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HOW MUCH IS TOO MUCH?

The Development of a Microplastic Pollution Significance Threshold for the Port Phillip Bay

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How Much is Too Much?

The Development of a Microplastic Pollution Significance Threshold for the Port Phillip Bay

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Abstract

The goal of this project was to help the Port Phillip EcoCentre design a microplastic pollution threshold model for Port Phillip Bay, contributing to the emerging effort to fight microplastic pollution. We developed a system with three main aspects: sampling and measurement, species sensitivity, and enforcement. Additionally, we created collateral on sampling and enforcement for educating those who can make change, as well as a flow chart to help waterkeepers identify levers for change in their communities. Finally, we devised a poster to help raise awareness of microplastic pollution in both the general population and the angling community. The design of a significance threshold system will be a crucial step in helping to protect Port Phillip Bay.

Executive Summary

Plastics are among the most pervasive pollutants in the world. The world has a major plastics dependence, and they are used for the sheer majority of both reusable and disposable products, from bags and water bottles to synthetic clothing and tires. There are millions of tons of plastic entering the Earth's waterways each year due to our mismanagement of plastic waste (Becker, 2021). These plastics accumulate within ecosystems due to their inability to decompose, instead breaking down into smaller and smaller plastic particles. Eventually these plastics reach the size of less than 5 mm in length, at which point they can be classified as microplastics. Several factors contribute to the breakdown of plastics, including UV radiation, wind, and waves (Royte, 2021). In addition to breaking down from larger plastics, there are also microplastics that are produced at this size for manufacturing purposes, which are extremely easy to spill into waterways due to their small size and light weight. Once microplastics enter a waterway they persist in the environment and the bodies of organisms, causing continuous harm to ecosystems.

Figure A: Port Phillip Location in Australia

Figure B: Port Phillip Bay Overhead View

Microplastics pose a grave threat to a wide variety of organisms, especially those in marine environments. It is easy for these animals to consume small plastic particles due to prey misidentification, and in the case of some species filter feeding. Little is known about the effects of microplastics on most organisms, but the few studies that have been conducted have shown deadly effects in both marine and terrestrial life. These effects, including loss of appetite, inhibition of movement, and reproductive defects, are experienced throughout the food chain due to bioaccumulation, the concept that pollutants are passed on from one organism to the next when consumed (Royte, 2022). In addition, the food chain does not end with the apex predators of the ocean. Terrestrial animals eat marine life along with the microplastic particles within them, and also consume particles from alternative sources such as fruits, vegetables and drinking water. Mice are often used as indicators of the effects on larger terrestrial mammals, and microplastic consumption testing has shown similar effects as those seen in marine life. Bioaccumulation and the effects studied in mice both suggest that should microplastic pollution continue, humans may face irreversible harm (Waring, 2018).

Figure C: Members of The EcoCentre Team

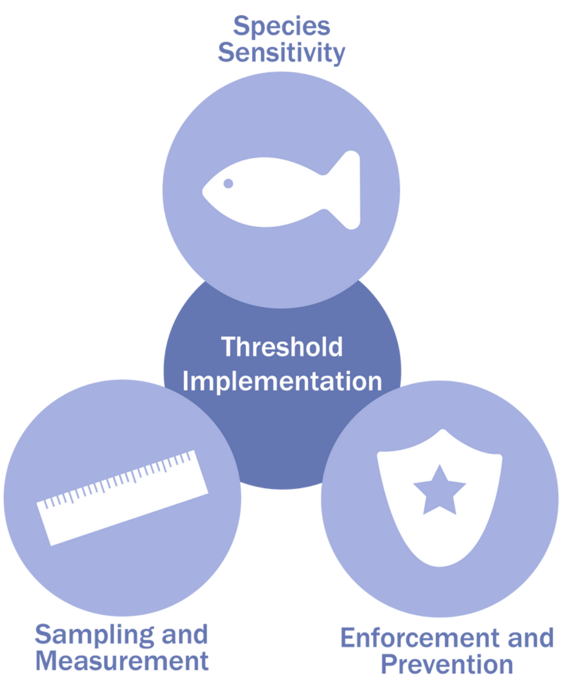

Figure D: Our Threshold Implementation Model

Port Phillip Bay is an area of great concern in regards to microplastic pollution. Located in Melbourne, Victoria at the Southern tip of Australia, this bay is almost completely closed off to the ocean. This causes mass accumulation of pollutants in the bay. While this is extremely detrimental to all the organisms living there, the large-scale pollution of the bay also poses a threat to the industrial and recreational businesses that rely on these waters (Marine and Coasts, 2021). The Port Phillip EcoCentre (Figure C) is a not-for-profit organization dedicated to protecting Port Phillip Bay and the species that make it their home. They have played a critical role in helping to raise awareness on the issue of microplastic pollution with both the Victorian Government and the people of Melbourne (Lawes, 2017).

Project Objectives and Methods

The goal of this project was to help the Port Phillip EcoCentre determine the processes needed to establish a microplastic pollution threshold for Port Phillip Bay. Having found three primary components for the creation of a pollution threshold (Figure D), we set three objectives to analyze how these could be used in the case of a microplastic pollution threshold.

- Determine methods for sampling and measurement of microplastic concentration in marine environments.
- Determine how a species sensitivity distribution can be applied to microplastics for the creation of a threshold value.
- Determine methods for the enforcement of a microplastic pollution threshold.

In order to compile the information necessary to make recommendations on the formation of a microplastic pollution threshold, three methods were used. The first of these methods was interviews with experts in various topics relevant to our project. This included six total interviews with university professors, waterkeepers, and an EPA official. These interviews not only provided information on the topics that we were researching, but gave insight into new avenues that required investigation.

The second method used for data collection was literature review. While relatively little research has been conducted on microplastics on a global scale, that which has been published has proved invaluable to our project for the assessment of all three threshold components. Finally, a case study was performed on the work underway in the state of California. While a microplastic pollution threshold does not exist anywhere in the world yet, California has been working on developing one, so we have tracked their ongoing developments throughout the duration of our project.

Findings

Several potential methods for sampling microplastics concentrations in water were assessed for our project: beach audits, water trawls, bioindicators, and sediment sampling. All of these methods were deemed to be valuable for different purposes. General aspects of each sampling method we hoped to gain more information on included the potential lab analysis techniques required, accuracy and reliability of results, cost, duration, repeatability, and overall feasibility for Port Phillip Bay. We found that beach audits provide quick results and engage the community, making them ideal for raising awareness amongst the general population. Water trawling was found to be an accurate method for directly sampling the surface water of the bay. Next, the use of mussels as bioindicators was found to be a reliable method for sampling the middle depths of the bay and could also be used to remove plastic from the bay. Finally, we found that sediment sampling may be used to obtain historical data of microplastic pollution at the bottom of the bay.

Though microplastics are a group of pollutants rather than a single pollutant, it was found that there are certain steps that can be taken to account for differences in plastic types and sizes when applying species sensitivity. While these steps make the system relatively applicable, it was found that there are several key branches of research that need to be pursued in order to be able to create a threshold using a species sensitivity distribution. The research needed most is a comprehensive analysis of the tolerances of species living within Port Phillip Bay. Tolerance data exists for very few species worldwide, as microplastics are an emerging field so few of these studies have been performed. However, it has been found that under certain conditions, approximations of species tolerances can be made based on species that have been studied sufficiently which fulfill similar roles in their ecosystems as species lacking data. Additional research needs to be conducted on the ability for chemicals absorbed by microplastics to transfer from the plastic particles to organisms that consume them. Many chemicals absorbed by microplastics can be very dangerous to marine life, so this research will allow scientists to gauge how much of an additional threat is posed by microplastic chemical absorption.

If a threshold were to be breached, there are currently no wide scale remediation methods for microplastic. In order to maintain a microplastics pollution level below a significance threshold, enforcement and preliminary measures are necessary. Nurdle spills are a significant source of microplastic pollution, making it necessary to target companies using and making when enforcing a microplastic threshold. It is also important to encourage businesses to voluntarily comply with spill prevention measures, following pledges such as Operation Clean Sweep. Additional preliminary measures must be taken to manage Melbourne's wastewater and stormwater systems to reduce the amounts of microplastics entering the bay. Finally, it is important for Victoria to ensure that plastic waste is not mismanaged by taking steps towards a circular plastic economy.

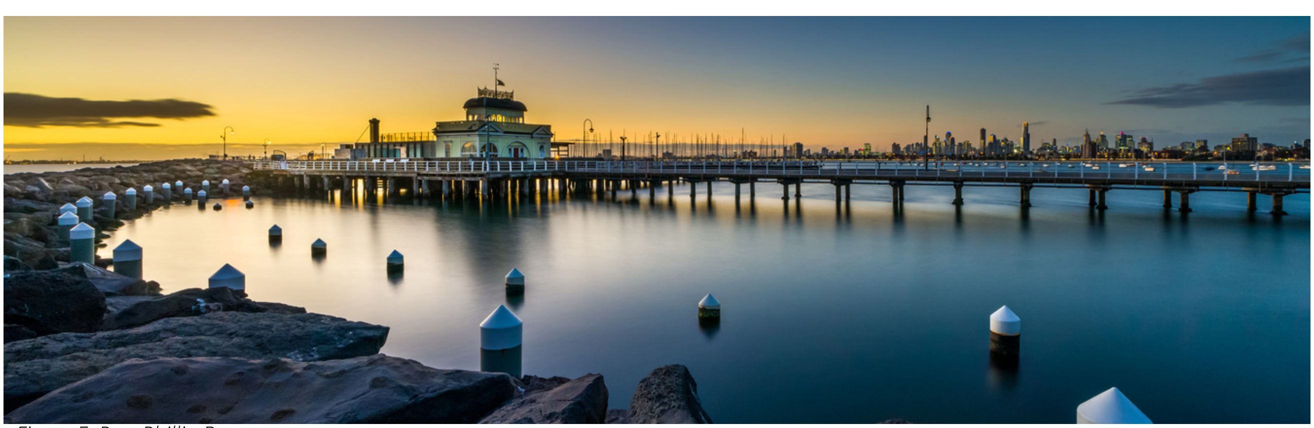

Figure E: Port Phillip Bay

Recommendations

Several recommendations on the direction of EcoCentre's microplastics initiatives can be made based on our findings. We recommend the use of water trawls and bioindicators as sampling methods should a threshold be established. This is due to the quality of data that these methods provide. Additionally, the continuation of EcoCentre's beach audits is recommended for engaging the local community, and it is recommended that sediment sampling be used to analyze how polluted areas in Port Phillip Bay have been historically. For species sensitivity, it is recommended that research into the tolerances of species be studied so that a threshold can be designed using a species sensitivity distribution to protect most of the species in the bay. Secondly, it is recommended that research be conducted on how chemicals transfer from microplastics to organisms so that the additional threat level from absorbed pollutants can be gauged. For enforcement and prevention, it is recommended that prevention be stressed over enforcement, as once plastics enter waterways it is very difficult to remove them. It is also important to make and enforce regulations around nurdles as this is one of the main sources of primary microplastic pollution. Finally, it is recommended that EcoCentre monitor developments made by the state of California as they work to create their microplastic pollution threshold, and to monitor the improving technology of geographic information systems, an emerging technology that could potentially allow for satellite tracking of microplastic pollution.

Outreach and Education

In order to help with EcoCentre's community outreach, our team designed a poster meant to raise awareness of the dangers posed to one of the iconic species of Port Phillip Bay (Figure F). In order to appeal to both the general public and the angling community, the Australasian snapper was chosen for this poster. As they congregate in one of the most microplastic polluted areas of the bay, the Australasian snapper is one of the many species that sees high risk from microplastic pollution. The Australasian snapper is highly prized by the angling community as a seafood staple for the area due to both their taste and texture. Their value as seafood among the public is also beneficial for raising awareness. We aimed to make it known that due to bioaccumulation, microplastics consumed by the snapper or their prey eventually reaches humans through their food

Figure F: Australasian Snapper Poster

In addition to this poster, two diagrams were made to be used by EcoCentre when educating local leaders and other relevant individuals on both the sampling methods and the potential enforcement model. The sampling method chart presents a short description of each sampling method as well as the pros and cons associated with each sampling method. It then makes recommendations as to when to use each sampling method based on their strengths and weaknesses. The enforcement diagram presents the enforcement system for the proposed threshold model. This flowchart shows the consistent loop of sampling and analysing needed to constantly check the concentration of microplastics. It additionally indicates the appropriate reaction towards a breached threshold and shows possible reactions targeting entities responsible for the pollution.

Figure G: Community Outreach at the EcoCentre

Finally, a flowchart was made to educate waterkeepers on the levers available to them to create change. This included several methods by which they can push for change. One path was based on preliminary actions to help raise social awareness on the problem of microplastic pollution with the goal of changing social norms when a pollution site's sources are not able to be identified. A pathway for when a pollution hotspot's source is identified is also available, with the goal here being to incentivize the polluter to make positive change. When this isn't an option, alternatives exist such as working with organizations including the EPA to develop stronger regulation.

Authorship

Alexander Almazan

Alexander was the primary writer of The Current Context of Microplastics Regulation section of the background, Expert Interviews section of the Methods, Beach Audits and Water Sampling sections of the findings, Beach Audits and Water Trawls sections in the recommendations, and Appendix A. He also contributed to the executive summary, the introduction, the writing of interview questions in appendices B-I, and was also involved in the creation of the project deliverables.

Jacob Morin

Jacob was the primary writer for the executive summary, species sensitivity section, the Port Phillip: A Bay in Need and Those who Care in the introduction, the literature review portion of the methods, and the conclusion. He also contributed to the recommendations, the writing of interview questions in appendices B-I, the project deliverables, and was the primary editor of the introduction, background, and methods amongst other part of the paper.

Drew Solomon

Drew was the primary writer of the Effects on Organisms, Methods introduction, Sediment Sampling for Measuring Microplastic Pollution, Mussels as Bioindicators and Water Filters, Analyzing Mussel Watch's Monitoring System, Mussel Watch's Consideration of Mussel Microplastic Monitoring, and Recommendations sections, Appendix B-J and the project deliverables. He was also the primary editor of the references section, and oversaw citations throughout the report.

Travis Thompson

Travis was the primary writer of the What are Microplastics?, The Current Developments of Microplastic Regulation in California, and Enforcement and Prevention sections. He also contributed to the Introduction, Conclusions and, Methods Sections.. Additionally he was responsle for the creation of the infographics throughout the paper, and the design of the project deliverables such as the Australasian Snapper Poster and the sampling methods chart.

Chenxin Tu

Chenxin was the primary author of Interconnections Between the Bay and Upstream Populations and the Cultural Context of Port Phillip Bay. She also contributed to the Geographic Information Systems sections, recommendations for the use of remote sensing in large-scale microplastic quantification in the future as well as Appendix K.

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01
Introduction

The threat of microplastics to our environment and ourselves is ever increasing as our oceans and landfills fill with an abundance of our plastic waste (Royte, 2021). This plastic waste proceeds to break down into extremely small plastic particles called microplastics, which are ingested by organisms and move up the food chain until they eventually reach humans. The effects of microplastics on humans are unclear, however based on the effects on other organisms it is evident they will be grave. Worldwide, the issue of microplastic pollution has been increasingly acknowledged with various regulations coming to light. Despite this, we are still far from establishing effective regulation to combat microplastic pollution and reduce the risk of harm to our environment and ourselves. One of the critical steps in enacting effective regulation is setting a threshold to establish a maximum amount of the pollutant that can be present in a body of water. This threshold will enable policy makers to enact regulations based on the pollution level of the affected area.

Port Phillip Bay in Southern Victoria is one of many bodies of water laden with microplastics, and in need of stronger regulation on pollution. The Bay, home to a wide variety of species, recreational sites, and industrial sites, collects a large amount of microplastics via its catchments. These microplastics pose a major threat to its ecosystem, especially to the unique species of Port Phillip Bay. There are many groups that are invested in the well-being of Port Phillip Bay, including the Port Phillip EcoCentre and the Waterkeeper Alliance. EcoCentre is a not-for-profit organization that is focused on maintaining the health and the values of the bay. As a global leader in microplastic advocacy, EcoCentre works with a wide variety of partners to fight for better monitoring and regulation of microplastic pollution. The Waterkeeper Alliance is a worldwide organization that consists of many smaller branches, with individuals dedicated to protecting many bodies of water. Port Phillip Bay and some of its major catchments each have waterkeepers who represent these bodies of water and work to protect them from pollution and other threats.

Implementation of a microplastic threshold is no easy feat due to the many complexities of sampling particles from water. One of the main complexities is that it is difficult to obtain reliable samples of microplastics' concentration in marine environments; the particles are spread unevenly throughout the water. Low density particles float on the water's surface while larger density particles sink and often become stuck in the sediment at the bottom of the water body. In addition, different areas of a body of water are habitats of different species, and thus the uneven distribution of microplastics through a body of water will affect species variably based on the area in which they live. Finally, as species have different tolerances to microplastics, another degree of complexity is added to the problem when trying to set a threshold to protect most of them.

Microplastics have contaminated the Earth for decades, but experts are just starting to understand the harm they pose. With an increase in recognition of the issue, there has been an uptick of research on the pollutant within the past couple of years. Furthermore, there is still a huge information gap on the issue with uncertainty on how and if different materials, shapes, and sizes of microplastics affect species and the environment differently. There is also an incomplete understanding of the effects on humans and other large animals. Due to this information gap, progress towards more effective regulation has been slowed. An example of this is the state of California's ongoing development of microplastic regulations, where experts had to conduct years of research to begin the implementation of their microplastic threshold. With the efforts of scientists and researchers from California and around the world, this information gap should continue to diminish.

This project is contributing to the emerging effort to fight microplastic pollution and is designed to help the Port Phillip EcoCentre establish a microplastic pollution threshold for Port Phillip Bay. This was achieved by creating a microplastic threshold implementation model that can be applied to any body of water. Implementing this threshold would entail methods of microplastic sampling, enforcement, and the determination of threshold value(s) through species sensitivity. This was approached with methods including a case study of the efforts being made in California to establish a microplastic pollution threshold, expert interviews with waterkeepers, marine biologists, and other environmental authorities, and through literature review into methods being used for establishing pollution thresholds for other pollutants.

02 Background

In this section we introduce microplastics, their effects on organisms, Port Phillip Bay, multiple stakeholders, and the context of regulation around the world.

Microplastics

In our waterways, there are trillions of microplastics floating on the surface weighing at least 100,000 tons (Becker, 2021). This number is increasingly growing, with five to fourteen million tons of plastic flowing into our waterways each year (Royte, 2021). Despite the growing concern over the number of plastics in our waterways, the production of plastics is increasing with an estimated increase of 8 to 44 tons of the annual plastics dumped into our ocean over the next 10 years (Parker, 2021).

What are Microplastics?

Microplastics are barely visible to the naked eye with their size less than 5 mm in length (National Geographic Society, 2019). These pieces can be classified into two categories: primary microplastics and secondary microplastics (Figure 1). Primary microplastics are plastics manufactured at a size of less than 5mm. Common examples of primary microplastics are microbeads for facial scrubs (Xu, 2020) and nurdles, which are plastic spheres used to manufacture larger plastics. Primary microplastics also come from the shedding of synthetic clothing resulting in plastic fibers, typically occurring in the wash (Ocean Clean Wash, 2021). Secondary microplastics are the result of the breakdown of our plastic waste over time. Breakdown of this waste is caused by the sun, heat, wind, and waves (Royte, 2021). Due to these breakdown factors, there is a diverse set of microplastics within the environment, all varying in size, shape, and polymer type. Microplastics can also absorb other pollutantants they come in contact with throughout waterways turning them into toxic bullets. These factors make this a very complicated pollutant since there is a vast spectrum of possible microplastics in the environment (Yu, 2020).

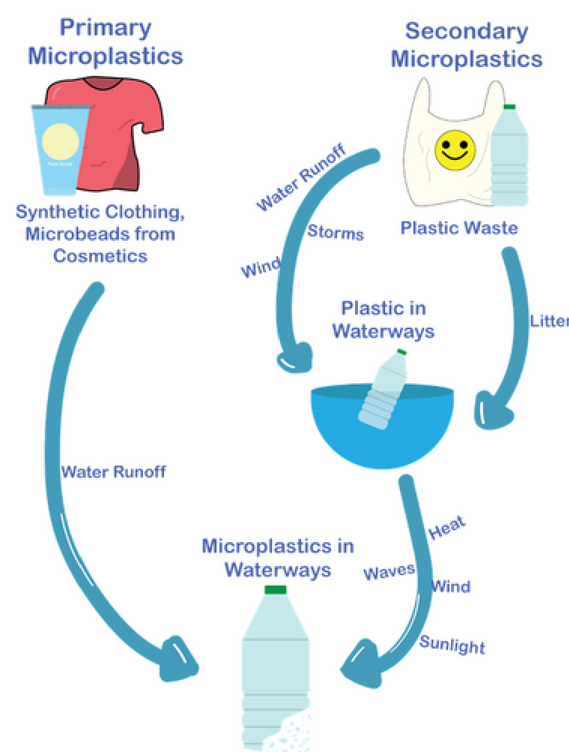

Figure 1: How Microplastics Enter Waterways

Due to the sheer amount of plastic in the Earth's oceans, the effects on organisms are beginning to be seen more clearly. Recently studies have even found microplastics in human stool (Yurtsever, 2019). Microplastics are being consumed by marine life and working their way up the food chain until they are eaten by humans (Nan, 2020).

Effects on Organisms

Research on microplastic pollution and its effects on organisms has only begun to accelerate relatively recently, a study published in 2020 noting that a whopping 80% of all articles on microplastics were published between 2016 and 2019 (Yu, 2020). On account of this, there is an exceedingly low amount of studies into how microplastics accumulation will affect humans specifically. However, studies of the effects of microplastic particles on smaller organisms from marine and terrestrial ecosystems are revealing that the effects are likely deadly. Thus, there should be significant concern over keeping the rate of microplastic pollution down to a sufficient level so that humans and other species may continue to live without being crippled by this highly dangerous pollutant.

Due to the small size of microplastic particles, they can easily be consumed unintentionally while eating, or mistaken for prey (Yu, 2020; Mercogliano, 2020). Organisms accumulate particles in their bodies over time, and when they are eaten by predators those particles are then passed on up the food chain to higher trophic levels (Mercogliano, 2020). Since a substantial amount of microplastic pollution occurs in the ocean, it is important to begin investigating the food chain of marine ecosystems. Generally speaking, the order of the marine food chain and the chain of microplastics accumulation from lowest to highest level is phytoplankton, zooplankton, filter feeders, predators, and apex predators (Mercogliano, 2020). Marine species, mostly from the higher trophic levels, are then consumed by land animals such as humans, bringing microplastics particles from the marine food chain into the terrestrial food chain (Mercogliano, 2020). Thus, what was at first an issue seemingly confined to the original environment of pollution now affects those beyond it.

A few important properties of microplastics make them extremely dangerous to organisms: their extremely small size, staying power, and ability to carry toxic materials. Being less than 5mm in diameter, microplastic particles can easily be ingested without being noticed, as opposed to macroplastics which can be seen with the naked eye without much effort (Charko, 2020). Not only the size, but also the shape of the particles factors into how they affect organisms. For example, debris can block the intestines, while sharper edged particles can penetrate the intestinal walls (Yu, 2020). As evidenced by the use of plastic components in surgical operations, plastic degrades extremely slowly in the bodies of organisms, and is estimated to have a lifespan which far exceeds that of the organisms it accumulates within (Waring, 2018). In addition to these two properties, microplastic particles often

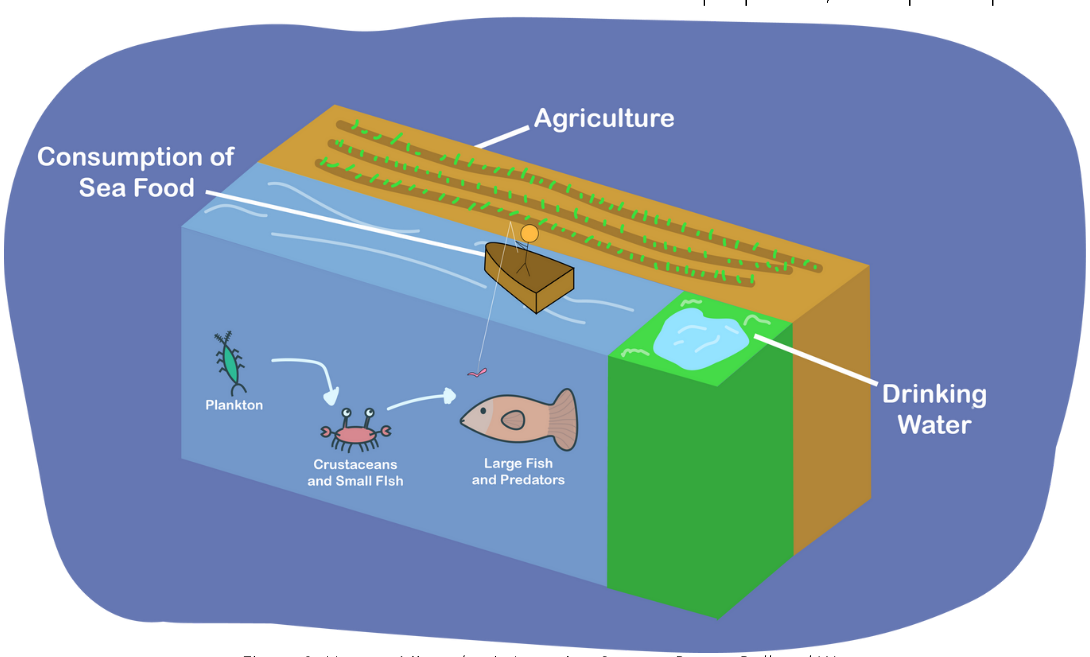

Figure 2: Human Microplastic Ingestion Sources Due to Polluted Waterways

contain additives such as plasticizers, flame retardants, and UV stabilizers, which can wreak havoc on the body (Yu, 2020). For example, Bisphenol A, used in polycarbonate production, can disrupt the human endocrine system with disastrous effects (Yu, 2020). In addition, microplastics have the capability of absorbing other, highly toxic pollutants such as heavy metals, pesticides, and pharmaceuticals (De-la-Torre, 2019). Since microplastic particles travel through the food chain from sea animals to land animals, they also act as a vehicle in transferring pollutants from the sea to land (Yu, 2020). When these properties are combined a massive danger to organisms is created; over time they will unintentionally ingest microplastics through the food chain, and the effects will not be seen until it is too late. Since plastic takes possibly thousands of years to degrade, these particles will not leave the food chain, and will be passed on from prey to predator, and parent to child. With no methods to rid organisms of the microplastics which plague them, the impacts of microplastic consumption are irreversible and will only worsen over time.

When a plant or animal accumulates microplastics within their body, usually through consumption of food, they begin to experience issues with their essential functions. Studies on many kinds of organisms, including both marine life and land dwellers, have shown that accumulation of microplastics can cause severe problems such as inhibition of movement, reproductive dysfunction, and developmental dysfunction. For example, brine shrimp have been observed to have reduced swimming ability when exposed to enough microplastic pollution over time, which made them more susceptible to being predated upon (Waring, 2018). Other kinds of marine life have experienced serious effects as well, such as microplastics entering the circulatory system through the gut in crabs, and bivalves undergoing oxidative stress and lysosomal perturbations (dysfunction in the body system which degrades cellular waste) (Ajith, 2020). In addition, reduced appetite, gut inflammation, reduced growth, and reduced reproductive output have been observed in many kinds of aquatic life (Royte, 2021).

As for land dwelling animals, a similarly diverse set of negative effects has been observed, with great overlap with those seen in marine life. Mice are often used as a model in studies on health risks in mammals, used to generate a prediction of how testing conditions would affect other mammalian species (Yu, 2020). In mice, microplastics accumulation was observed to lead to a weakened immune system, lower sperm count and abnormal sperm, and increased fetal mortality (Waring, 2018; Becker, 2021). Notably, research done on the effects on mammals were done through dosing lab mice with microplastics, but most of the observations of marine life were completely natural; marine life is being affected by this issue at a more evident rate than land animals (Becker, 2021).

With this information, the elephant in the room is clear: what are the effects on humans? As of now, there is minimal research on what exactly the accumulation of microplastics can do to humans, but by using mice as a general model for how microplastic particles affect mammals (Figure 3), humans will experience a similar range of effects as in smaller organisms once they ingest enough microplastic particles (Waring, 2018). Plastic particles have been found inside the human placenta, which suggests that they interact with the human reproductive system (just as observed in other terrestrial and marine species), but currently at a level which does not cause major negative

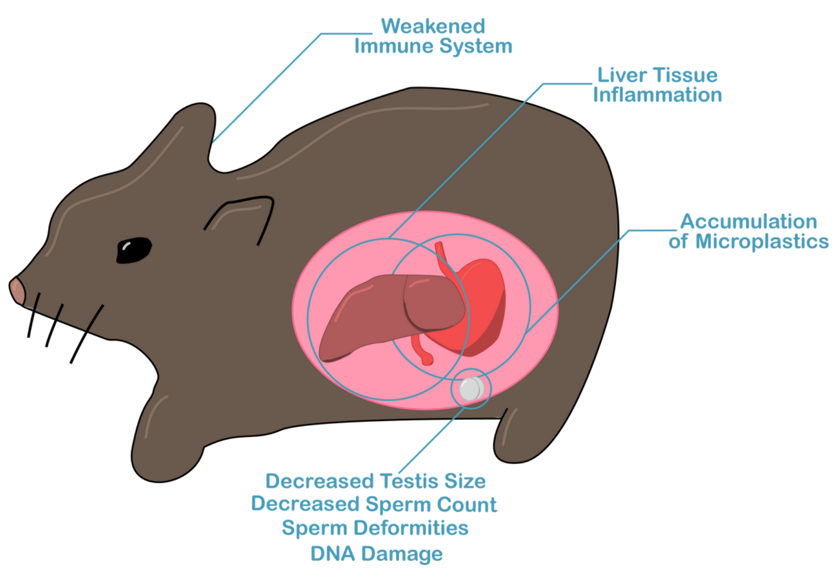

Figure 3: Effects of Microplastics on Mice

effects (Waring, 2018). It has also been observed that particles smaller than 150μm can enter the human circulatory system (De-la-Torre, 2019). As mentioned previously, microplastics can also carry highly toxic pollutants which we do know the effects of, which is cause enough to be alarmed about microplastics ingestion even with the present lack of knowledge (Yu, 2020). Fortunately there is still time to make change before humans are severely affected by microplastic pollution as many smaller organisms already are.

Despite the lack of information on many facets of microplastic pollution, there is information available on the rate at which humans and other species consume microplastics going through their daily lives. Studies show that on average, adults take in 883 microplastic particles per day, with children averaging 553 particles per day (Mohamed Nor, 2021). However, the range is extremely wide, being between 12 and 100,000 particles per day (Lim, 2021). Certain food groups have been observed to have high concentrations of microplastics including seafood, fruits, vegetables, and salt, while others had lower but still notable concentrations such as mineral and tap water, beer, and sugar (De-la-Torre, 2019; Mohamed Nor, 2021). The main link between all of these food items is that they all involve water in their production. If the level of microplastic pollution in waterways is not sufficiently regulated, humans will continue to consume a growing concentration of microplastics through their food. It does not help that the intestines and liver are particularly susceptible to accumulating microplastics over time, making the effects of blighted foods even greater (Mohamed Nor, 2021). In marine animals, it has been found that bottom dwelling organisms tend to accumulate more microplastics than surface dwelling species, likely due to particles sinking to the bottom of water bodies as they settle (Ajith, 2020). The rate at which marine species consume microplastics is not necessarily consistent, as some species like whales consume a much larger amount due to their filter feeding nature (Ajith, 2020). Different factors affect an organism's rate of consumption, but there is not much one can do to actively lower it.

Over time it will become more and more evident what the effects of microplastics on humans are as we continue to accumulate particles through the food chain, but this issue must be prevented before we reach this point. Since it is virtually impossible to remove microplastics from the human body once ingested, if the point of finally seeing the negative effects in humans is reached, it will be irreversible. The issue of microplastic pollution needs to be treated sufficiently while there is still time to prevent disastrous consequences for the human race and nature as a whole.

Port Phillip: A Bay in Need and Those Who Care

Port Phillip Bay is the largest shipping port in Australia. With an area of over 1,900 square kilometers, an average depth of 13 meters, and a coastline of 333 kilometers, this bay is only about 10,000 years old (Marine and Coasts, 2021). Port Phillip Bay, like many other bodies of water, is home to many unique species that are not found elsewhere. It is also home to Victoria's largest commercial ports and many popular recreational sites (Marine and Coasts, 2021). The bay's catchments have an area of almost 10,000 square kilometers, and range from rivers to storm drains. The largest of these catchments are the Yarra and the Maribyrnong rivers. These rivers flow through a heavily urbanized portion of Melbourne into the Northern section of the bay, transporting microplastics into the bay (Charko, 2020).

Figure 4: Port Phillip Location in Australia

Figure 5: Port Phillip Bay

Port Phillip Bay is one of many bodies of water affected by microplastic pollution. Every year, more than two billion microplastic fragments flow into the bay from the Yarra and Maribyrnong rivers alone. Variables that affect the amount of pollutants flowing into Port Phillip Bay are seasonal variations, rainfall, and litter traps. A study performed as part of EcoCentre's Clean Bay Blueprint found that beach litter at Port Phillip Bay was over forty percent nurdles, and over thirty-five percent miscellaneous microplastic fragments. These pollutants prove to be a major threat to Port Phillip Bay (Charko, 2020).

Port Phillip Bay falls under a wide variety of jurisdictions when it comes to its management and upkeep. Federal, state, regional, and local governments all have some responsibility for the management of the bay. The Department of Environment, Land, Water, and Planning has been leading the efforts for the bay's management. The Environmental Protection Agency of Victoria has been responsible for environmental health issues with regards to the bay. The primary concerns for the health of Port Phillip Bay are pollutants and pathogens that may endanger human health. Key priorities for the bay identified by the government of Victoria include: improving both understanding and appreciation for the bay's values, increasing collaboration and finding partnerships for maintenance, ensuring that the bay has ideal nutrients levels and reducing the levels of pollutants, reducing litter, minimizing risks to human health, conserving the habitats of marine life, and managing pests. These priorities are aimed at the full spectrum of problems that ail the bay (Marine and Coasts, 2021).

The Port Phillip EcoCentre is an organization devoted to taking care of and educating individuals on Port Phillip Bay. They are a not-for-profit organization that runs several education programs, including their "marine biologist for a day" program that teaches people about proper care for the beaches and waters of Port Phillip Bay. All proceeds raised by EcoCentre are funneled back into research (Lawes, 2017). EcoCentre is a crucial part of Victoria's "Port Phillip Bay Environmental Management Plan 2017-2027" (Marine and Coasts, 2021). This was done via EcoCentre's "Clean Bay Blueprint". This document is a summary of their research in which they provided recommendations for the best steps to take in protecting Port Phillip Bay. The research for this project included performing beach audits and water trawls to analyze the amounts of microplastics in Port Phillip and in its catchments (Charko, 2020). Working with partners such as waterkeepers is crucial to the EcoCentre's operations.

Figure 6: Port Phillip EcoCentre Team

Given that microplastic pollution often occurs in bodies of water, one of the most important groups involved is waterkeepers. Waterkeepers are individuals who fight for the cause of clean water, firmly asserting that it is a fundamental human right, and do so through holding polluters accountable for their actions and educating the public on how they can do their part in preventing water pollution (Who We Are, 2021). They are united by the Waterkeeper Alliance, a multi-national non-profit organization of more than three hundred waterkeeper groups which aims to bring individual waterkeeper groups together as one to fight for clean water worldwide, and provides funding to these groups so that they can do so (Who We Are, 2021). Operating in more than forty five countries, 1.1 million members and 2.5 million square miles of water covered, the Waterkeeper Alliance is the largest single force in keeping waters clean worldwide (What We Do, 2021; Who We Are, 2021).

The Waterkeeper Alliance has several campaigns which cover different facets of the overall fight for clean water, with the one most applicable to the issue of microplastic pollution being the Clean Water Defense campaign. This campaign works to protect, restore, and support clean waterways, and defend and enforce water quality laws even as laws are rolled back to serve corporate interests. In order to accomplish this, the Alliance has formed strong partnerships with experts in law, engineering, biology, hydrology, and economics, to cover all bases necessary to make cases for improved water protection law and maintain waterways. An extremely relevant initiative that acts as part of the Clean Water Defense Campaign is the Ocean Plastic Recovery Initiative, which aims to create plastic recycling facilities which not only recover plastic from bodies of water before they enter the ocean, but sort and bale the recovered plastic to be used in the manufacturing of new products (Campaigns, 2021). While it seems these facilities can only collect and recycle macroplastics currently, if a valid way to collect microplastics particles from water at a reasonably fast rate were to be discovered, this technique could be extremely effective in reducing microplastic pollution. Notably the Waterkeeper Alliance has not addressed microplastic pollution at the same level as macroplastics yet, likely because of the general lack of data on the topic. Due to the influence of the individual waterkeeper in local water politics and of the Waterkeeper Alliance in larger scale water politics, however, working with waterkeepers will assuredly be important in exploring ways to reduce microplastic pollution.

The Current Context of Microplastics Regulation

There are currently no official legal thresholds or regulations in place dedicated to addressing microplastic pollution in waterways. However, within the last decade development of microplastic regulation systems has begun worldwide. Awareness of microplastic pollution has also grown with organizations such as the United Nations addressing the issue. With an increase of awareness and research, regulations will continue to be created to address the issue of microplastics.

World Wide Regulation

The state of California is leading the world in terms of research into microplastic pollution and progression towards the implementation of legal thresholds for waterways and drinking water. To achieve their objective in establishing health-based guidelines for acceptable levels of microplastics in drinking water, the state of California ordered its Water Board to conduct a four-year statewide monitoring of microplastics in drinking water (Mosko, 2021). The United Nations has also recognized the growing issue of microplastics over the past few years. In 2014, the United Nations Environment Assembly (UNEA) identified microplastics as an emerging marine pollutant placing marine microplastic management on the agenda of several countries worldwide (Xu, 2020). Nations across the globe have their own types of aquatic pollution regulations with some limiting the overall quantity of all pollutants entering waterways while others go further and regulate the quantities of each specific type of water pollutant. These regulations are based on the potential harm and the quantity required to harm humans and the environment. For example, in the U.S there is the Clean Water Act and the regulation system of Total Maximum Daily Loads (TMDL's). These regulation systems set a standard for the amount of a particular pollutant that should enter a body of water within a given day (EPA, n.d.).

While laws and regulations specifically regarding aquatic microplastic pollution do not exist, a large number of nations have enacted laws that regulate specific forms of plastic pollution. Two of the most prominent plastic pollutants that countries have already cracked down on are plastic bags and microbeads in personal care products (PCPs). Some nations have completely banned plastic bags while others such as the U.S., Australia, and the UK have imposed a tax on them (Xanthos, 2017). Furthermore, countries including the U.S., France, UK, Netherlands, Austria, South Korea, Italy, New Zealand, India, and Sweden have all banned the use of microbeads in PCPs (Xu, 2020). In the U.S. in 2014, the State Government of Illinois enacted the first prohibition of production and sales of PCPs that contain microbeads, which subsequently led to the U.S. 'Microbead-Free Water Act of 2015' (Xu, 2020).

Regulations in the State of Victoria

While the state of Victoria does not currently have microplastic pollution regulations, Victoria has implemented water pollution and waste discharge legislation that influences the concentration of microplastics in waterways. Industrial facilities are required to have permits to legally discharge waste meaning that the EPA must approve of the waste that a facility wishes to dispose of (EPA Victoria, 2021). These permits are currently limiting the amount of waste being discharged into waterways, which would include primary microplastics from factories. Next, the EPA has administered guidance on waste management for industrial facilities, which requires facilities to prevent, reuse, and recycle waste whenever possible (EPA Victoria, 2021). This guidance issued by the EPA is another method that has reduced primary microplastic pollution in Australian waterways. Furthermore, clean drinking water regulations in the state of Victoria ensure that water suppliers and water storage managers provide safe and clean drinking water to all Victorians (Department of Health and Human Services, 2015). While these regulations do not specifically target microplastics in drinking water, they do reduce the risk of there being dangerous concentrations of microplastics in it. The state of Victoria has also enacted a plastic bag ban throughout the state, which has greatly reduced concentrations of secondary microplastics in Victorian waterways (Victoria State Government, 2019). Microbeads in personal care products have also been completely phased out of the cosmetics industry in Australia, minimizing the quantity of primary microplastics in water bodies (Chemical Watch, 2018). Finally, Australia's National Plastics Plan is intended to end all plastic fabric microfiber aquatic pollution by 2030, phase out polystyrene packaging material by the end of 2022, and target cigarette butt pollution (Sánchez, 2021; Mirage News, 2021). Overall, Australia's National Plastics Plan will be a large contributor to the reduction of aquatic microplastic pollution in Australian waterways.

Current Developments in California

California is leading the world in developing microplastic regulations in waterways and drinking water. In 2018 California passed The California Safe Drinking Water Act: Microplastics (SB-1422, 2018). This bill requires the State Water Resources Control board to adopt a definition of microplastics in drinking water required by July 1st, 2020, adopt a standard methodology in testing drinking water, testing for four years of microplastic contamination of drinking water, and reporting the results to the public, required by July 1st, 2021. California also passed the Ocean Protection Council: Statewide Microplastics Strategy bill (SB-1263, 2018) in the same year. This bill requires The Ocean Protection Council to adopt a strategy to tackle the concern of microplastics on the ocean's health. Including the study of developing risks of microplastics, standardization of methods for sampling, detecting, and characterizing microplastics, risk assessment of exposures of microplastics to organisms, and research of approaches for reducing the introduction of microplastics into marine environments. These laws have rapidly expedited research in the field with new information on the pollutant constantly being shared.

The Southern California Coastal Water Research Project has taken the leadership of the completion of these mandates. In September of 2021, they announced their research findings in a webinar, Microplastics Health Effects Workshop, including their strategy on the creation of a threshold for microplastics. They addressed the complications of microplastics and one of the looming questions about them: do different types of microplastics affect species more than others? Their conclusion was that more data was required to find a correlation. The one correlation that was found is that larger microplastics affect species more dramatically in a smaller quantity and smaller microplastics affect species more dramatically in a larger quantity. They also addressed the creation of a threshold for an aquatic environment. Their end method was the use of multiple thresholds, using a tier system (Figure 7). Each tier has a different level of

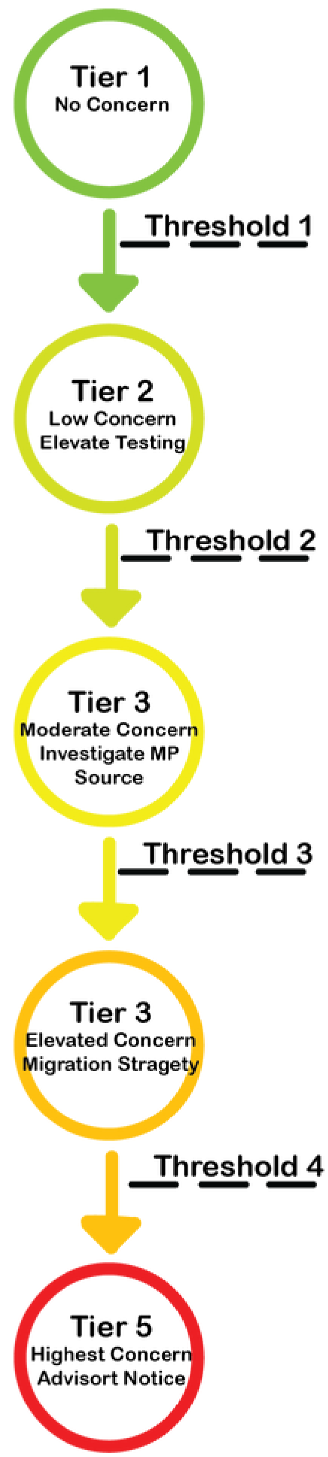

Figure 7: California Tiered Threshold

severity with Tier 1 being no concern and Tier 5 being of highest concern. They next addressed how to derive a microplastic threshold based on the health of animals in the ecosystem. They created these thresholds using a species sensitivity distribution, creating this distribution with 22 manuscripts, 297 data points, and 16 species. A threshold was created for food dilation and tissue translocation; the two main ways microplastics affect marine life. An expert was then tasked with determining the confidence in the strategy and reported he had high confidence in the threshold method. The final part of the webinar focused on microplastics in drinking water. Its task was to determine thresholds for microplastics in drinking water to keep the residents of California safe. For these thresholds, they also used a multi-tiered approach. Since data was limited on the consumption of microplastics in humans, they came to the assumption that twenty percent of microplastic consumption comes from drinking water. This assumption was used to determine a TMDL that could then be used to determine the number of microplastics entering the water, measured in nanograms per liter. A number of 6.4 nG/L was given as an extremely rough estimate not to be used for policy making. More data is needed to be able to create a more confident level. To measure the quality of drinking water a sampling volume of three thousand liters was determined necessary. The developments in microplastic threshold creation are still in their infancy but with the increase in studies, it is hopeful that more exact and accurate threshold numbers will be available in the next couple of years.

03 Methods

This project was designed to help the Port Phillip EcoCentre establish a microplastic pollution threshold for Port Phillip Bay, contributing to the emerging effort to fight microplastic pollution. In order to make a model for implementing this threshold, we had to identify the most important elements involved (Figure 8). The first of these elements is a reliable and logistical method for sampling the pollutant, as a standard for this process ensures consistency in the sampling results. Without reliable data on the level of microplastics in the water, there is no use for a threshold. The second of these elements was a method for creating the threshold value for this pollutant. In this case a system based on species sensitivity data was determined to be the best method to find threshold values as it puts a focus on determining a value to protect a majority of species in Port Phillip Bay. The last element identified was a process of enforcement and prevention to hold polluters accountable when they breach the threshold and to work to keep plastics from entering the bay in the first place. These elements together comprise our proposed model to regulate the microplastics within Port Phillip Bay. In order to perform the research necessary for the creation of a microplastic pollution threshold model for Port Phillip Bay, we employed methodologies including expert interviews and literature review. In addition, we also followed the advancements in the state of California towards their development of a microplastic pollution threshold during the period of our project studies. Our inability to travel to Australia due to COVID-19 restrictions lead us to design our methodology for a remote environment.

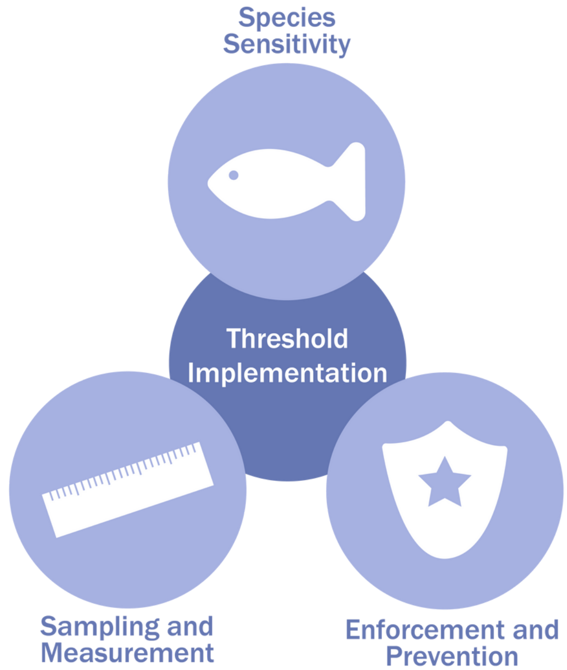

Figure 8: Threshold Implementation Model

California Case Study

To properly stay informed on the most recent developments worldwide, our first method was to perform a case study on the developments within the state of California on their microplastic threshold creation process. To date, California is the world leader on developing proper microplastic pollution regulation with their mandate to the Ocean Protection Council to adopt a strategy for combating the concern of microplastic pollution in California's waterways. This case study provided critical information about appropriate approaches and considerations necessary for designing a model for a microplastic pollution threshold. Through this study we also gained necessary context on assessing the toxicological risk of microplastics on species at specific concentrations, criteria for sampling, and the design of a threshold model. This formed the groundwork for our design and influenced our literature review and interviews.

Expert Interviews

Another valuable method employed to gather information for this project was to conduct interviews with professionals in a variety of fields. We chose to interview individuals involved in each of the three overarching aspects of our threshold implementation model including sampling and measurement, species sensitivity, and enforcement and prevention. We sought to obtain relevant professional knowledge, insight, and perspectives from the interviews we conducted, and apply what we learned to our model. The three types of individuals we interviewed were waterkeepers, EPA officials, and knowledgeable university professors. We found our interviewees by searching the internet for professionals with relevant backgrounds in the U.S as well as in Australia, and reached out to them via email. Our sponsor, the Port Phillip Ecocentre, was also able to help us secure interviews amongst their contacts. The interviews were conducted via Zoom and lasted between thirty minutes to one hour. For most interviews, two of us were the facilitators and two of us were the notetakers. For each interview, we alternated who was in the facilitator role. Overall, our interviews followed a semi-structured format since our interviewees had valuable knowledge that we did not anticipate learning about prior, and keeping the interview process organic allowed us to change our questioning based on the information received.

One of the three types of professionals we interviewed was waterkeepers. By interviewing waterkeepers, we became more familiar with potential enforcement stakeholders as well as viable microplastic pollution sampling methods. Examples of standardized interview questions we asked waterkeepers included: "How have you been involved with working on microplastic pollution in the past?", "What partners and organizations do you work with in order to enforce water regulations?", "What influences your selection of monitoring methods?", and "What roles do you have in the development of new environmental law?" (Appendix B). Furthermore, we tailored specific interview questions for each waterkeeper we interviewed based on our research into their specific role and background. As an example, we interviewed Mike Jarbeau, the Narragansett Bay Riverkeeper, who we learned has experience with boat support for microplastic research. Therefore, a specific interview question we asked him was: "We were told by your colleague that you have provided boat support for microplastic research at URI, could you tell us about that?" (Appendix G).

Another type of professional we interviewed was a U.S. EPA official. By interviewing a U.S. EPA official, we gained more knowledge on how a microplastic pollution threshold would potentially be enforced and the potential parties involved in the enforcement process. Additionally, we became more familiar with the many complexities that exist when trying to regulate a seemingly omnipresent pollutant such as microplastics. Some examples of standardized interview questions we prepared for EPA officials were: "How does the EPA respond to aquatic pollutants of emerging concern before there are legal thresholds and triggers?", "What do you do when a legal threshold is breached?", "How have you been involved with microplastic pollution in the past?", and "Are you familiar with species sensitivity distribution?" (Appendix C). In addition to these standardized interview questions, we created specific interview questions for the EPA official we interviewed based on our research into their specific role and background. We interviewed Tom Wall of the U.S EPA who is also an environmental scientist. Therefore, a specific interview question we asked him was: “How would a threshold like this be enforced since a majority of pollution comes from non-point sources and not one entity?” (Appendix I).

The third type of professional we interviewed was knowledgeable university professors. By interviewing university professors with relevant backgrounds and research experience, we were able to obtain useful knowledge in the areas of sampling and species sensitivity. We used only two standardized interview questions for university professors, which were: “Could you tell us about your past work?”, and “Is there anything else you consider relevant to this project that you would like to add?”. We found that because the university professors specialized in such specific areas of study, we couldn’t ask them standardized questions. Because of this, the overwhelming majority of interview questions we asked university professors were specifically tailored to their backgrounds and areas of study. For example, we interviewed Dr. Graeme Allinson of the Royal Melbourne Institute of Technology, who has experience with water sampling for microplastics and stormwater management. Therefore, an example of an interview question we asked him is: “How would you account for inconsistencies created by stormwater runoff in regular sampling of an aquatic pollutant?” (Appendix E). Another example is our interview with Professor Steven J. Oliver of Worcester State University, a professor of marine biology who has experience with species sensitivity. Thus, an example of an interview question we asked him is: “Are there any families or genera that you would generally think would have low microplastic tolerances?” (Appendix F).

Literature Review

Our final method used for this project was literature review. This method was utilized to fill information gaps in our project that could be answered with published research, and was a crucial method for all three of our objectives. Our literature review consisted of scholarly journal articles, academic books, and online databases to answer the questions posed by our project.

For the sampling and measurement objective, we investigated several sampling methods, including beach audits, water sampling, sediment sampling, and bioindicator species sampling. For each sampling method, we had three key research questions. The first of these questions was how microplastic samples should be collected. We investigated both the feasibility of each sampling method, as well as the quality of the data that it produces. Secondly, we investigated the means of separating the microplastics from the sample, once again assessing the feasibility of the different methods of doing so. Finally, we investigated the means of measuring the microplastic concentration in the sample. This process includes both verifying that the particles found in the samples are microplastics and measuring the amount of microplastics found in the samples. In addition to these three main research questions, research into each method revealed additional questions to be answered. For example, one of these questions was “Which species would make good bioindicators?”

For species sensitivity, many avenues had to be investigated to determine the validity of using a species sensitivity model to make a microplastic pollution threshold. Among these were the use of well studied foreign species in place of those native to Port Phillip Bay and the complexity of the variations in microplastic sizes. Furthermore, literature sources were used to identify greater taxa groups that are likely to have low microplastic tolerances for use in the species sensitivity model.

For enforcement and prevention, we learned about current regulations on both macroplastics and microplastics. We also investigated the role of organizations including the Waterkeeper Alliance and the Victorian and U.S. EPA in the creation of better pollution regulation. There were several key aspects of our enforcement model that required further research of published literature. The first of these was research into methods for preventing microplastics from entering the bay in the first place. Another problem that required literature review was learning how to appropriately conduct risk assessment, which we deemed crucial for designing our enforcement model.

04 Findings

The first section of our findings pertains to the culture and history of Port Phillip Bay and the surrounding region. Following this there are breakdowns of the methods for sampling and measurement, species sensitivity, and enforcement and prevention elements. Finally, there is a breakdown of GIS, a promising field for tracking pollution via satellite data.

Interconnection Between The Bay and Upstream Populations

Port Phillip Bay offers a multitude of ecological, recreational and cultural values to the city of Melbourne. The Bay underpins the lifeblood of Melbourne and its surroundings, with over four million people residing within its catchment areas totalling to 9790 square kilometres (Baker et al., 2016; Department of Environment, Land, Water and Planning, 2016). Providing a range of ecosystem services of high economic benefit to the city of Melbourne, the biodiversity in the Bay contributes AUD$11 billion to the local economy through nitrogen filtration alone (Department of Environment, Land, Water and Planning, 2016). The ecosystem diversity within the study site encompasses saltmarsh, mangroves, seagrass, rocky reefs and soft sediments, each being a crucial asset to the city of Melbourne through regulating, provisioning and supporting services (Eigenraam et al., 2016; Commissioner for Environmental Sustainability Victoria, 2016).

Over 90% of the Bay's species are endemic to the region (Port Phillip and Westernport Catchment Management Authority, 2004), with the management of the biodiversity complicated by the interconnection with Victoria's capital city at its north end, and the state's second largest city, Geelong, at its west (Baker et al., 2016). Since European settlement, 99 known marine species have been introduced to Port Phillip Bay (Hewitt et al., 2003), including the Northern Pacific Sea star, Japanese kelp and European fan worm threatening the ecosystem health (Commissioner for Environmental Sustainability Victoria, 2016). Due to increased shipping traffic and aquaculture, the Bay is potentially one of the most disturbed and invaded marine ecosystems in the Southern Hemisphere (Hewitt et al., 2003). The seven upstream bioregions that converge at the Bay have also undergone significant disturbances since European settlement, degrading the ecosystem health of the region (Port Phillip and Westernport Catchment Management Authority, 2004). Of particular concern are the shellfish reefs in the Bay (Eigenraam et al., 2016; Commissioner for Environmental Sustainability Victoria, 2016) which are complex systems comprised of oysters, mussels and other shellfish that act as important filter feeders, food sources and shelter for other marine species in addition to carbon sequestration (Eigenraam et al., 2016; Commissioner for Environmental Sustainability

Victoria, 2016). Before European settlement, these habitats provided crucial food sources for Indigenous Australians, and are now "functionally extinct" due to historic commercial harvesting by settlers (Eigenraam et al., 2016). These habitats in Port Phillip Bay are at even more pressure due to the risks posed by microplastics to the filter feeder species at the benthic level, which have been found to have higher accumulation rates of microplastics than other organisms along coastlines (Thushari et al., 2017; Griffin et al., 2018). Combined with the shallowness of the Bay, with less than half of the area being less than 8 metres deep, and its particularly narrow entrance the potential for bioaccumulation and pollutant accumulation is considered high (Baker et al., 2016).

Of the upstream bioregions that feed into the Bay catchment, 25% of the native vegetation quality has been estimated to be in poor condition (Port Phillip and Westernport Catchment Management Authority, 2004), suggesting that the ecosystem services for regulating water health upstream will be of concern in the future. The upstream bioregions contain different levels of protection for different vegetation classes, and management strategies vary by land tenure in public, private and government managed lands (Port Phillip and Westernport Catchment Management Authority, 2004). Of the 1860 native plant species and 616 vertebrate faunal species, 296 and 128 respectively are endangered, but all contribute to the region's highly biodiverse ecosystem Port Phillip and Westernport Catchment Management Authority, 2004. Parts of the Yarra and Lerderderg rivers have been identified of high environmental and cultural significance, with major wetlands at Port Phillip and surrounds being internationally recognised under the RAMSAR Convention (Hale, 2020).

Cultural context of Port Phillip Bay

Port Phillip Bay contains a rich cultural history prior to European colonisation (Eidelson, 2014; State of Victoria Department of Jobs, Precincts and Regions, 2019). The Woiwurrung and Boonwurrung people of the Kulin nation have age-long connections to the Melbourne area. The Boonwurrung word for Port Phillip Bay, Nerm or Nairm, entails a spiritually affirming tale, where the area was once land that provided for kangaroo hunting and social events (Eidelson, 2014; State of Victoria Department of Jobs, Precincts and Regions, 2019). Later, when Nairm became flooded, the sea level transgression was suggested to be a manifestation of anger from ancestor spirits; this is known as a time of chaos in Boonwurrung culture (Eidelson, 2014). Today, evidence of this flooding supports these stories, where Nairm sat further inland from the mouth of the Yarra River about 7000 to 10,000 years ago, which emptied into the ocean (State of Victoria Department of Jobs, Precincts and Regions, 2019. A complex network of wetlands surrounded by health, dunes, woodlands, salt marsh and beaches formed a dynamic system, and these waterways formed the boundaries between clans (Eidelson, 2014).

The site, rich in food resources in the form of seafood, animals and plants, provided for the Aboriginal people across the Bay (Eidelson, 2014; State of Victoria Department of Jobs, Precincts and Regions, 2019). The Yalukit Willam, known as the River People, are a Boonwurrung clan most closely connected to the Bay, where they fished and hunted sustainably with their allotted pockets of land, and met with others of the Kulin nation, providing for their livelihoods (Eidelson, 2014; State of Victoria Department of Jobs, Precincts and Regions, 2019). There estimated to be about 30 tribes in Victoria before European occupation (Eidelson, 2014), with the Yalukit Willam occupying the coastline of the present Bay, from St Kilda to Williamstown, Port Melbourne, South Melbourne and Prahran Eidelson, 2014; State of Victoria Department of Jobs, Precincts and Regions, 2019.The area was also a place for regular social activities, trade, ceremonies and judicial events for the Kulin nation (Eidelson, 2014). Today, many shellfish middens remain around the Bay (Hobsons Bay Libraries, 2015) as evidence of the Yalukit Willam's highly efficient and sustainable farming and fishing techniques (Eidelson, 2014).

In 1835, the British government rejected the Batman's treaty that John Batman and John Fawkner proposed, which outlined that Indigenous people had the right to their land, and that they could exchange it for rations and other resources (Eidelson, 2014; City of Yarra, 2021). Instead, the City of Melbourne was claimed as "terra nullius" so that the land could be owned by the British government and be sold, sparking an influx of settlers to purchase land (Eidelson, 2014; City of Yarra, 2021). This eventually forced the Boon Wurrung people to retreat to Mordy Yallock (presently known as Mordialloc) after their populations fell by 90% due to the cultural invasion (Eidelson, 2014).

Today, the Port Phillip area remains a life force the Indigenous people of Melbourne (Eidelson, 2014; State of Victoria Department of Jobs, Precincts and Regions, 2019). Bunjil, the eagle totem to the Boon Wurrung people, is believed to be protecting the waterways (Eidelson, 2014). The site is known as the land of Bunjil, to which all visitors must obey Bunjil's laws and not to harm the children or the land (Eidelson, 2014), emphasising the need to mitigate the invisible threats to this sacred land. In stark contrast to the current government's position to view the study are as a resource to be tabulated (Eigenraam, 2016), as is the dominant Western paradigm (McGregor et al., 2020), the First Peoples' understanding of the land need to be considered in decision making to ensure Indigenous environmental justice. Water management not only needs to ensure equitable access as specified by the United Nations, but also be considerate of the ecosystem as a "living entity with rights" of its own (McGregor et al., 2020). Future campaigns on microplastic management should consider these elements to connect citizens to their environment to not marginalise Indigenous Australians' understanding of the land, as well as considering any uses of the marine resources by First Peoples that may not be protected under legislation. For the upstream catchments, Indigenous peoples' management of the inland waters have received little to no legal recognition of their efforts until the 2017 "Yarra River Protection Act", which treats the Yarra River as a living entity to be protected, while conferring the river "an independent voice" by a statutory advisory body comprised of Indigenous members (O'Bryan, 2019). The effectiveness of this Act has yet to be proven as it is quite recent, and does not give any legal status to the Yarra River, or its representatives, in court for any environmental damages (O'Bryan, 2019). The invisible threat of microplastics, therefore, cannot be held accountable by the council formed under this Act, and calls forth a greater need to shift to a more inclusive future towards Traditional Owners in the context of water management, both upstream of Port Phillip Bay, and within Nairm itself.

Approaches to Sampling and Measurement

	Beach Audits (Method used in Clean Bay Blueprint Study)	Water Trawling	Bioindicators	Sediment Sampling
Water Column Level	All	High	Mid	Low
Accessibility	✓			
Community Engagement / Outreach	✓		✓	
Micro-FTIR Analysis Possible	✓	✓	✓	✓
Direct Water Concentration Data		✓	✓	
Other	Quick Results	Large Area Sample	Filters Water	Historical Data

Figure 9: Sampling Methods Criteria

Water Sampling and Measurement

Water sampling involves measuring the concentration of positively buoyant microplastics in surface waters of the bay. To obtain a measurement from a sample, three processes must take place. Firstly, a sample must be collected and particle debris must be separated from the sample (Hale, 2021). There are several methods for completing this first process including large sampling methods such as water trawls and small sampling methods involving the filtration or centrifugation of a small water sample (Hale, 2021). Secondly, microplastics must be separated from other particle debris (Hale, 2021). Thirdly, the amount of microplastic particles must be quantified (Hale, 2021). Once the quantity of microplastic particles in the sample is known, their concentration in the sample may then be determined by dividing the number of microplastic particles by the volume of the water sample (Frias, 2019). This calculation will yield the value for the concentration of microplastics in the sample with units of particles per unit volume (Frias, 2019). In some instances, based on the sampling method, a calculation for estimating the volume of water in the sample is required to calculate the concentration value (Frias, 2019).

While water sampling might seem like a flawless method for analyzing surface water for positively buoyant microplastics, there are several environmental factors that must be accounted for. Weather and environmental conditions can have a dramatic impact on the concentrations of microplastics throughout a body of water (Hale, 2021). These types of conditions can yield unrealistic readings of microplastic concentrations in water bodies that do not accurately represent normal conditions. Weather conditions such as rainstorms have been found to sharply increase the quantity of microplastics in water bodies (Hale, 2021). A study conducted in the Cooks River estuary in Australia found that after two days of heavy rain, the concentration of microplastics increased from 400 particles/m^3 before the storm to up to 17,383 particles/m^3 after the storm, a 40-fold increase (Hitchcock, 2020). Furthermore, other environmental conditions such as varying concentrations throughout different depths, shifting currents and tides, basin morphology, and weather patterns can all potentially have significant impacts on microplastic concentration levels (Hale, 2021). With this being said, all of these factors must be taken into consideration when conducting water sampling. If water sampling is to occur it should take place under conditions with calm waters, and not immediately after a rainstorm. This would ensure the most accurate measurements are obtained.

Using water trawls is one of the most viable methods for collecting particle debris from surface waters. Water trawls are large fine nets that are towed behind a boat and dragged under water to collect large quantities of particle debris (Figure 10). Compared to other water sampling methods, using water trawls allows for sampling large volumes of water at a time. Sampling large volumes of water is ideal because large samples provide a more representative measurement of the concentration of microplastics in a body of water compared to collecting small water samples for lab processing (Hale, 2021). Changes in weather and varying environmental conditions can easily influence small volume water samples making them inaccurate compared to larger volume samples (Hale, 2021). Furthermore, water trawls can be dragged several meters below the surface of a water body where microplastic concentrations are higher compared to the surface layer of a water body, where small volume water samples are generally taken (Hale, 2021). Sampling the water several meters below the surface is beneficial because it also ensures that any microplastic concentration measurements obtained are more representative of the environment of marine life as most aquatic organisms live significantly deeper than the surface layer. There are two means of determining the volume of water filtered through a trawl or net while sampling. The first of which involves simply multiplying the area of the mouth of the net by the distance traveled during the tow, which can be computed from GPS start and stop positions (Frias, 2019). The second method involves using a flowmeter with the net and applying its appropriate formula to calculate the volume of water filtered (Frias, 2019). It is recommended that both techniques are used as each can yield very different results (Frias, 2019). By using both techniques, each of their results can be compared and considered (Frias, 2019). All calculated volumes should be presented in units of liters.

Figure 10: Water Trawls

After the collection of particle debris is complete, it must then be brought to a lab for the chemical digestion process. Using chemical digestion to dissolve organic materials in the particle debris is an ideal lab technique for obtaining solely the microplastics in the debris. Microplastics are theoretically the only non-organic material in particle debris meaning that chemical agents can be used to digest all organic materials so that only microplastics remain. Compared to other lab techniques for obtaining microplastics from particle debris, chemical digestion is one of the most widely known and accepted techniques as it has proven to be straightforward and effective (Frias, 2019; Hale, 2021). The chemical digestion of organic materials is typically done by adding a solution of KOH 10% (ratio 1:3) to the particle debris and keeping it at 40 C until either all organic material is dissolved, or 72 hours have passed (Frias, 2019). If there is still organic material present, a solution of KOH 10% (ratio 1:3) can be added and the particle debris can be kept at 40 C until either all organic material is dissolved, or 72 hours have passed (Frias, 2019). If organic material remains present, density separation can be conducted to separate any remaining organic material from the microplastics so that the microplastics can be obtained (Frias, 2019).

Once the microplastics have been collected from the particle debris, micro-Fourier Transform Infrared spectroscopy (μ-FTIR) can be used in the lab to determine the quantity of microplastics obtained. μ-FTIR is one of the most effective ways of finding the number of microplastic particles obtained as it is less expensive, less time consuming, and is more easily available compared to other lab analysis techniques (Frias, 2019). μ-FTIR is based on the samples' absorptions of infrared radiation, with every chemical having a unique spectral signature that acts similarly to a fingerprint for the identification of that chemical. Additionally, the concentration of a given chemical in the sample can be calculated based on the height of the absorbance peak (Chen, 2015). The greatest advantage of using this technique for microplastic analysis is that it requires very little sample preparation. Additionally, μ-FTIR does not destroy the samples during the testing, allowing for other tests to be performed on the samples if necessary (Harrison, 2012). Once the number of microplastic particles obtained from the water trawl sample is known, its concentration in the sample can be calculated by dividing the number of microplastic particles by the calculated value of the volume of water filtered through the trawl (Frias, 2019). The concentration value obtained should be in units of particles of microplastics per liter of water.

Sediment Sampling for Measuring Microplastic Pollution

Sediment sampling is a microplastic sampling method very similar to beach audits, with the major difference being that sediment samples are collected from sand under water rather than on beaches (Prata, 2019). These samples can be collected with any kind of scoop, but samples from lower depths require precise equipment that won't leak during retrieval. This equipment is most often operated vertically from a wading boat and includes large scoops called dredges, and coring devices, which can sample a vertical column of sediment (U.S. EPA Lab Services, 2020). Coring devices are particularly important: by taking a sample that consists of several layers of sediment, historical data of the sampling area can be gathered (U.S. EPA Lab Services, 2020). Since there is so little historical data on the level of microplastics in water worldwide, if this knowledge gap can be filled it could have great implications on future research.

The methods used to process and analyze these samples are largely the same as those used in beach audits. Initially the samples are filtered and sorted, and in the case of measuring for microplastics concentration, the clean samples are analyzed using μ-FTIR and μ-Raman spectroscopy to gain a measure of particle quantity in the sample (Prata, 2019). Naturally, this method is used to gain data on the concentration of negatively buoyant microplastic particles in the lower water column. On account of this unique attribute and the ability to use a coring device to collect microplastic concentration data relating to the past, sediment sampling has a place in any robust sampling plan.

Beach Audits for Measuring Microplastic Pollution

Conducting beach audits may be considered as a method for quantifying positively, neutrally, and negatively buoyant microplastic pollution in Port Phillip Bay (Charko, 2020). A common type of beach audit is one that involves taking samples of sand from a beach, separating the microplastics from the sand sample, and quantifying them. Typically, samples of sand are collected from targeted locations across a selected beach using either shovels, trowels, or spades. Next, a combination of sieving, filtration, density separation, and dissolving of natural organic materials is conducted to separate the microplastic particles from the sand samples. Finally, once the microplastic particles are obtained from the samples, they are commonly quantified by being massed, counted individually under a microscope, or through the use of μ-FTIR (Masura, 2015).

Another common type of beach audit, such as those conducted by local community group volunteers, not-for-profits, and education institutes alongside Port Phillip EcoCentre officials during the

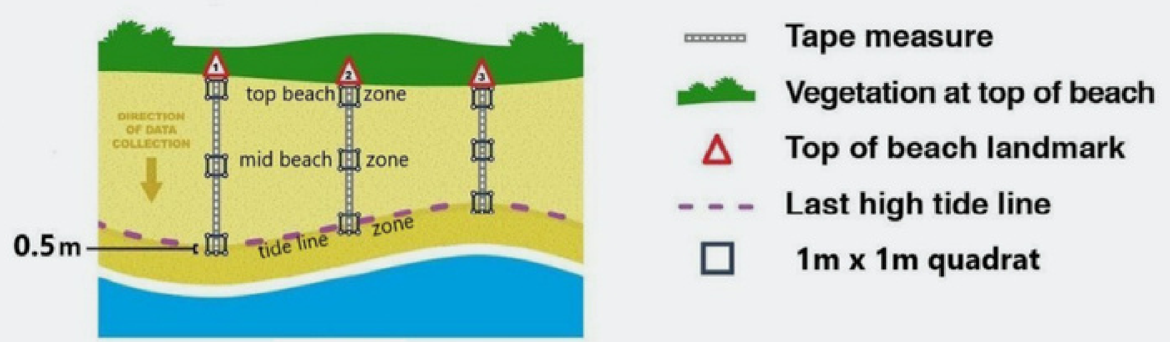

Figure 11: EcoCentre's Beach Audit Method
From: Clean Bay Blueprint

EcoCentre's Clean Bay Blueprint study, is less complex and does not involve laboratory processing. This type of beach audit involves recording the visible microplastics on the surface of the sand. During Port Phillip EcoCentre's Clean Bay Blueprint study, they conducted beach audits where data was collected from three transects across a beach located at the widest, central and most narrow sections of beach (Figure 11). Data was collected from three quadrats in each transect and each quadrat measured 1m by 1m. Each beach audit was typically conducted by 2 to 3 people in under an hour. These beach audits provided the EcoCentre with valuable data allowing them to better understand pollution levels of beaches, pollution levels of the water, which beaches and catchments in the bay area are the most polluted, movement patterns of microplastic pollution, and the types of microplastic pollution on beaches. Overall, this type of beach audit is significantly less time consuming and much more cost effective (Charko, 2020).

Mussels as Bioindicators and Water Filters

Mussels are commonly used as a bioindicator because of their high filter-feeding activity (Kumar, 2021). Shellfish such as these mussels are already being used to help reclaim damaged ecosystems and monitor other pollutants, and could easily be utilized to measure microplastics particles (Griffin, 2020). Bivalves, including mussels, filter bacteria, algae, microplastics and most other microorganisms and pollutants out of their surrounding area, with adult mussels filtering up to 15 gallons of water a day (Toussaint, 2021). Mussels are a high-tolerance species, meaning they are not significantly harmed by the plastics they take in as part of the filtering process (Toussaint, 2021). They can be analyzed through one of two main methods: analyzing the tissues inside of them or by measuring their pollutant-filled waste (Toussaint, 2021; Vartan, 2020).

Since mussels don't have a liver, pollutants concentrate within them over time until their levels are at equilibrium with the water they live in (Vartan, 2020). This means their tissues make for accurate snapshots of the state of pollution of their living environments, and can be used as valid measurements (Vartan, 2020). Since its conception in 1976, the Mussel Watch (MW) program in the U.S. has taken advantage of this property of mussels to measure for pollutants in bodies of waters across the entire United States, notably including both saltwater and freshwater sites (NCCOS, 2020). The primary method of Mussel Watch is to cage mussels and submerge them in water for a standard amount of time before collecting them for analysis, MW doing so for 3 months during a consistent annual period on a per-site basis (Vartan, 2020). Caging the mussels reduces the opportunity for variability in data collection by adding a degree of control over the mussels while also protecting them from predators (Vartan, 2020). If these mussels could be predated on, it would put microplastic particles back into the food chain and be counterintuitive to the cause (Toussaint, 2021). These cages are suspended in the middle of the water column where mussels live naturally, and can primarily be used to measure the concentration of neutrally buoyant microplastics in an area's water. After the 3 months is up, the mussel cages are collected and the mussels' tissues are scraped into a large blender-like machine and made into "smoothies" (Vartan, 2020). These samples are then analyzed to check for the presence of about 20 heavy metals and 150 organic compounds (Vartan, 2020). In order to attain data on the amount of microplastics within one of these samples, first the organic material must be digested using an enzymatic purification protocol (Kumar, 2021). This leaves behind only the inorganic material of the sample, including microplastic particles. Next, the microplastic particles are sorted by size through a filter, which separates particles >50μm and <50μm (Kumar, 2021). Particles >50μm being analyzed with FPA-based μ-FTIR, and particles <50μm being analyzed with micro-Raman spectroscopy (μ-Raman) (Kumar, 2021). Through these methods, particles can be detected and characterized, and a final number of particles present can be found.

Although mussel waste analysis is a less established method than tissue analysis, it is an emerging new method of measuring microplastics (Toussaint, 2021). This measurement method is also showing promise as a microplastic removal method in aquatic environments (Toussaint, 2021). As filter feeders, mussels ingest much more than is edible to them, and they simply excrete most of the waste they take in as a compact package (Toussaint, 2021). This waste includes microplastic particles they consume that don't become stuck in their tissues. The collection of their waste makes it easier to remove microplastic particles from water, which otherwise is a tedious and wasteful task (Toussaint, 2021). For example, when researchers try to use fine sieves to collect microplastics from water, they often pick up a lot of unintended materials and marine life (Toussaint, 2021). The use of mussels circumvents this issue and produces cleaner microplastic samples that are easier processed and analyzed.

The waste of these mussels, containing microplastics and other pollutants, can be collected as it sinks using nets with receptacles (Toussaint, 2021). This waste then can be either analyzed or disposed of accordingly. This method, just as with tissue sampling, would involve keeping mussels and their receptacles in cages so that predators can't eat them (Toussaint, 2021). Cages made with separate upper and lower chambers can be used for this method, with the mussels being on top and the waste collection mechanism on the bottom (Toussaint, 2021). Lab testing has been done to measure the efficiency at which mussels filter microplastics, with the results showing great promise for practical use. One lab test in particular concluded that each mussel filtered more than 250,000 microplastics particles per hour (Toussaint, 2021). Approximately 25% of all the particles in the test environment were filtered (Toussaint, 2021). This useful filtering property of mussels is already being implemented to monitor water for other pollutants such as heavy metals (Toussaint, 2021) (Appendix J).

Monitoring microplastics with mussels produces reliable results, but this method has a few notable downsides. The first is that in order to produce a reliable sample, mussels must be submerged in the waters of a sampling site for a substantial amount of time. Mussel Watch requires samples that are submerged for a three-month period, and in addition to that, time is needed to transport and process the samples before results can be found (Vartan, 2020). This could prove inconvenient for waterkeeping organizations which desire to consistently sample local waters and provide updated data often. The second downside of this method is that a particularly large amount of effort is involved due to the number of steps in the process. Mussels need to be acquired, transported, caged, submerged, collected, transported to a lab, and then finally analyzed. Each of these steps requires a great deal of time and effort. Although, judging by the success of Mussel Watch, it is certainly possible to attain a sufficient level of volunteer help to accomplish them through outreach.

Analyzing Mussel Watch's Monitoring System

Mussel Watch is one of the world's largest and most accomplished water monitoring operations using bioindicators, and there is a lot to learn from the way in which it operates in implementing a mussel-based water monitoring system for microplastics. While originally funded by the U.S. EPA from 1976-78, the program was revived in 1986 by the National Oceanic and Atmospheric Administration (NOAA) and has been powered by their funding and an ample amount of volunteer work from then through present day (NCCOS, 2020). The workforce is made up of U.S. government staff from departments including the U.S. Department of Fish and Wildlife, volunteer members of the commercial fishing industry, and the average citizen (Vartan, 2020). From start to end, the Mussel Watch annual process requires the assistance of these individuals for tasks ranging anywhere from mussel distribution to analyzing their tissues.

The first step of the process involves determining which mussel species to use for a given site and distributing mussels to the site. Since no single mussel is applicable to every body of water across the U.S. covered by Mussel Watch, local species are used since survival is ensured and their introduction to the site ecosystem won't induce drastic effects. The most notable example of this is that the Great Lakes are made up of freshwater while most coastal sites are composed of saltwater, so a single species of mussel would not be able to be applied to both environments (NCCOS, 2020). This also applies to Port Phillip Bay; similar to the example of the U.S., the bay is host to a saltwater coast and freshwater catchments which flow into the bay. The bay's native blue mussels (Mytilus edulis) could be used for monitoring and filtering microplastics, as they are already being produced en masse by farms and being used to help reclaim ecosystems (Gavine, 2002; Griffin, 2020). As for how these mussels are acquired, they are often donated to the cause by generous local producers, but may also be bought from commercial sources if no donor can be found for a given site (Vartan, 2020). As for the freshwater catchments, the situation is unfortunately not quite as simple. In Australia most freshwater mussels species are critically endangered to the point they might not survive past 2050 under the conditions at present (Pancia, 2018). These conditions include the drying climate, rising salinity levels of water, and rising pollution levels (Pancia, 2018). Two example species of freshwater mussels native to Australia are Carter's freshwater mussel (Westralunio carteri) and the Glenelg freshwater mussel (Hyridella glenelgensis) (Pancia, 2018). The survival of species such as these would not only be critical towards the continued health of Australia's freshwater bodies, but also in being able to accurately monitor freshwater bodies for a wide range pollutants including microplastics. Since tissue analysis involves the killing of mussels in the process of sampling, waste analysis would be the best choice on how to analyze freshwater mussels, at least while they are still considered endangered. Historically freshwater mussels have been difficult to raise awareness for since they generally are not appealing to the public and also don't have a great taste, meaning there is very little leverage to use in saving them (Pancia, 2018). In spite of these difficulties, outreach and other efforts to save Australian freshwater mussels must be done without delay to avoid the loss of these species, and a valuable method for microplastic monitoring. If Australian freshwater mussels are saved, the use of saltwater and freshwater mussel species will allow for microplastics monitoring and filtration of all water bodies in Port Phillip Bay, as well as the greater Melbourne region.

After the mussels are acquired, volunteers collaborate in distributing them to sampling sites as well as with setting up mussel cages and collecting them after the three-month period of sampling is up (Vartan, 2020). The 300+ coastal sites as well as 100 freshwater sites in the Great Lakes. then send their samples to central locations in their respective states to have their tissues removed and prepared for lab analysis (Vartan, 2020). The results of the analysis for each site's sampling are recorded in a database which dates back to the inception of the program, even including some data sets predating Mussel Watch (NOAA, 2021).

Mussel Watch's Consideration of Mussel Microplastic Monitoring

With the rising concern over microplastics and recent studies showing that shellfish can be used to monitor and filter microplastics in water, NOAA in the U.S. has begun to consider using them for microplastics measurements (NCCOS, 2020). Testing is currently being done to see if using mussels is a valid method for measuring microplastics concentrations in marine environments (NCCOS, 2020). The research efforts are the result of a collaboration between NOAA MWP, Loyola University Chicago, and the NOAA Marine Debris Program (NCCOS, 2020). If it is concluded that this method is valid, microplastics will be added to the list of pollutants measured in yearly Mussel Watch samples (NCCOS, 2020). This would be a major step forward for microplastics monitoring, and would verify the effectiveness of shellfish in this matter.

Species Sensitivity

Species sensitivity distribution is a critical technique often used to determine pollution thresholds. When using this method, the most vulnerable species in an environment are used to determine a pollution threshold based on their tolerances to the pollutant in question. This process consists of using data on the effects of a pollutant on the various species in an ecosystem, then establishing a threshold that would be safe for most of the species in that environment (Southern California Coastal Water Research Project, 2021). This technique was developed in the 1980's, and though there have been some minor modifications, the process has been relatively unchanged (Fox, 2021). A species sensitivity distribution is designed to protect a given percentage of species in an ecosystem. This percentage is called the protective concentration. Throughout species sensitivity literature, the protective concentration is almost always set to protect ninety-five percent of the species. The inverse of the protection concentration is called the hazardous concentration, the "final acute value" or the "final chronic value". The protection concentration is determined using toxicity level data that is derived via laboratory study. This data is made into a curve and is modeled as a logarithmic function (Hose, 2004). Australia uses the species sensitivity distribution method for derivation of their water quality benchmarks. Adopted in the year 2000, they originally used a three parameter Burr distribution model. It was found that this system created unnecessary uncertainty in smaller data sets, so now they have adapted such that any set with eight or less species now uses a two parameter log-logistic distribution (Fox, 2021). Species sensitivity distribution has proven to be a key element in our proposed threshold implementation model. With that being said, there were several concerns that needed to be addressed in order to apply the model to microplastic pollution.

A major difficulty with the application of species sensitivity to microplastic pollution is the severe lack of sensitivity data. Since microplastics are a diverse group of pollutants that have only recently become a major focus in research, few studies have been done to determine species' microplastic tolerances. The task of studying all of the world's species to develop sensitivity data may seem completely insurmountable; this is amenable by looking at similar species that live elsewhere that fill the same ecological niche and extrapolating sensitivities of native species from them. While this is a controversial technique and it is only circumstantially applicable, very similar species that live in similar climates have proven to be comparable enough for general comparison. This means that theoretically not all species need to be studied. Rather, sensitivities can be approximated for use in species sensitivity distributions (Jin, 2015; Stephen. J. Oliver, personal communication, November 8, 2021).

Another difficulty is the wide range of microplastic shapes and sizes. In order to make the species sensitivity system applicable, testing must be standardized to ensure that all data is comparable. However, there is an alternative to this method. In a study performed by Koelmans and colleagues, rather than modifying lab data collection methods, the results can be mathematically rescaled to account for different shapes and sizes of microplastics. First, data sets from studies with different microplastic sizes can be aligned in order to make the data comparable. The range of particle sizes in a natural environment follows a power law function. This means that a correction factor can be used to predict the number of microplastics of a given size will be in an environment based on the number of microplastics of another size that are present. The next process for data alignment is using the number of microplastics to predict their mass and volumes. This is based on simulating a diverse sample of microplastics and using distribution data for microplastic shapes and sizes to predict their length, width, and height. Then, density distribution data is used to predict the masses of the simulated microplastics based on their volumes. This distribution becomes more accurate as more particles are included in the simulation, as smaller samples tend to have a less representative distribution in shape, size, and density. The data from tests on a variety of species with a range of microplastic shapes and sizes can be rescaled to properly fit a species sensitivity curve. This is done by using the previous methods to take the species sensitivity data found with testing with one type of microplastic and rescaling this data so that it is representative of total environmental microplastic concentrations. Once this is done for several data sets with different species, the species sensitivity curve can be produced with data simulating real environmental conditions (Koelmans, 2020).

There are key taxa groups of concern that will require further study to determine their microplastic tolerances. One of the organism groups of concern that is already dwindling in numbers is whales. Due to their size many might think that whales would not be particularly vulnerable. However, many whales are filter feeders. This means that they can consume very large amounts of microplastics during their regular feeding (Stephen. J. Oliver, personal communication, November 8, 2021). Beyond whales, many shellfish that are filter feeders are also threatened. Though many mussels were on the forefront of studies and were determined to have relatively high tolerances, some oysters were determined to have very low tolerances. Because of this, shellfish will need to be heavily studied to determine which are vulnerable (Everaert, 2020).

Another aspect of the risk posed by microplastics is their ability to absorb other pollutants. Because of this, microplastics pose a high risk to a much wider variety of organisms. For example, one of the main taxa groups of concern is coral. Of the class Anthozoa, corals are highly vulnerable to a great deal of chemicals. Microplastics carrying these chemicals thus present a huge threat to coral. Many other species see similar threats. Many fish, including damselfish of which there are multiple species in Port Phillip Bay, are vulnerable to sex change via endocrine disruption. Many endocrine disruptors can be absorbed and carried by microplastics. Unfortunately, it is not well studied how easily these chemicals transfer from the plastics to the organisms, and more research will need to be conducted in order to determine how much of a threat is truly posed (Stephen. J. Oliver, personal communication, November 8, 2021).

Enforcement and Prevention

The vast amount of sources in which microplastics enter the environment (figure 12) makes the enforcement process of a microplastic pollution threshold extremely complicated. This is especially prominent with sources such as wastewater, stormwater and mismanaged plastic waste. These sources typically do not have one sole entity responsible for the pollution, dismissing the opportunity to hold an individual or organization accountable. Sources like these require preliminary actions from government regulations to minimize the pollution entering the environment. Other sources such as factories that handle nurdles and the transportation of nurdles can be traced back to an entity that could be held accountable for a mass pollution event. These entities can be targeted and regulated to minimize the pollution they contribute towards the environment.

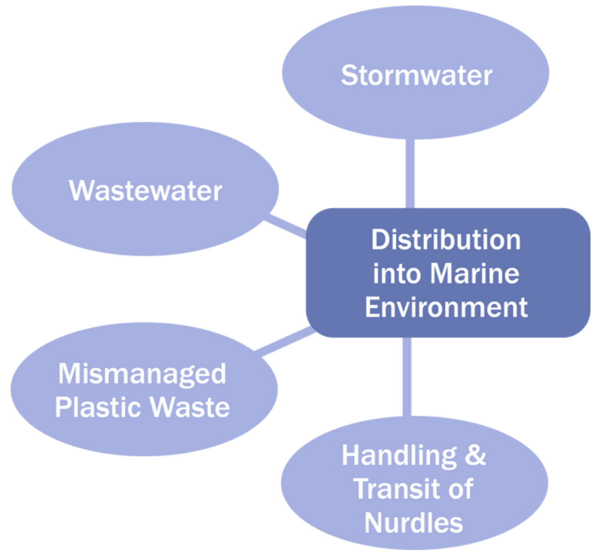

Figure 12: Microplastic's Entrance into Port Phillip Bay

Enforcement at the point of Nurdle Production

One of the biggest targetable pollution sources comes from the nurdle supply chain (Figure 13), with factories, ships, trains and trucks being responsible for spilling about 10 trillion nurdles worldwide each year (Fawcett-Atkinson, 2021). Some estimate half of all microplastic pollution is due to the transport and mismanagement of nurdles (Schlanger, 2019). This is due to their small size and light weight making them easy to be spilled and blown, washed or brushed away into water bodies (Fidra, n.d.). These nurdles are often moved around using pneumatic hoses such as vacuums to load them onto vehicles for shipping (Schlanger, 2019). When hoses are connected and disconnected nurdles often fall out. Nurdles can also spill during their transport onto roads, tracks and waterways (Schlanger, 2019). Once they have touched the ground they are not to be used for manufacturing due to the foreign materials such as dirt which contaminate the raw material (Schlanger, 2019). Currently there are no waste regulations on factories' management of nurdles.

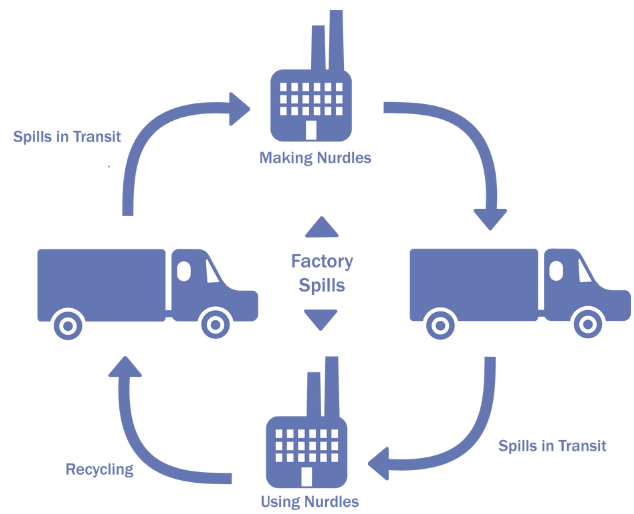

Figure 13: Nurdle Supply Chain Spills
Adapted From: Nurdle Hunt

In order to minimize the amount of nurdles entering the environment, companies need to apply better prevention methods and implement proper infrastructure and systems to react to spills. An example of an effective regulatory principle for these companies to follow is the voluntary Operation Clean Sweep Pledge. This pledge states that companies will follow six commitments: "Improve Worksite set-up to prevent and address spills", "create and publish internal procedures to achieve zero industrial plastic material loss", "provide employee training and accountability for spill prevention, containment, clean-up and disposal", "audit performance regularly", "comply with all applicable state and local regulations governing industrial plastics containment", and "encourage partners (contractors, transporterns, distributors, etc..) to pursue the same goals" (Operation Clean Sweep, n.d.). This pledge pushes companies to take better precautions, causing less nurdles to end up in the environment. If a principle like this was translated into law, it would first require government officials to recognize the problem of nurdle pollution. Then policy would need to be put in place to mandate proper prevention and cleanup actions for spills. Additionally a maximum pollution discharge amount would have to be put in place with either a zero pollution policy or a TMDL (Appendix A), with a considerable tax on the company if they exceed their discharge limit. As long as this tax is set a sufficient amount, it should pressure companies to improve their practices since it would be less expensive than polluting. Finally, a regulatory figure like the EPA would need to inspect these companies to ensure their following of these principles by inspecting their facilities in addition to their discharge amount.

Minimizing Pollution from Wastewater and Stormwater

In Melbourne, wastewater and stormwater are handled by independent systems. Microplastics enter stormwater through the collection of paint, tire particles, construction debris and litter in storm drains as water runs across roads and land (Watt, 2021). Microplastics enter wastewater through personal care products, abrasions of plastic products and washing of synthetic textiles (Watt, 2021). In order to minimize the amounts of microplastics flowing in through these systems, improvements in infrastructure are necessary. Stormwater ponds and other systems such as free water surface wetlands, can be built to minimize the amount of plastics flowing into waterways (Coalition Clean Baltic, 2017). For wastewater, improvements on the filtration of water with more emphasis on removing microplastics is needed.

Additionally the adoption of washing machine filters by 2030 in Australia will minimize the amount of plastics flowing into wastewater (DAWE, 2021). These sources need to be properly addressed in order to maintain a microplastics pollution level below a significance threshold.

Minimizing Mismanaged Plastic Waste

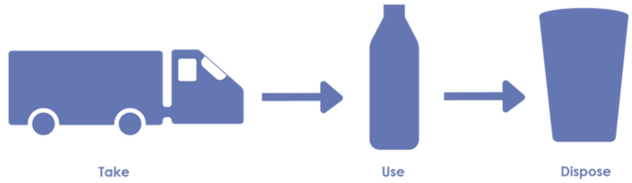

Figure 14: Linear Plastic Economy

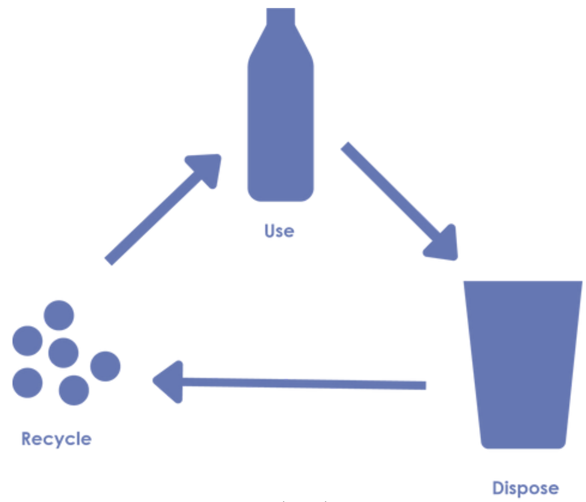

Figure 15: Circular Plastic Economy

One of the most viable routes for water restoration is tackling the source of the problem: improper waste management (Watt, 2021). Increasing proper waste management will lessen the amount of plastics flowing into the environment, prohibiting the creation of microplastics from these plastics (Royte, 2021; Watt, 2021). Currently, a majority of Australia's plastic waste follows a linear economy (Figure 14) with only 39% of all plastic packaging being recycled in 2018 (DAWE, 2021). To properly manage plastic waste, a circular economy of plastics (Figure 15) is necessary (Watt, 2021). A circular economy will promote the longevity of a plastic's lifetime and minimize the amount of plastics that can be disposed of improperly (Watt, 2021).

Australia is already moving towards a circular plastic economy with its national plastic plan (DAWE, 2021). This plan is targeting 50% of all packaging products recycled yearly, which is an 11% increase from their current level of recycling (DAWE, 2021). This plan is also aiming for 100% of all plastic packaging to be reusable, recyclable, or compostable by 2025 (DAWE, 2021). This change is both environmentally and economically beneficial due to the decrease of virgin plastics being created and reducing oil consumption which plastics are currently responsible for 20% (Syberg 2021; Watt, 2021). Although, it is currently impossible to indefinitely recycle pieces of plastic due to loss in mechanical performance, structural integrity and thermal stability (Watt, 2021). Australia's plan falls short of what's needed for substantial minimization of plastics entering the environment.

For Australia to better reach their goals of moving towards a circular economy more drastic measures need to take place. First there needs to be more emphasis on community education (Schiavo, 2021). Community education will help improve the amount of plastics being recycled by removing the confusion of what plastic can be recycled and where. Additionally, Australia needs to mandate their voluntary packaging and recycling goals instead of leaving them as just a goal for companies (Nagtzaam, 2021). Without these mandates there is an inconsistency of commitment between consumers and industry at the state and territorial level (Nagtzaam, 2021). Ultimately mandating regulations will expedite industries' speed of implementation of better plastic packaging and push the circular economy initiative.

Remote Sensing of Marine Microplastics with GIS

Research on microplastic pollution has been propelled by the increased recognition of microplastics as a global pollutant (Cowger et al., 2020; Rochman, 2018). A vast array of sampling methods to quantify microplastics has been developed in response to this (Cowger et al., 2020). However, such techniques have high temporal and financial costs associated with them (Primpke et al., 2020; Wiggin & Holland, 2019). Microplastic analyses often include spectral imaging to classify and quantify the particles present, where images contain bands of different information (for example, the most common red-green-blue colour display known as RBG would contain 3 bands of information). Optical sorting of different plastic polymers in the near-infrared (NIR) to short-wavelength infrared (SWIR) spectral bands has been used in the waste industry to separate different particles for processing by analysing the reflected bands of information from the multispectral image (Moroni et al., 2015).

Geographic Information Systems (GIS) have developed to become an emerging field that can be applied to large-scale microplastic sampling (Garaba & Dierrsen, 2018; Sorensen, 2021). It is a system for "storing, managing and displaying geospatial data" (Chang, 2019), and has been used in land use planning, natural resource management, public services and other sectors of government (Chang, 2019). Over the last few decades, the system has been integrated with the Internet, Global Positioning System (GPS), wireless technology and Web mapping to produce location-based services for a range of purposes (Chang, 2019). Geospatial data, derived from open-sourced satellites, such as the Sentinel 2 and Landsat 8, have been used to these ends by geospatial analysts for many years (Chang, 2019). GIS has been increasingly adopted as decision support tools (Eastman, 1996). GIS models, based on representations of reality, allow analysts to assemble information about the earth's surface in an efficient manner by integrating different layers of data to produce outputs in the form of maps for intuitive interpretation (Chang, 2019). Given the ability of microplastics to be transported across great distances in the marine environment based on their sizes and buoyancies (Ballent at al., 2012; Zhang, 2017), conducting large-scale studies on them is challenging (Sorensen, 2021). GIS, however, with their ability to store, manage and manipulate large quantities of data, can allow for marine microplastic modelling at large scales (Sorensen, 2021). Data such as ocean currents, marine species movements, population density and topography can all be combined in GIS to predict microplastic risk to marine life (Guerrini et al., 2019), as well as modelling sites of likely accumulation (Harr et al., 2019).

Current GIS Models of Marine Microplastics Pollution

The National Centres for Environmental Information (NCEI) of the National Oceanic and Atmospheric Administration (NOAA) has compiled a NCEI Marine Microplastics database that can be converted for analysis in GIS software (National Centres for Environmental Information; 2021). The world-first platform is open-access and contains global data on marine microplastics, combined with ocean current data to allow a more comprehensive understanding of microplastic movements software (National Centres for Environmental Information; 2021). The data on the platform has been collated from researchers around the world and can be used to verify any remotely sensed data on microplastics (National Centres for Environmental Information; 2021). With more data collection in the future, this platform can be made more versatile in supporting decision making and risk management. In another large-scale study, the University of Michigan used data from the Cyclone Global Navigation Satellite System (CYGNSS) to remotely derive microplastics on ocean surfaces based on the reflected radio signals (NASA, 2021). Ocean wind speeds collected from NOAA sources were used to validate the accuracy of the CYGNSS measurements and allow for microplastics modelling on a daily scale (NASA, 2021). The study found some seasonal variations in microplastics concentrations and noted particularly concerning microplastics sources (NASA, 2021). These programs can allow for timely and accurate monitoring of microplastics pollution in the future on a global scale and invites for contemplation of a unified approach to microplastic management.

A recent study in the North Atlantic Ocean found that spectral reflectances of microplastics "could be represented as a single bulk average spectrum with notable absorption features at ~931, 1215, 1417 and 1732nm" through ocean colour imagery (Garaba & Dierrssen, 2018). The European Space Agency (ESA) has been attempting to address the issue of remotely quantifying microplastics in marine environments through their Sentinel-3 data under the 'Optical Method for Marine Litter Detection' ("OptiMAL") program (European Space Agency, 2018; Plymouth Marine Laboratory, 2019; Martinez-Vicente et al., 2020). The Sentinel-3 satellite has been used to detect both macroplastics and microplastics in the sea surface, but is still an emerging technology (European Space Agency, 2018). Under the same program, the Sentinel-2A and B satellites, collect data every two to five days at high resolution (10m), allowing for their multispectral instrument sensors to detect smaller objects over terrestrial and coastal land covers (Plymouth Marine Laboratory, 2019). The optical "signature" reflectances of the detected floating marine macroplastic debris were able to allow researchers to distinguish litter from buoys, small boats and foam on water across several study sites along the east coast of Scotland and the San Juan Islands of British Columbia (Plymouth Marine Laboratory, 2019). However, the exact composition of the macroplastic patches could not be determined through the available technology (Plymouth Marine Laboratory, 2019). These issues are attributed to the current inability of airborne sensors to reliably assess global micro-sized polymers in marine environments (Garaba & Dierrssen, 2018), but can be mediated through cross-referencing with in-situ data, with consideration of transport mechanisms (Martinez-Vicente et al., 2020).

The potential of GIS in different sociocultural contexts

In a study on microplastics pollution within watersheds close to urban areas, significant positive correlations were found between urban development and microplastic concentration at four selected sites in the Chespeake Bay, USA (Yonkos et al., 2014). Land cover, watersheds and population density were derived from both census data and remotely sensed topographic data, with samples collected through surface trawling (Yonkos et al., 2014).

Although such methods may be applied to a regional scale, larger studies will likely prove financially challenging. However, similar approaches may be taken once the technology for monitoring microplastics pollution has been improved, where demographic data can be overlaid to pollutant data to determine sociocultural groups that are most vulnerable to this emerging threat. In another study conducted in Florida, microplastic datasets provided by NOAA were overlaid with demographic data from the 2010 US census to determine whether there was correlation between microplastics and likely point-sources from manufacturing facilities (Roderick et al., 2019). The study found no significant correlation between microplastics concentration at the study sites and the nearby manufacturing sites (Roderick et al., 2019). Similarly, no correlation was found between population density and microplastic concentration (Roderick et al., 2019). Such findings may be useful in guiding management authorities to identify other sources of microplastic pollution if the major point sources can be eliminated in a similar manner. Other less formal studies based on crowdsourced GIS data on microplastics have been detailed in Appendix K.

In the Australian context, the Australian Bureau of Statistics can provide similar demographic information in the Social Economic Indexes for Areas (SEIFA) database (Australian Bureau of Statistics, 2018). Indigenous populations, socioeconomic groups, education and occupation groups as well as age-sex groups can be derived from the SEIFA database and uploaded to geospatial processing software (Australian Bureau of Statistics, 2018). Together, such layers of data may pave a more culturally sensitive way for environmental justice by highlighting areas that may be at higher risk of microplastic pollution, while identifying potential point sources and major polluters within urban environments. Given this potential, GIS models on microplastics may support legislative decisions to confer protection to vulnerable groups, and offer more efficient monitoring strategies.

05 Recommendations

Based on our research described above, we recommend particular actions and options for each component of the threshold model.

Methods for Sampling Microplastics Concentrations

Each sampling method has their own role to play in implementing a microplastic pollution threshold, and thus should all be considered for their unique strengths (Appendix L).

EcoCentre's standard beach audit method is an effective tool for community engagement as it allows local community group volunteers, not-for-profits, and education institutes to become involved with microplastic pollution sampling. Conducting these types of beach audits also raises public awareness of the growing threat of microplastic pollution. Furthermore, the data obtained from these beach audits is highly valuable to EcoCentre as it improves their knowledge of pollution levels of beaches, pollution levels of the water, which beaches and catchments in the bay area are the most polluted, movement patterns of microplastic pollution, and the types of microplastic pollution on beaches. In addition to these benefits, they are also time and cost effective, and thus should continue to be conducted regularly.

Sampling the surface water of Port Phillip Bay using water trawls is an accurate and reliable method for measuring the concentration of positively buoyant microplastics in the surface water of Port Phillip Bay. However, one caveat that must be recognized is that due to the large size of water trawls, this sampling method should only be used in non-shallow waters of the bay. Despite its limitations, water trawling under favorable conditions remains a highly effective method for directly sampling the surface water of the bay. Because of the several favorable qualities of water trawl sampling, this method should be used for the sampling aspect of our threshold implementation model.

Use of bioindicator species should be a high priority since it would not only provide accurate measurements in both the Port Phillip Bay and its freshwater catchments, but also contribute to the health of these water bodies. Blue mussels are one of the most available and effective bioindicators of microplastics in Port Phillip Bay, but action must be taken to help save endangered freshwater species from extinction. Since this method takes a great deal of time, the U.S. Mussel Watch program suggesting a 3-month sampling period, a staggered sampling scheme may be appropriate. This would ensure that samples would still be able to be produced consistently despite the wait time needed for a sample to be ready. The validity of waste analysis of mussels should be verified as well, since it would allow for the analysis process to occur without the destruction of mussels and likely would reduce sampling time needed. In the case that waste analysis proves to be more effective than tissue sampling on some or all fronts, it should be adopted. No matter the analysis method used, sampling mussels or other bioindicators should be implemented in tandem with other methods. This is because this method is used in sampling the middle of the water column, and in order to gain a full picture of the state of Port Phillip Bay, all levels must be sampled.

Sediment sampling covers the last hole in the plan as it is used to sample the bottom of the water column, more specifically the sediment of the bay. Coring samples particularly will be of great use in data gathering since they are able to give historical data of sedimentary microplastics. Since there isn't a great deal of microplastics data from further than the past few years, data from the past is necessary to fill the knowledge gap. Although this method can't be used to directly calculate the concentration of microplastics in the water, the data can still be extrapolated to draw conclusions.

Approach for Determining the Threshold Value Through Species Sensitivity

Before a microplastic pollution threshold can be established using a species sensitivity system, more research into organisms needs to be conducted. The two key branches of this research are studies conducted on microplastic tolerances and on transfer of harmful absorbed chemicals. Studying the tolerances is the more important of these two categories, as species sensitivity is inherently based on plotting these tolerances. Additionally, it is important to research not just one polymer type, but all of the most common types of plastics seen as pollutants. However, with microplastics as a unique case compared to other pollutants, the absorption factor must also be highly considered. If studies find that absorbed chemicals easily transfer to any particular organisms, then these species would see a far greater vulnerability to microplastics. This would require additional research from experts to determine how this would be taken into account when modeled for a species sensitivity distribution.

Minimizing the Microplastics Entering the Bay Through Enforcement and Prevention

If a microplastic threshold were to be established for Port Phillip Bay, we recommend the regulatory process seen in Figure 16. This flowchart shows the consistent loop of sampling and analysing needed to regularly check the concentration of microplastics within the bay. Additionally this chart indicates the appropriate reaction if a threshold were to be breached, showing possible reactions towards targeting entities responsible for the pollution. If a proper microplastic cleanup strategy for aquatic environments comes to light, this flowchart should be reworked to incorporate a microplastic cleanup strategy when the threshold is breached.

We are recommending that in addition to pushing for a microplastic pollution threshold, EcoCentre continues to push for better regulation of nurdles. Since nurdle pollution is a huge contributor of microplastics within the bay. Additionally, improvements in wastewater and stormwater infrastructure to better handle microplastics should be pushed for. The threshold will act as good leverage to push for these regulations, but if action can be taken sooner, the bay will be in an overall safer state.

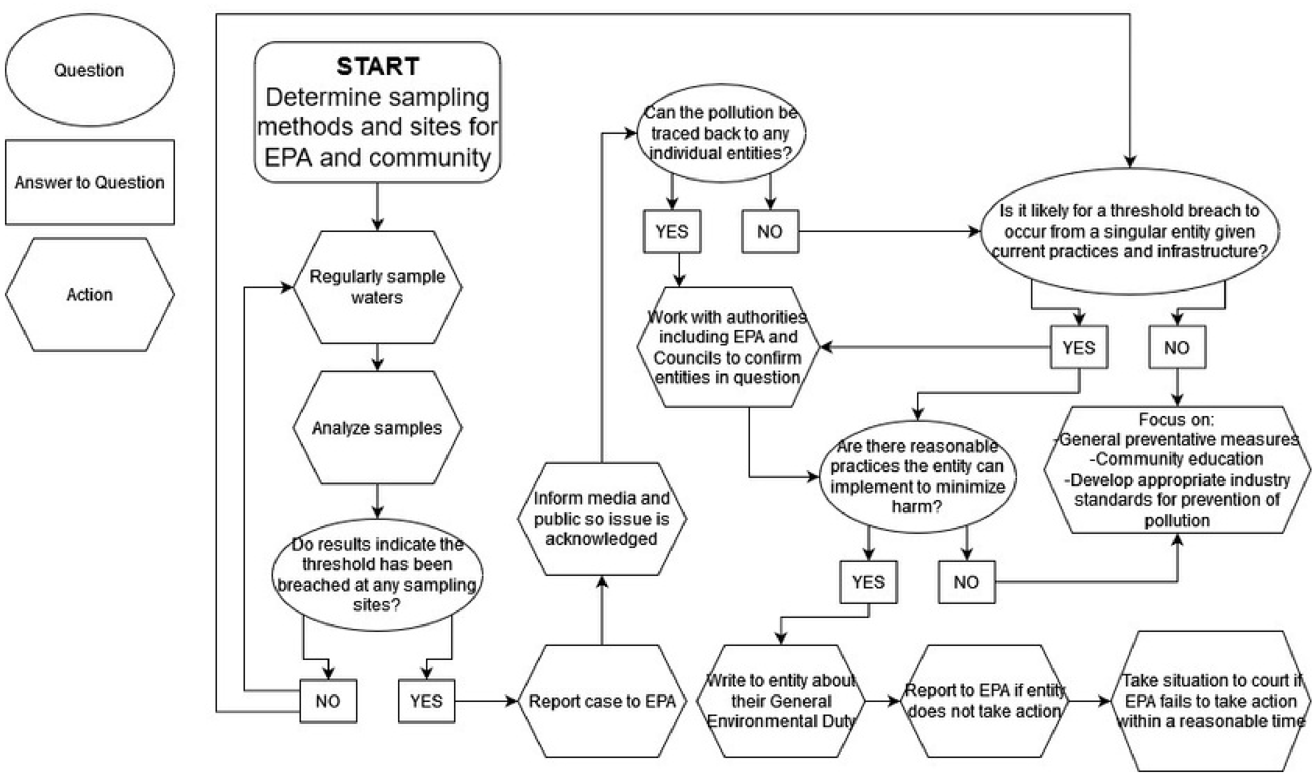

Figure 16: Process of Pollution Threshold Enforcement

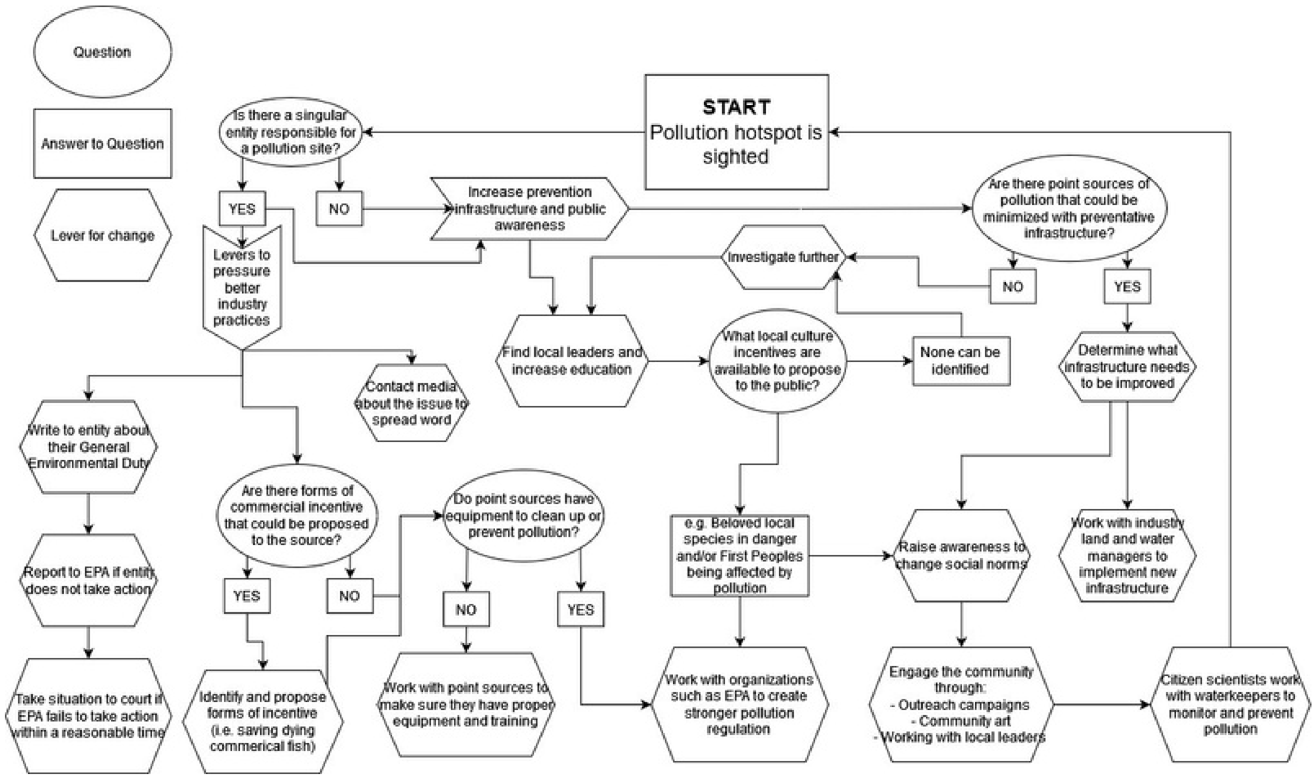

Figure 17: Waterkeepers: How to Find Levers for Change when a Pollution Hotspot is Found

Finally we are recommending the Levers for Change flowchart for waterkeepers seen in Figure 17. This flowchart will assist waterkeepers in determining the appropriate responses when a pollution hotspot is found. It dives into when to target an entity and when to focus on raising awareness through community engagement and public incentives. The chart also shows the appropriate steps to use General Environmental Duty (Appendix A) to lever for change, additionally stating when to contact the EPA.

Current Developments within California

We recommend that EcoCentre follows the developments within California on their threshold creation. The state should be releasing their microplastic threshold numbers soon as well as an interactive database to explore the toxicity of microplastics on humans and ecosystems called ToMEx. Additionally after their threshold is implemented, a study of their preferred sampling method(s) and period of sampling should be done.

The Future of Geospatial Analysis

GIS allows for a direct visualisation of spatial information by decision makers in intuitive ways as well as overlaying existing datasets with remotely sensed data for more nuanced outcomes (Lynch, 2018). Even though the technology is not yet well developed for analysis of microplastic pollution, the recent progress made in this field shows the potential for GIS to become a powerful tool. The flexibility afforded by GIS can provide a future of accurate near-time measurements across the globe once more developed. It is recommended that GIS and remote sensing technologies be considered for large-scale microplastic monitoring in the future to minimise monetary costs of sampling, while allowing for responsive, adaptive management strategies and to hold polluters accountable. Public dissemination of such data may also be useful for educational campaigns and can allow for better understanding of the scope of the issue. The array of emerging microplastics monitoring programs can be powerful tools in holding polluters accountable if point sources can be identified in real-time, and prevention may be made possible if topographic data can be used to determine areas of microplastics accumulation. Thus, GIS can be a versatile decision-support tool in the future of microplastics management and regulation with the development of higher resolution remote sensing technologies.

06
Conclusion

Microplastic pollution will undoubtedly become a more difficult problem to solve the longer it is left unregulated due to particles' ability to accumulate within the food chain. These particles will continue to cripple ecosystems at an increasing rate, and the point at which humans begin to experience noticeable complications from them will come ever closer. The need for a proper system to limit microplastic pollution is dire. The three elements of our threshold model are crucial for the making of a threshold. Sampling methods with consistent results are necessary to analyze the amount of microplastics in the bay so that a threshold can be monitored. Species sensitivity is necessary in order to determine a threshold based on the species that make the bay their home. Finally, enforcement and prevention are necessary to keep plastics out of the bay, as once they enter they cannot be removed. With current technology, site remediation is not possible. However, a threshold is a valuable tool in leveraging for better regulation of microplastic pollution in order to protect the people of Melbourne and the species that live in the bay.

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Appendix A
Supplemental Information

Total Maximum Daily Loads (TMDL's):

In the United States, a strategy called Total Maximum Daily Loads is used to determine a pollution threshold for a given water body based on its specific circumstances. The threshold is a summation of the allowed pollution from wasteload allocation (WLA), load allocation (LA), and a margin of safety (MOS), using the equation TMDL = ΣWLA + ΣLA + MOS (Overview of Total Maximum Daily Loads). Wasteload allocation consists of pollution from point sources under the regulation of the Clean Water Act's Pollutant Discharge Elimination System (NPDES) and consists of wastewater treatment facilities, stormwater discharges and waste from Concentrated Animal Feeding Operations (CAFOs), or mass meat production facilities (EPA, n.d.). Load allocation consists of pollution from all remaining sources of the pollutant in question including natural sources, and the margin of safety is created due to the uncertainty factor in predicting a safe threshold for reasons such as seasonal variability in conditions (EPA, n.d.). One of the most notable characteristics of Total Maximum Daily Loads is that thresholds are made on a case-by-case basis, rather than having a single, all encompassing one. While this most likely leads to better results, it seems like having a single threshold for all water bodies would be easier to enforce.

The Environment Protection Act 2017 and the Environment Protection Amendment Act 2018:

The Environment Protection Act 2017 as well as the Environment Protection Amendment Act 2018 cover the regulations involving industrial waste discharge in the state of Victoria (EPA Victoria, 2021). Under these acts, permits and authorizations from the EPA of Victoria are required to legally discharge industrial waste (EPA Victoria, 2021). The EPA regulates the approval of wastewater discharge in special water supply catchments and prohibits the discharge of waste into waterways from vessels (EPA Victoria, 2021). The EPA can grant different permits and licenses for industrial facility developments and projects that could harm the environment if gone unauthorized (EPA Victoria, 2021). Furthermore, the EPA conducts inspections of industrial facilities to ensure compliance with the Act's and can require action to be taken by polluters to manage risks of harm to human health and the environment (EPA Victoria, 2021). The EPA can pursue strong sanctions and penalties and impose fines on unauthorised environmental polluters (EPA Victoria, 2021).

General Environmental Duty (GED):

The general environmental duty (GED) is the focal point of the Environment Protection Act 2017. The GED states that businesses are responsible for protecting the environment as well as human health (EPA Victoria, 2020). Furthermore, it states that businesses must manage their environmental risks whenever possible (EPA Victoria, 2020). In addition, the GED applies to all Victorians, requiring them to reduce the risk of harm to the environment from their activities (EPA Victoria, 2020).

Environment Protection Regulations 2009:

The Environment Protection Regulations 2009 outlines the laws on the management of industrial waste in the state of Victoria. This piece of legislation states that businesses must prevent, reuse, and recycle industrial waste whenever possible (EPA Victoria, 2021). If none of those tactics are feasible then a business may receive approval to dispose of industrial waste safely into a landfill or waterway (EPA Victoria, 2021). The EPA provides businesses guidance on wastes including waste tyres, bushfire waste, glass processing waste, operating composting facilities, plastic resin pellets (nurdles), and combustible recyclable and waste materials (CRWM) to name a few (EPA Victoria, 2021).

The Safe Drinking Water Act 2003 and the Safe Drinking Water Regulations 2015:

The Safe Drinking Water Act 2003 and the Safe Drinking Water Regulations 2015 encompass drinking water laws throughout the state of Victoria (Department of Health and Human Services, 2015). These pieces of legislation obligate water suppliers as well as water storage managers to provide safe, quality drinking water (Department of Health and Human Services, 2015). The Safe Drinking Water Act 2003 provides a regulatory framework that includes a framework for risk management 'from catchment to tap', numerous standards for key water quality criteria, requirements for information disclosure for water businesses, and community consultation processes (Department of Health and Human Services, 2015). The act applies to a wide range of designated water suppliers and water storage managers as well as other statutory authorities that supply drinking water to the public, including Parks Victoria and alpine resort management boards (Department of Health and Human Services, 2015). The Water Program at the Department of Health and Human Services supports and works with these key stakeholders to ensure that the Act is upheld across the state of Victoria (Department of Health and Human Services, 2015).
Melbourne Water Corporation:

Melbourne Water Corporation:

Melbourne Water samples water at over 100 monitoring sites to assess changes in water quality in rivers across Melbourne over time (Melbourne Water, n.d.). Melbourne Water tests for conditions such as water temperature, dissolved oxygen, salinity, pH levels, nutrients (forms of nitrogen and phosphorus), faecal contamination (E. coli), and metals (arsenic, cadmium, chromium, copper, lead, nickel and zinc) (Melbourne Water, n.d.). Melbourne Water's water monitoring results are then used to advise the Victoria EPA so that they can make forecasts, advisories, and report cards (Melbourne Water, n.d.).

National Plastics Plan:

Australia currently has future plans for ending plastic fabric microfiber pollution from clothing as well as phasing out several additional common aquatic plastic pollutants through the Commonwealth Government's National Plastic Plan (Sánchez, 2021) (Mirage News, 2021). The National Plastic Plan will put an end to plastic fabric microfiber pollution in waterways and oceans (Sánchez, 2021). To do so, the Australian government is planning on working with industry to ensure that all new washing machines have microfiber filters in them by 2030 (Sánchez, 2021). This will capture plastic microfibers that flow into waterways from households across Australia (Sánchez, 2021). Additionally, the National Plastic Plan has a commitment to phasing out loose fill and moulded polystyrene packaging by July 2022 as well as expanded polystyrene foodware, oxo-degradable plastics (also known as bioplastics), and PVC packaging labels all by December 2022 (Mirage News, 2021). All of these smaller plastics are known to exist in Australia's waterways and ocean ecosystems (Mirage News, 2021).

State of Victoria Plastic Bag Ban:

A plastic bag ban in the state of Victoria took effect on November 1st, 2019 (Victoria State Government, 2019). Single-use thin plastic bags were identified to be one of the most common types of plastic pollutants in aquatic ecosystems. According to the Victoria State Government, “At its peak, Victorians used over one billion lightweight plastic shopping bags every year.” (Victoria State Government, 2019), additionally, “An estimated 10 million bags become litter each year.” (Victoria State Government, 2019). Plastic bags have been found to break up into smaller pieces over time meaning that the impacts of plastic litter are long term and become more difficult to manage over time (Victoria State Government, 2019). The ban put in place will prevent further plastic bag pollution in water bodies, which pose a serious threat to marine wildlife.

The Phase-Out of Microbeads:

Virtually all microbeads in personal care products have been phased out in Australian cosmetics as of the end of 2018 (Chemical Watch, 2018). Microbeads dispensed from personal care products were identified to be one of the most common types of plastic pollutants in aquatic ecosystems. A ban was never implemented, however, as of the end of 2018 nearly all microbeads have been phased out in all personal care and beauty care products throughout Australia (Chemical Watch, 2018). The cosmetics industry has done so on a completely voluntary basis meaning that no bans or mandates were ever necessary to achieve this (Chemical Watch, 2018).

Appendix B
Waterkeeper Interview Questions

- What does your average day as a waterkeeper look like?
- What are your current methods for water quality analysis and regulation?
- What resources do you use in creating change?
- What are your largest challenges in addressing microplastic pollution as a Waterkeeper?
- What do you think could be improved about current regulations on microplastic pollution?
- If you had to come up with a model for the creation of a microplastic pollution threshold, what elements would be included in this model?
- What are the most practical/effective means of sampling water for microplastics from your perspective as a waterkeeper?
- In our research to determine an appropriate method for sampling the level of microplastics in water, the most valid option seems to be biological sampling.
  - Do you have any thoughts on using this method?
- Would it be logistically possible to take biological samples and send them to a lab for analysis on a regular basis?

Appendix C
EPA Official Interview Questions

- *How does the EPA respond to aquatic pollutants of emerging concern before there are legal thresholds and triggers?*
- *What do you do when a legal threshold is breached?*
- *Given the impossibility of continuously monitoring all waterways, how does the [US/Victoria] EPA identify priority monitoring?*
- *What monitoring is done by the EPA?*
- *What monitoring by third parties is accepted by the EPA?*
- *How have you been involved with microplastic pollution in the past?*
- *Are you familiar with species sensitivity distribution?*
- *How does the EPA use this system for other pollutants?*
- *(For US EPA Only) What analysis method does the US EPA use when tracking species sensitivity data (example: Burr distribution)?*

Appendix D
Dr. Yung En Chee Questions

Occupation: Ecology Professor at University of Melbourne

- *Which families or genera are most likely to have species with low microplastic tolerances?*
- *In our research we have seen a massive variability in microplastic shapes, sizes, and composition, as well as the ability to absorb other pollutants.*
- *How would you go about modelling such a complex issue on a habitat level?*
- *What is the role of modeling habitat suitability in making pollutant regulations?*
- *What kinds of lab data do you use in your work?*
- *Should we be monitoring the catchments that flow into Port Phillip Bay more than the bay itself?*

Appendix E
Dr. Graeme Allinson Questions

Occupation: Associate Professor in Environmental Chemistry at the Royal Melbourne Institute of Technology

- Could you tell us about your past work?
- Throughout your research and work on chemical pollutants, do you have any experience with case studies involving a pollutant of emerging concern becoming regulated?
- What methods do you use in the microplastics lab to identify the polymer type?
- How can the absorption of other pollutants be accounted for in regulation on microplastics?
- How familiar are you with using species sensitivity distributions to analyze how a pollutant affects aquatic ecosystems?
    - [If so] How have you used species sensitivity distributions for other aquatic pollutants?
- How would you account for inconsistencies created by stormwater runoff in regular sampling of an aquatic pollutant?
- Are there any conditions during which you can't anticipate a storm, or when sampling must occur during a storm?
- Could you tell us more about the microplastics lab at RMIT?
- Is there anything else you consider relevant to this project that you would like to add?

Appendix F
Dr. Stephen J Oliver Questions

Occupation: Marine Biology Professor at Worcester State University

- *Could you tell us about your past work?*
- *What do you know about microplastics?*
- *Are there any families or genera that you would generally think would have low microplastic tolerances?*
- *Are you familiar with species sensitivity distribution?*
- *Species sensitivity models look at the tolerances of different species in an ecosystem to determine a threshold that will protect most of the species in the environment from a given pollutant.*
    - *Do you think it would be a valid method to use data on well studied North American species in place of their similar, less studied Australian counterparts?*
- *Throughout our research we have investigated the use of bioindicators as part of our sampling methods for determining microplastic concentration in a body of water.*
    - *Are there any taxa groups that have species that you believe would make good bioindicators of microplastic concentrations in both marine and freshwater environments?*
- *Could you tell us more about your work with chemical pollutants such as agent orange involving bioacoustics?*
- *Since microplastics are already pervasive in all the ocean's environments, how do you set a baseline for a pollution threshold?*
- *Could you tell us more about how endocrine disruption can affect populations of water dwelling animals?*
    - *Could this be a problem for terrestrial animals as microplastics make their way into the terrestrial food chain?*
- *Is there anything else you consider relevant to this project that you would like to add?*

Appendix G
Mike Jarbeau Questions

Occupation: Narragansett Bay Riverkeeper

- *Could you tell us about your work?*
- *How have you been involved with working on microplastic pollution in the past?*
- *If you were to encounter an emerging problem in a waterway what would be your steps to address the issue?*
- *What partners and organizations do you work with in order to enforce water regulations?*
- *To what degree is citizen involvement necessary for your organization to succeed in its goals?*
- *What influences your selection of monitoring methods for aquatic pollutants?*
- *Are standards for how pollutants should be sampled defined based on effectiveness of the method, availability of the resources needed for the method, or a combination of both?*
- *Are you familiar with the use of bioindicators in water sampling?*
  - *Individuals in the U.S. we have interviewed have not mentioned much use of bioindicators in water monitoring, is this generally uncommon in the U.S.?*
- *What roles do you have in the development of new environmental law?*
- *How do you counteract corporate pressures put on the EPA that prevent the passing of environmental legislation?*
- *Is a tier based approach valid for a microplastic pollution threshold?*
- *Are the multiple methods you have mentioned using, being water trawls and water pumps, both used at the same time or is one or the other used depending on certain conditions?*
- *Is there anything else you consider relevant to this project that you would like to add?*

Appendix H
Ian Wren Questions

Occupation: Staff Scientist at San Francisco Baykeeper

- *Could you tell us about your work?*
    - *How have you been involved in working with microplastic pollution in the past?*
- *Could you tell us more about the San Francisco stormwater system?*
- *Could you tell us about the type of advocacy work you do?*
- *California is working on their microplastic threshold for waterways, what would your role in this implementation be?*
- *How does the environment you work in influence the sampling methods you select for monitoring the quality of water?*
- *About catchments*
- *Could you tell us about the key species of concern in San Francisco with respect to microplastics?*
- *What levers for change can waterkeepers employ when addressing a pollution issue such as microplastics?*
    - *How would sampling for microplastics in the bay differ from sampling for microplastics in the rivers leading to the bay?*
    - *How would you monitor microplastic pollution in an estuarine environment?*
- *Is there anything else you consider relevant to this project that you would like to add?*

Appendix I
Tom Wall Questions

Occupation: U.S. EPA Watershed Restoration, Assessment, and Protection Division Director

- *Could you tell us about your work with the EPA?*
- *How does the EPA respond to aquatic pollutants of emerging concern before there are legal thresholds and triggers?*
- *What resources would be required to implement a threshold for microplastics?*
- *In terms of collaboration and communication with the public, what are some cultural sensitivities you need to consider when working with native tribes?*
- *Is the EPA planning on addressing microplastic pollution with more drastic measures?*
    - *Would the EPA consider implementation of a microplastic threshold similar to the one California is working on?*
    - *How would a threshold like this be enforced since a majority of pollution comes from non point sources and not one entity?*
- *Is there anything else you consider relevant to this project that you would like to add?*

Appendix J
Port Phillip Bay Shellfish Reef Restoration Project

One cleanup operation mussels are currently being used in is the Port Phillip Bay Shellfish Reef Restoration project, where they are being used to help reclaim lost ecosystems (Griffin, 2020). Mussels and other shellfish once covered over 50% of the Bay floor, but almost all reefs in Port Phillip Bay were destroyed due to overharvesting, disease, and urban runoff over the last 100 years (Griffin, 2020). Without shellfish reefs to filter the water, biodiversity diminished in these areas and the water became more dangerous for both marine life and humans (Griffin, 2020). To help revive these ailing ecosystems, tons of blue mussels were deposited across the sea floor; it will take 7-10 years for these mussels to mature and for the full effect of their filtering to be seen (Griffin, 2020). If this operation proves successful and Port Phillip Bay's critically endangered marine ecosystems are saved, it would make Australia the first country to revive ecosystems from such a level of decline (Griffin, 2020). The Victoria State Government has been making efforts such as this project to revitalize the state's declining fishing industry, meaning there is economic incentive to be using shellfish such as mussels to help filter Port Phillip Bay's water, with the waste produced being usable for microplastics measurements (Jupp, 2020). Future research on the use of mussels in cleaning and monitoring water may be focused on areas where microplastics enter water, including storm drains, water treatment plant pipelines, marinas, and harbors (Toussaint, 2021).

Appendix K
The Power of the Public

Crowdsourced Geospatial Data of Marine Microplastics

Currently, the public also has access to highly accurate geospatial data collectors on their hands, which can be used to crowdsource data on microplastic pollution in citizen science and Volunteered Geographic Information (VGI). "OpenStreetMap" is one such project that allows everyday citizens to collect and disseminate geospatial data (Lynch, 2018). Estimates of world marine plastic pollution have also been made by various members of the public and are available on ArcGIS Hub ("Plastic pollution with ocean currents", 2019; "Estimate of plastic pollution in the World's Oceans", 2020). Another program, "Litterati" claims to have crowdsourced over one million Instagram hashtags of litter through the publicly available social platform (Litterati, 2021). Although the data quality may be of uncertain standards (Lynch, 2018), a future of data open for download through such platforms can be made possible through public education. The Marine Debris Tracker from the US National Oceanographic and Atmospheric Administration (NOAA) has compiled over 1.2 million tags of such information on litter (Debris Tracker, 2021), and Clean Swell from the Ocean Conservancy has compiled recorded and cleaned up more than 16.5 thousand tonnes of marine litter (Ocean Conservancy, 2021). "OpenLitterMap" is another project under development targeted at microplastics, containing a variety of native languages available for different geographic locations, as well as virtual blockchain token "Littercoin" as an incentive for contributing geospatial data for its users (Lynch, 2018). The software allows for users to simply upload geotagged photographs for data collection, while providing a selection of hundreds pre-defined litter types, ranging from cigarettes, microplastics, medium plastics, macroplastics, drugs to food and sanitary packaging for its users (Lynch, 2018). Such data are useful for georeferencing, or "ground truthing", in which satellite imagery may be cross-referenced with ground data to determine the level of scientific accuracy (Chang, 2019).

Preliminary Survey of Residents Within the Port Phillip Region and Their Awareness of Marine Microplastics

In November 2021, a survey was conducted on Melbourne residents to gauge the degree of public awareness on the microplastics pollution issue in Port Phillip Bay and surrounds. The survey was distributed by the Port Phillip EcoCentre to its existing affiliates; responses were recorded on a voluntary and anonymous basis, and all respondents were aged over 18.

The survey consisted of seven questions with two questions for any further information that participants may have wished to volunteer. The question was based on a scale of 0-5, with 0 being no knowledge of microplastics, and 5 being expert level. Of the 90 respondents, almost 50% evaluated themselves to have a reasonable degree of knowledge on microplastics (Figure 18).

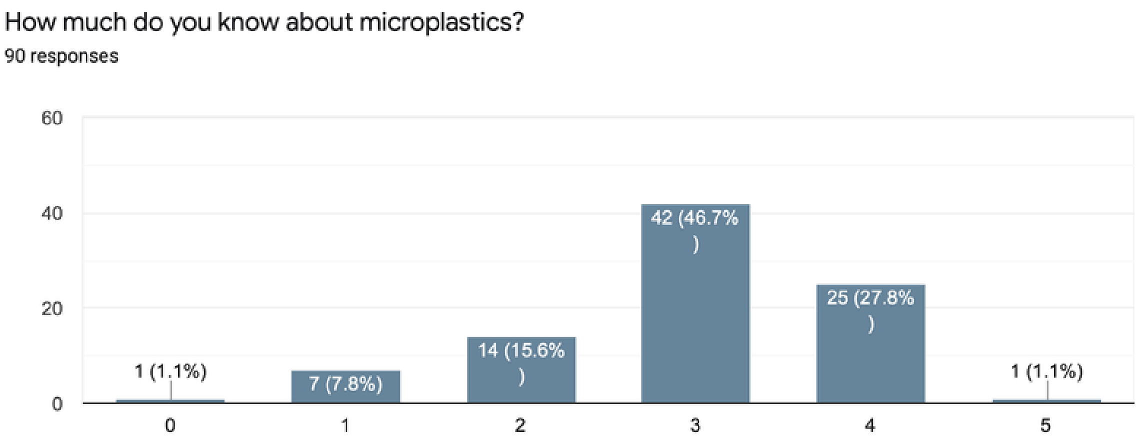

Figure 18: Voluntary responses to the question on the participants' degree of knowledge on microplastics on a scale of 0-5, with 0 being no knowledge, and 5 being expert level.

Similarly, most of the respondents judged themselves to have a medium to high level of knowledge on the potential effects of microplastics on marine species, with over 85% of the respondents rating their knowledge on the subject matter of 3 or above on the 0-5 scale provided (Figure 19).

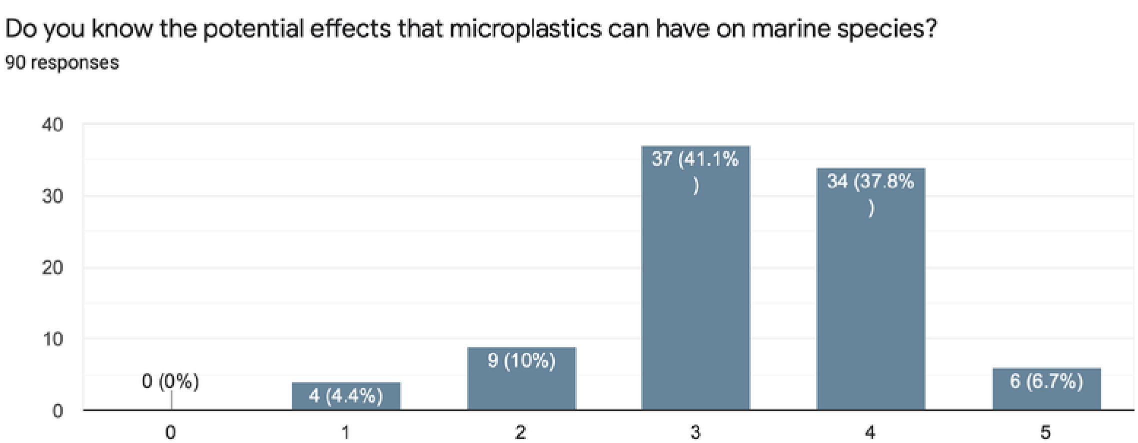

Figure 19: Voluntary responses to the question on the participants' degree of awareness of the potential effects of microplastics on marine species on a scale of 0-5, with 0 being no knowledge, and 5 being expert level.

Exactly half of the respondents indicated that they were also well-informed of the pathways of microplastic transport into the natural environment (Figure 20). None indicated that they had no knowledge of the transport mechanisms, all respondents knowing at least one transport mechanism.

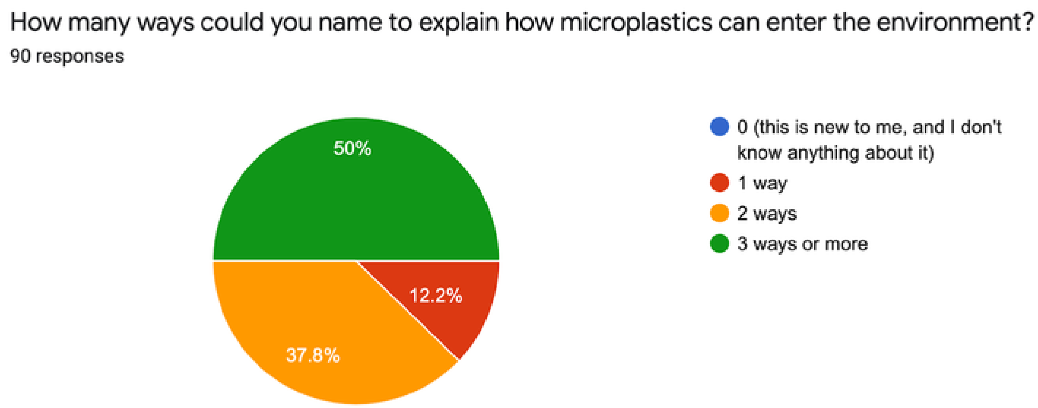

Figure 20: Voluntary responses to the question on the participants' degree of awareness of the transport mechanisms of microplastics into the environment, ranging from no knowledge of the transport mechanisms (0) to 3 or more ways of microplastic transport into the environment.

Many respondents also showed a moderate to high degree of awareness of the ways in which microplastics can be consumed by humans. However, 5.6% of the participants indicated that they did not know of the transport mechanisms of microplastics into the human body (Figure 21). Compared to the question of the transport mechanisms of microplastics into the environment, the respondents seemed to show a lower level of awareness of the impacts of microplastics ingestion by humans.

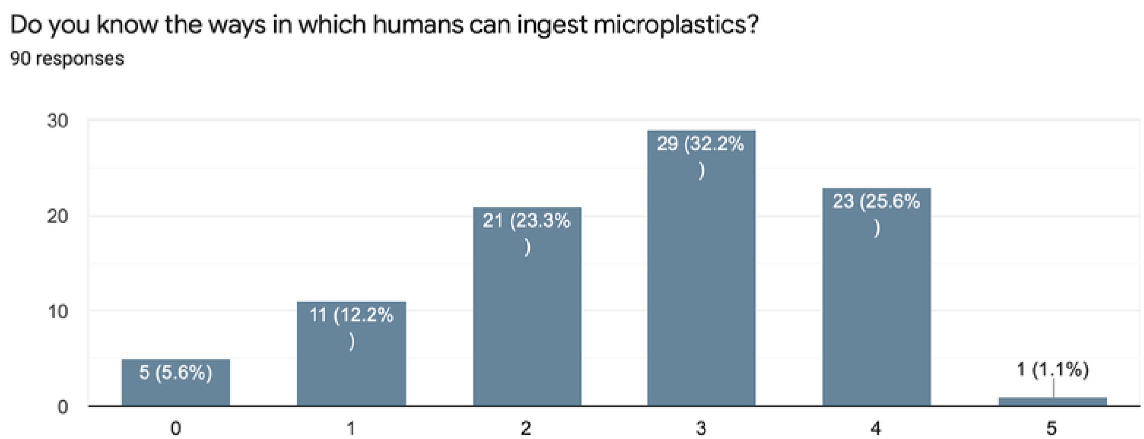

Figure 21: Voluntary responses to the question on the participants' degree of awareness of the transport mechanisms of microplastics into the human body. The question was based on a scale of 0-5, with 0 being no knowledge of microplastics, and 5 being expert level.

Almost 70% of the respondents indicated that they were aware that humans were ingesting microplastics on a daily basis (Figure 22).

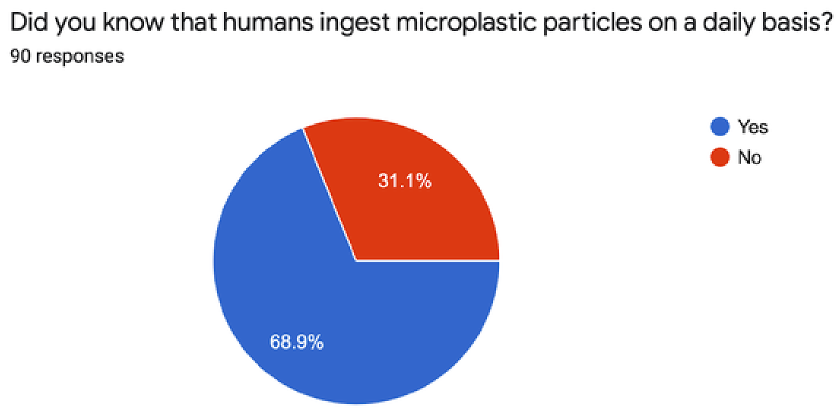

Figure 22: Voluntary responses to the question on the participants' awareness of whether humans were ingesting microplastics on a daily basis or not.

When asked whether the participants knew of the ways they could help to combat microplastic pollution, 41.1% indicated that they had no knowledge of the options available (Figure 23).

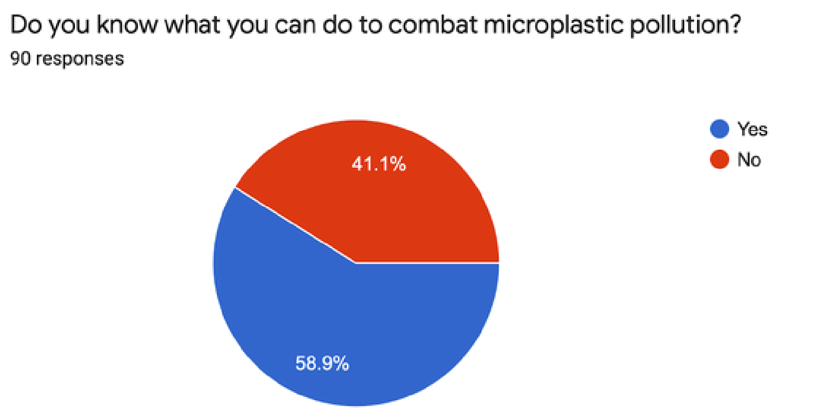

Figure 23: Voluntary responses to the question on the participants' awareness of the potential actions they could take to combat microplastic pollution or not.

As the public can play a crucial role in monitoring, the final question was on whether they have ever reported pollution to EPA Victoria. Almost 80% of the respondents had never reported pollution, while 21.1% indicated that they had experience with the reporting process (Figure 24).

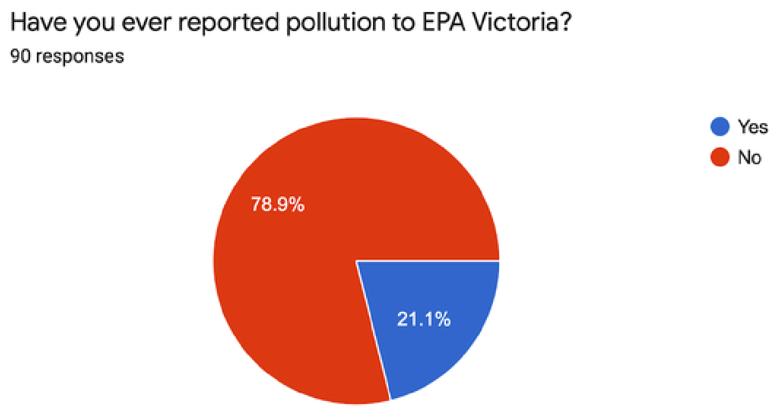

Figure 24: Voluntary responses to the question on whether participants had ever reported pollution to the EPA Victoria.

When asked about any further comments, some respondents expressed concern for the lack of information they received in their daily lives about how to prevent microplastics from entering the environment. Of particular interest, one respondent inquired whether there were “legislation for [microplastic] management in Australia”, and two others indicated that their knowledge of the issue originated from volunteering with Port Phillip EcoCentre’s beach audits. Almost 28% of 76 the respondents who provided their postcode in the final question were from Elwood, while another 34.2% were from the Saint Kilda and Saint Kilda East areas; these are areas close to the EcoCentre, and are also seafront suburbs in south Melbourne, suggesting that EcoCentre’s activities may have played a role in adding to public awareness of microplastic management, or that their geographic proximity to the Bay may have encouraged them to take the survey as the issue may have presented microplastics as a more direct threat to their environs.

While most respondents had some knowledge of the issue, it should be noted that the survey is unlikely to be representative of the demographic of the Greater Melbourne area, as 47 of the 76 respondents who volunteered their postcodes were located near the EcoCentre. As the survey was also sent to the EcoCentre’s affiliates, who are consequently more likely to have a keener awareness of environmental issues, responder bias may, to a certain extent, have impacted the results of the survey. However, from the preliminary analysis of the results and the additional comments volunteered by some respondents, it can be seen that most participants were concerned about microplastic pollution, and by harnessing their willingness, legislative processes may be expedited by a stronger public will, if guided by wider educational campaigns on the issue.

Appendix L
Sampling Methods Attributes and Recommendations

Microplastic Sampling Methods

	Beach Audits (Method used in Clean Bay Blueprint)	Water Trawls	Bioindicators (Method used by the U.S. Mussel Watch Program)	Sediment Sampling (Method used by U.S. EPA)
About	• Recording visible microplastics in selected quadrats within selected transects of a beach • Transects include the widest, central, and narrowest sections of a beach	• Collecting particle debris from the water's surface by towing a large net • Particle debris is analyzed for microplastics quantities • Allow for large water samples which yield more representative results of microplastic concentrations	• Species such as mussels can be used to measure microplastics in the environment • Most appropriate bioindica tor species for Port Phillip Bay is the native Blue Mussel • Involves submerging mussel cages and then analyzing their tissues for microplastics	• Scooping sediment from the bottom of the water body to quantify the amount of microplastic particles present
Pros	• Engage the community • Can raise public awareness • Last under 1 hour • Cost-effective • Can provide information about catchments and pollution patterns • Provides data from the top, middle, and bottom water columns	• Cover a large area • Direct sample of the water • Remove plastic from the environment • Provides data from the top of the water column	• Mussels help filter and clean the environment they live in • Provides accurate measurements • Provides data from the middle of the water column	• Sampling with a coring device can show historical microplastic data • Provides data from the bottom of the water column
Cons	• Can't provide direct MP concentration data for water	• Removes organic material and organisms • Influenced by environment conditions • Cannot be used in shallow water • Requires experienced personnel and a lot of equipment	• Sampling and analysis can take a long time (up to 3 months underwater) • Certain species of Freshwater Mussels are endangered in Australia	• Can't provide direct MP concentration data for water • Requires experienced personnel and a lot of equipment
Recommendations	EcoCentre's beach audits should be used to raise public awareness, engage the community, and gain valuable information on catchment pollution and pollution patterns throughout the Port Phillip Bay area.	Water trawls should be used for accurately sampling large volumes of surface water for positively buoyant microplastic pollution.	Bioindicators should be used because they provide reliable data on the environment in which they live in. They can be used to sample the middle of the water column, and should also be used to help filter microplastics from the environment.	Sediment sampling should be used to obtain baseline data about the state of the bed of the bay and not for regular condition sampling. It should also be used to fill in gaps in historical data.

Figure 25: Sampling Methods Attributes and Recommendations