¼ cup)	Agar Agar	3 g (1 tsp.)	2.5 drops
Plant	50 ml (¼ cup)	Cornstarch	9 g (2 tsp.)	5 drops

Materials:

- 2 feet aluminum foil
- Non-stick spray (Pam)
- Tap Water
- Bio-based substrates:
  9 g (2 tsp.) Corn starch
  12 g (3 tsp.) Unflavored gelatin
  3 g (1 tsp) Agar agar
- Appx. 1 TB plasticizer (glycerin)
- Heat-resistant, disposable cups
- Plastic straws for mixing
- Medicine dropper for measuring plasticizer
- Teaspoon
- ¼ cup measure

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Part 2: Making the Bioplastic

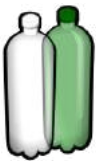
1. For each of the three source types, mix tap water, substrate and glycerin in a heat resistant cup using the follow proportions in the chart. Stir each cup until there are no clumps.
2. Heat each mixture separately in a microwave until it begins to froth, usually less than a minute. To prevent boiling over, carefully watch the mixture through the microwave window. Stir after heating.

Creating Biodegradable Plastic, continued

3. Pour each mixture type out into three molds. Try to pour the plastic to the same thickness (about 0.5 - 0.75 cm) in each mold.
4. Allow the mixture to dry in a warm place. This can be three to five days.
5. Once the folk handles have completely dried, use the multiple samples you made to test the different substrate materials' characteristics. The chart below has a list of items to test. Record your results.

CHARACTERISTIC	OBSERVATIONS	CORN STARCH	AGAR AGAR	GELATIN
Color & Opacity: Can you see light through the material? Y or N				
Flexibility: Rate 1 = cracks; 2 = stiff; 3 = somewhat flexible; 4 = very flexible				
Freezing: To simulate winter conditions, freeze a sample then rate flexibility.				
Heat: To simulate summer conditions, heat samples up to 120° F under a lamp or in an oven. Rate for flexibility.				
Stain Resistance: Place a drop of coffee or mustard on the plastic. Does it stain when you try to wipe it off? Y or N				
Tensile Strength: Tape pennies, one at a time, on to the end of samples. Hold a sample by one end. How many pennies can you tape on before it breaks?				

Annex 4: Instructions to create the Casein bioplastic



Biodegradable Plastic Lab

You will be synthesising one of the first “plastics” ever introduced into mainstream production, called casein. Milk contains many molecules of a protein called casein. Each casein molecule is a monomer and a chain of casein monomers is a polymer. The polymer can be shaped up and moulded, which is why plastic made from milk is called casein plastic.

PURPOSE:

To investigate the polymerization of casein to compare it’s properties to synthetic plastic. To apply the process of polymerization of casein to design a durable and biodegradable alternative to the synthetic pollutant polymers widely used today.

MATERIALS:

-Milk (2%, lower fat content is better) -100mL Beaker

-White Vinegar - Food colouring

-Cheesecloth/ Filter Paper -Wax Paper

-Hot Plate -Pipe Cleaners

-Two 500 mL Beakers

-Stir Rod

-Beaker Tongs

-Cookie Cutters/Moulds (optional but recommended)

PROCEDURE:

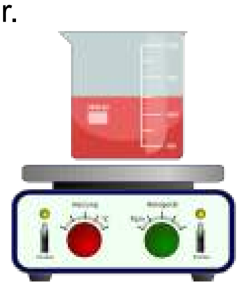
1. Measure out 250mL of milk into your 500mL beaker.

2. Measure out 50mL of white vinegar into your 100mL beaker.

3. Take a second 500mL and do not add anything to it.

4. Bring all three beakers to your lab station.

5. Drop a few drops of food colouring into your beaker of milk and stir. This will be the colour of your casein plastic end product.



6. Turn your hot plate on to medium/high. (7-8 on your adjustment knob)

7. Place your beaker of milk on the hot plate using the beaker tongs.

8. Heat the milk until it just barely begins to boil and remove it from the hot

plate immediately using the beaker tongs. DO NOT LET THE MILK BOIL OVER ONTO THE HOT PLATE!

9. Set the beaker on the lab counter and add the vinegar slowly while stirring with the stir rod. 10. Stir the mixture constantly for about 1 minute.

11. You should see lumpy globs begin to form.

12. If you do not see blobs, you may need to reheat your milk mixture and add more vinegar. Notify your teacher and they will assist you with this step.

13. Place the cheesecloth or filter paper over the empty 500mL beaker.

14.Pour the lumpy milk mixture through the cheesecloth or filter paper into the empty beaker. 15. Left behind in the cheesecloth or filter paper is your plastic casein product. It is VERY HOT, so wait 1-2 minutes for it to cool to room temperature before handling.

16. Once your casein has cooled slightly, you may squeeze out any remaining liquid with your hand. **NOTE: You can reheat and add vinegar to the liquid that remains after straining out your casein if your teacher allows.

17. Place the casein plastic onto a small sheet of wax paper and begin to form it into the shape you want. Use the cookie cutters and moulds if they are available to you!

18. Place your moulded plastic casein creation into a designated area of your lab to dry and harden.

19. Clean all your beakers with soap and water and set them on the drying rack.

Annex 5: *Posidonia oceanica* Experiment

I did a small experiment in my high school's laboratory to check if the article I had read about *Posidonia oceanica* picking up plastic was true. To do this I picked up the Neptune balls of this plant while I was on holiday in Menorca and then observed them in a microscope.



After inspecting about 20 different samples of these Neptune balls I found two microplastics entangled in between the dry leaves of the posidonia. These results mean that Posidonia oceanica can pick up microplastics from the sea bottom.


In short, given the result of the experiment, I believe that by protecting the Posidonia meadows, we will help to collect the tiny plastics and it is a really good option taking into account all the other side effects mentioned in the project.