PORT PHILLIP ecocentre

Clean Bay Blueprint

Microplastics in Melbourne | October 2020

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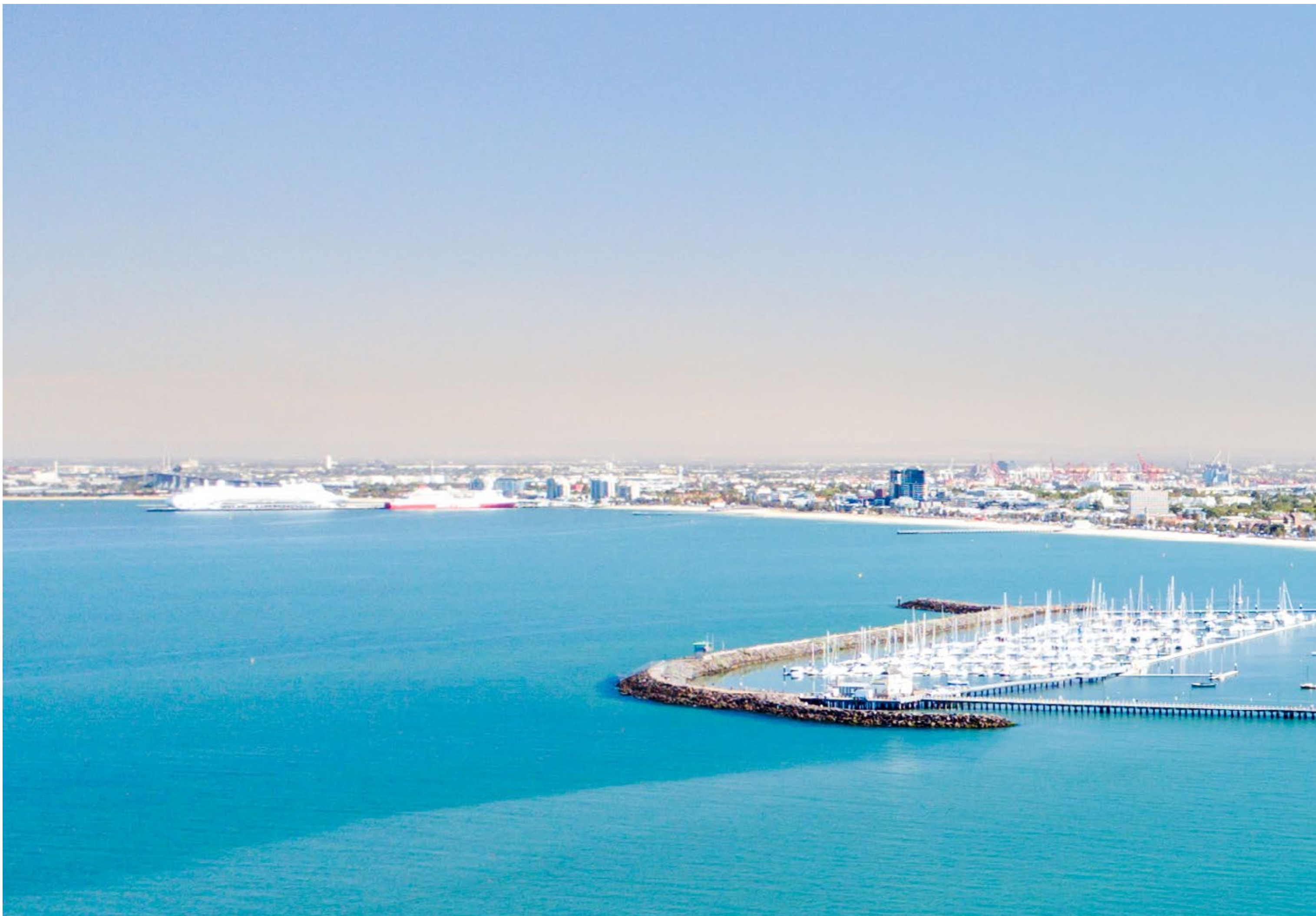


Acknowledgement of country

The Port Phillip EcoCentre acknowledges the First Peoples on whose lands and waters this research took place.

We acknowledge Kulin Nation Elders past, present, and emerging and we strive to uphold their connection to the land and waters. We recognise that their sovereignty of these lands and waters was never ceded.

Partners

Clean Bay Blueprint involved a large geographical range, and associated land and water managers and communities. The project outcomes achieved would never have been possible without the collaboration and contribution of our project partners.

Our primary project partners were the Department of Environment, Land, Water and Planning, Yarra Riverkeeper Association, Werribee River Association, Beach Patrol Australia (in particular the St Kilda, Rye, Seaford, Frankston, Mt Martha and Werribee groups), Balcombe Estuary Reserve Group Mt Martha, Dolphin Research Institute, Bellarine Catchment Network, Monash University, Worcester Polytechnic Institute, Blairgowrie Yacht Squadron, and 5 Gyres Institute. A full list of contributors can be found in the Acknowledgements.

Clean Bay Blueprint was funded by the Port Phillip Bay Fund.

VICTORIA
State Government

Contents

St Kilda breakwater, Port Phillip Bay.

Executive summary

Clean Bay Blueprint is a three-year litter study conducted between July 2017 and June 2020. The project was funded by the Victorian Government's Port Phillip Bay Fund, as part of their commitment to deliver the *Port Phillip Bay Environmental Management Plan 2017–2027* (Port Phillip Bay EMP). The aims of Clean Bay Blueprint are conducting rigorous and replicable methods to quantify plastic pollution through microplastics trawls and beach litter audits; engaging the community in citizen science activities; and building partnerships with other organisations that target litter and Bay health. A range of complementary investigations were undertaken in parallel to the project's primary research and where appropriate, such activities as well as peer-reviewed research, inform the Clean Bay Blueprint recommendations.

Microplastics in the Yarra and Maribyrnong rivers

The potential for microplastic pollution to harm aquatic life is recognised by scientists as a global problem. Microplastics are classified as pieces of plastic smaller than 5 mm in diameter, which originate from broken-up larger plastic products. This study highlights the pervasiveness of plastics in our urban water catchments and reflects their ubiquitous use, mobility, and extreme persistence.

The trawls removed a total of 40,030 litter items from the surface waters of the Yarra and 13,658 litter items from the surface waters of the Maribyrnong River. **In total, over 2.5 billion litter items flow into Port Phillip Bay annually from the two rivers' surface waters. Over 2 billion (85%) of these items are microplastics.** Microplastics accounted for 85% and 83% of the total litter count in the Yarra and Maribyrnong, respectively.

In both rivers, the vast bulk of the litter caught consisted of hard plastic remnants of broken-up plastic items, followed by polystyrene and soft plastics. Polystyrene is more problematic in the Yarra, whereas the Maribyrnong carries relatively more nurdles, plastic bottle caps, plastic straws, twine and cigarette butts.

Although large variations in monthly collections were noted through the entire study period, it was found the Yarra River carries significantly more litter than the Maribyrnong.

An alarming result of this study is that litter is increasing in both the Maribyrnong and the Yarra, with plastic pollution in the Yarra increasing at a much faster rate. The rate at which plastic pollution in both rivers is increasing is very high: litter in the Yarra increased by 400% in 2017 compared to 2016, and then in 2019 it again more than doubled compared to 2018 levels. The Maribyrnong saw a more gradual increase over time, but still increased by around 57% to 83% year on year since 2017.

Interestingly, plastic straws is the only litter item category declining over time. This is most likely due to community advocacy and action by retailers to reduce their use, showing that community action and individual behaviour change work.

Microplastics trawls in the Bay

To gain insight into the relative quantities of microplastics entering the Bay from Bass Strait as compared to the major rivers, a pilot project of nine manta net trawls was conducted at the entrance to Port Phillip Bay.

Of the nine trawl samples collected at Pope's Eye in Port Phillip Bay, eight contained plastics. Microplastics made up 64% of samples. The most prevalent items were hard plastic fragments, which aligns with results from the river trawls and Baykeeper beach litter audits.

Baykeeper Beach Litter Audits

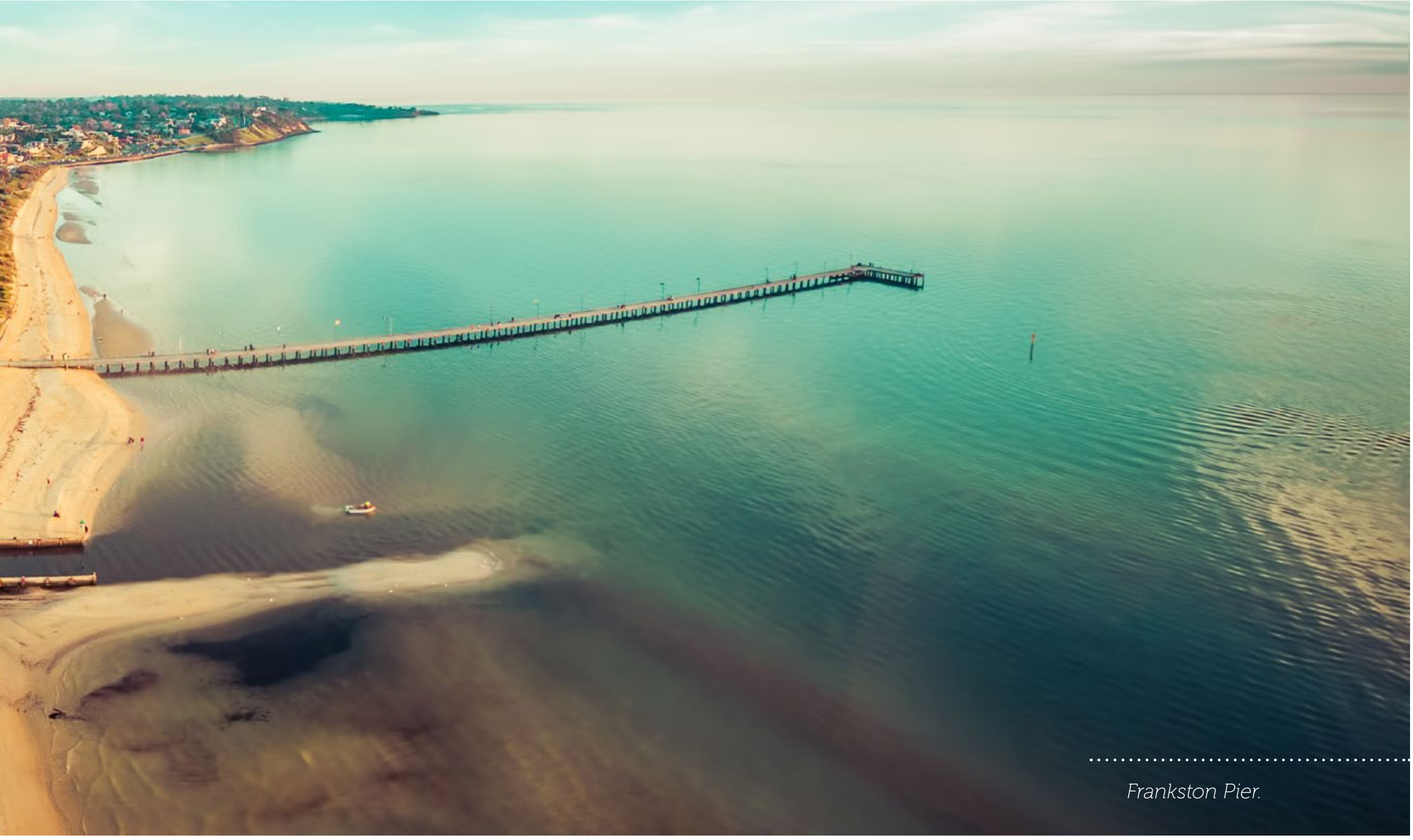
The Baykeeper Beach Litter Audit is a citizen science method designed to focus on microplastic pollution. Twelve beaches around the Bay were surveyed multiple times with the help of various community groups. Hard plastic fragments and nurdles were the most recorded items.

Recommendations

In view of the high quantities of litter and microplastics recorded in this study, the negative effects plastic pollution may have on wildlife in Port Phillip Bay, and the potential threat to human health in the longer term, six recommendations for land managers, government, industry and researchers have been formulated based on the findings in this report.

1. Improve product stewardship

- 1.1. Transition to a circular economy model
- 1.2. Invest in implementing alternatives to plastic
- 1.3. Set limits on virgin plastic production
- 1.4. Ban broad-scale groups of problematic single-use plastics
- 1.5. Make the **Operation CleanSweep** program mandatory


Frankston Pier.

2. **Cultivate effective partnerships**
3. **Support local councils in waste management**
   3.1. Install and maintain pollutant traps in drain outlets that discharge into creeks and rivers
   3.2. Enforce litter and illegal dumping laws
   3.3. Run effective litter prevention and education programs
   3.4. Review and improve current street-sweeping schedules
4. **Continue monitoring (micro)plastics pollution**
5. **Increase education and 'plastic literacy' of all plastic users**
   5.1. Set standard legal definitions
   5.2. Develop project grants, forums and strategic, ongoing partnerships
   5.3 Adequately resource groups who educate and facilitate action on plastic pollution.
6. **Conduct further research**
   6.1. Conduct depth-sampling studies
   6.2. Conduct sediment studies
   6.3. Prioritise understanding the contaminants carried by plastic in waterways, and associated human health risks
   6.4. Conduct on-ground investigations for major sources

A wide body of research now confirms that the current pace of rethinking plastics is insufficient to match the scale of increasing plastic pollution in our air, water, soil, food chain and human bodies. Substantial changes are justified. This study demonstrates that Melbourne faces an alarming increase in waterway contamination. This poses particular concern considering the relatively enclosed configuration of Port Phillip Bay, and the Bay's importance as a recreational fishery.

As of July 2021, the jurisdictions studied in Clean Bay Blueprint are subject to Victoria's legislated General Environmental Duty to protect the environment and human health. We hope this study's baseline data provides government, land and water managers, businesses and community with a clear mandate to invest in reforms that address plastic pollution's ongoing threat to Victoria's economic, social and environmental wellbeing.

EcoCentre volunteers conducting a Baykeeper Beach Litter Audit.
Image: Nat Saldumbide

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Introduction

> *Port Phillip EcoCentre*

The Port Phillip EcoCentre (the EcoCentre) is an independent environmental not-for-profit organisation. Its mission is to build relationships, educate and demonstrate sustainable environmental practice and strengthen people's connection to the natural world.

The EcoCentre is a leading community-managed organisation with a dedicated team of scientists, educators and volunteers who design and implement innovative environmental programs. Its expertise is to activate people to look after the health of Port Phillip Bay and its waterways and catchments, as well as the urban ecology of Greater Melbourne, within the traditional lands and waters of the Kulin Nation. The EcoCentre delivers specialist education, citizen science research and community action projects with over 250 cross-sector partners.

The EcoCentre is also home to the Port Phillip Baykeeper, who provides an independent voice for Port Phillip Bay. The Baykeeper is affiliated with the Waterkeeper Alliance (an international network of waterways protectors) and works closely with the Yarra Riverkeeper and Werribee Riverkeeper in protecting their respective waterways, each with a strong local support base.

Port Phillip Bay and catchments

Port Phillip Bay is the largest marine embayment in Victoria, with a surface area of 1,934 km^2 and 333 km of coastline (DELWP, 2017). It is relatively shallow at 13 m average depth, and almost half of it is less than 8 m deep. Situated along its northern shores is the City of Greater Melbourne, with a population of nearly five million people (DELWP, 2019). The City of Greater Geelong is located in the south west.

The Bay's catchment area is 9,694 km^2, with several rivers, creeks and many storm water drains draining into the Bay (DELWP, 2017). The Yarra and Maribyrnong are the largest of the rivers, and flow through heavily urbanised areas before reaching the north end of the Bay.

FIGURE 1

Figure 1: *Port Phillip Bay and catchment (Image source: Port Phillip Bay Environmental Management Plan 2017–2027, DELWP, 2017).*

Clean Bay Blueprint project

Clean Bay Blueprint is a three-year litter study conducted between July 2017 and June 2020. The project was funded by the Victorian Government's Port Phillip Bay Fund, as part of its commitment to deliver the *Port Phillip Bay Environmental Management Plan 2017–2027* (Port Phillip Bay EMP). Clean Bay Blueprint delivers outcomes for the Port Phillip Bay EMP's Priority Area 4 – Litter.

Clean Bay Blueprint takes a catchment-to-coast approach, investigating catchment, coast and Bay litter as a whole. Litter recognises no geographical boundaries as it travels from the 'burbs to the Bay; all areas are connected, which makes an integrated approach to litter research necessary. This integrated approach will help to get a better understanding of litter prevalence and movement, with the goal of informing local litter source reduction plans to achieve better environmental outcomes. To gather data from a range of regions over time, a citizen science approach was applied for community volunteers to collect and contribute data according to prescribed methods.

Project aims

This project's research methods were designed primarily to document microplastics, which are defined by Thompson et al. (2004) as plastic pieces between 1 µm and 5 mm in diameter. Microplastics in the environment mostly result from the inappropriate disposal of consumer products and industrial by-products and waste that break up into smaller pieces. Their small size renders them unlikely to be collected in conventional litter traps, by beach-cleaning rakes or manual clean-ups. The small size of microplastics causes them to be easily overlooked when picking up litter, even when clean-ups include a data recording component. Microplastics are recognised as a threat to waterways and oceans worldwide due to their small size, which makes them easily ingested by wildlife. Clean Bay Blueprint is the latest of the EcoCentre's microplastics research projects, which commenced in 2013 and has refined study methods in consultation with CSIRO, RMIT University, EPA Victoria and others.

The three aims of Clean Bay Blueprint are:

> *1. Conducting rigorous and replicable methods to quantify plastic pollution through microplastics trawls and beach litter audits*

To reflect the catchment-to-coast approach, river and Bay boat trawls as well as land-based litter audits were conducted. The quantification of microplastics in rivers by trawling is the first research project of its kind in Australia (see Chapter 3). The Baykeeper Beach Litter Audits quantify plastics and microplastics on seven beaches associated with urbanised stormwater catchments around the Bay, using an audit method that is specifically designed to collect samples that are representative of all conditions on a beach, and can be performed by citizen scientists (see Chapter 5).

> *2. Engaging the community in citizen science activities*

Citizen science is an excellent way of engaging the community in place-based learning, empowering people to take practical action to create positive change for the environment, as well as regularly gathering data to track volumes of plastic pollution over time. The Baykeeper Beach Litter Audits conducted for this project engaged various community groups, schools, tertiary students and individual community members in scientific data collection, education and conversations about plastic pollution. Awareness raised through citizen science activities is aimed to increase positive behaviour change, in addition to collecting useful data.

Evidence to support the case for governments, industry and communities to make changes to reduce any threatening process, will necessarily be collected systematically over time and space to confirm the threat is widespread and ongoing. The extent of data collection required over such time and space would not be achievable without the contribution of dedicated citizen scientists.

> *3. Building partnerships with other organisations that target litter and Bay health*

Many government, environmental and community organisations have started researching, educating and raising awareness on litter. As litter has become a problematic issue on many different levels, integrated approaches and cross-sector collaborations are integral to the success of its reduction in the environment.

Over the project life, a range of complementary projects and additional investigations took place, including land surveys, data visualisation, polymer analysis of plastic fragments, and prototyping a depth-sampling device to extend surface trawls.

Plastic pollution in the global context

Widespread production and consumption of single-use plastics, inadequate waste management and infrastructure and regulations, improper waste management practices, inadequate wastewater treatment and littering have led to tonnes of marine plastic pollution entering the ocean on a daily basis. Jambeck et al. (2015) estimated that around eight million metric tonnes of our plastic waste enter the oceans from land each year, often via rivers (Mani et al., 2015).

Two main types of hard microplastics are found most often in waterways and oceans: nurdles and fragments (Barnes et al., 2009). Nurdles, also known as pre-production pellets, are the pre-fabrication material for a wide range of industrial and consumer plastic products. They are classified as primary plastics and they enter the aquatic environment mainly through accidental spillage and poor product management at processing plants and during transport (Cole et al., 2011). They are spherical or flat-cylindrical in shape and are often transparent or black, although it is not uncommon to find white, red, yellow and blue nurdles (picture 1). Hard plastic fragments are known as secondary microplastics, and are derived from the breakup of larger plastic items. They are irregular in shape and vary greatly in colour due to their primary design. Once in the ocean, microplastics can persist for thousands of years (Andrady, 2006) and have been observed in marine systems worldwide (Cole et al., 2011, Barnes et al., 2009).

PICTURE 1

Picture 1: *Nurdles (left) and hard plastics fragments (right).*

In 2018 alone, 359 million metric tonnes of plastic were produced globally (Statista, 2020) and modelling by Borelle et al. (2020) shows that predicted levels of plastic lost in the environment will be 53 million metric tonnes per year by 2030 if no additional action is taken. Because of plastic's durability and extreme mobility (it floats, flies and sinks), it eventually enters our waterways either by accident or intentionally (Moore and Phillips, 2011).

The large litter items frequently captured in this study, including straws, lolly wrappers and plastic bottle caps, eventually deteriorate through physical, biological and chemical processes (Andrady, 2011) into tiny fragments that enter Port Phillip Bay at an alarming rate and can be ingested by aquatic animals.

> *Effects on living organisms*

Marine plastic pollution has become an urgent issue affecting wildlife in waterways and oceans. Worldwide, at least 690 species have encountered plastic pollution, many of which are listed as threatened species (Gall and Thompson, 2015). Ingestion of plastic, including microplastics, can lead to injury (e.g. blocked digestive tracts and organ rupture) and death (Lavers et al., 2014).

Furthermore, in addition to leachable chemicals that are added in the manufacturing process itself, plastics adsorb (attract as an exterior film) organic micro-pollutants or persistent organic pollutants (POPs), which include polychlorinated biphenyls (PCBs), Dichlorodiphenyldichloroethylene (DDE) and nonylphenol (Teuten et al., 2009). The ingestion of these toxic chemicals is known to affect the physiology and behaviour of organisms, which ultimately affects population stability, as shown by reproductive dysfunctions caused by PCBs in orca and dolphin populations in Europe (Jepson, 2016). Lamb et al. (2018) calculated that the likelihood of disease in corals that are in physical contact with plastics increases from 4% to 89% and that by 2025, an estimated 4.44 billion pieces of plastic items will be entangled in coral reefs through the Asia-Pacific. Plastic chemicals bioaccumulate and biomagnify up the food chain (Figure 2). This increasing concentration of toxic chemicals in the tissues of organisms at successively higher levels in a food chain has been linked to disease and death in several top predators (Gall and Thompson, 2015).

FIGURE 2

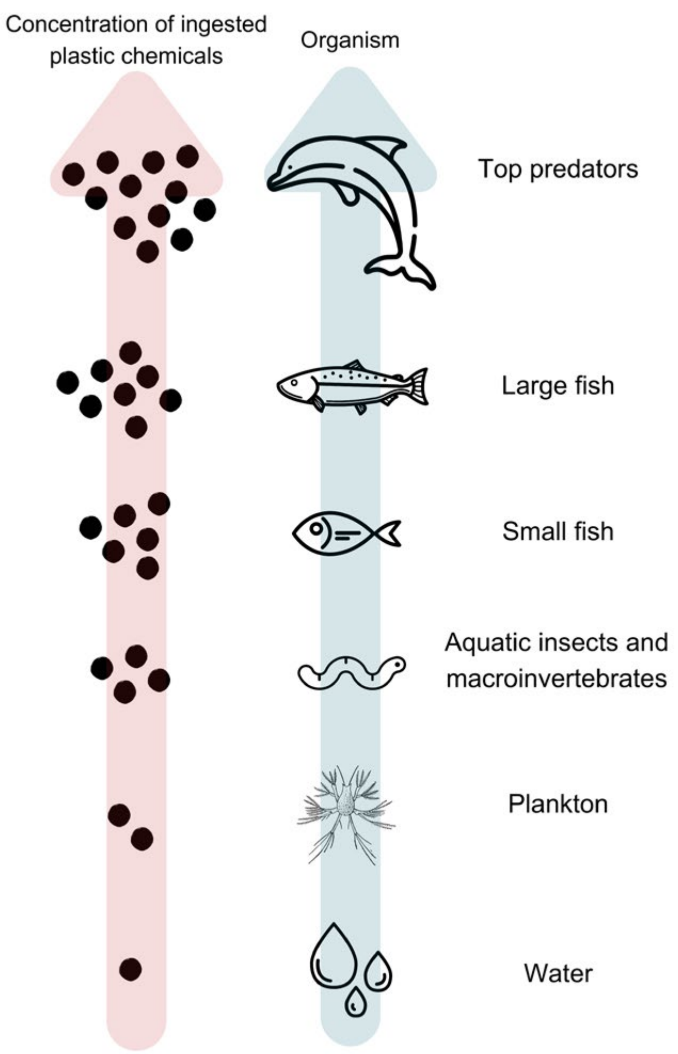


Figure 2: The process of biomagnification of plastic toxins up the food chain.

Relatively few marine and freshwater systems in Australia have been systematically investigated for microplastic pollution. This is of grave concern considering coastal and estuarine systems around Australia are some of the most biodiverse ecosystems in the world. More particularly, the relatively enclosed waters of Port Phillip Bay, which supports an aquaculture industry and a growing recreational fishery, are subject to runoff from urbanised catchments. The potential for marine plastic pollution to cause environmental harm is recognised as a global problem and is listed as one of the greatest threats to marine biodiversity (Gall and Thompson, 2015, Depledge et al., 2013). A review of current understandings of microplastics in the environment and future research needs by Zeynep and Basak (2019) concluded that the extent and effects of microplastic pollution in continental environments such as rivers, lakes, soil and air is still poorly understood. Microplastic contamination of aquatic environments will continue to increase for the foreseeable future and at present there are significant knowledge gaps on the occurrence in the aquatic environment and organisms of the smaller sized microplastics (less than 150 µm) and their possible effects on seafood safety (Lusher et al., 2017).

Several studies have shown that plastics are now inside human bodies via our food (Kim et al, 2018), drinking water (Orb Media, 2017) and even the air we breathe (Gasperi et al., 2018). It is currently unknown what, if any, health effects there are on human populations (WHO, 2019). However, in 2019 a research program started in the Netherlands, investigating the potential health effects of ingested microplastics in humans (ZonMW, 2019). Results of these studies will be released in the near future.

> *Climate impacts of plastics*

Plastic is linked to climate impacts through emissions at multiple stages of its lifecycle. Greenhouse gas emissions happen at every step in the lifecycle of a plastic product: the extraction of fossil fuels and transport; plastic refining and manufacture; plastic waste management and the ongoing impacts of it while polluting the environment, including the oceans (CIEL, 2019). Plastic continues to release greenhouse gases as it photodegrades when littered (Royer, 2018), and produces methane when degrading in landfills (Chidambarampadmavathy, 2017). Plastic production also requires large volumes of water in a world with finite availability of clean freshwater.

> *The cost of marine plastic pollution*

The following paragraphs are taken from *Toxic tide: the threat of marine plastic pollution in Australia*, a report delivered to the Federal Senate by the Environmental & Communications References Committee (Commonwealth of Australia, 2016):

> *2.66 Professor Smith stated that 'a key problem in determining the source of all items is that fragmented plastics are often the most numerous and there is no simple way to determine their source'. Professor Underwood similarly told the committee that there is 'insufficient research' to answer the question of where marine plastic pollution is sourced.*

> *2.96 Dr Britta Denise Hardesty, CSIRO, commented that 'the cost of littering and debris to fisheries, small business and human health remain poorly understood, and littering costs to local government due to remediation and tourism losses are substantial'. In answer to the committee's questions concerning the estimates of the damage from marine debris on Australia's tourism, fishing and shipping, the Department of the Environment added that it did not have any estimates nor did other Commonwealth agencies including the Great Barrier Reef Marine Park Authority, the Australian Maritime Safety Authority and the Australian Fisheries Management Authority.*

Other than projects funded by the Port Phillip Bay Fund, there has been limited research to address knowledge gaps in relation to sources and ecosystem impacts of plastic pollution across Australia since the release of the Senate Inquiry report in 2016.

Plastic pollution in Victoria

Locally, Port Phillip Bay and surrounding waters are supporting an ecosystem that is home to an estimated 10,000 species, with many of those species unique to the Bay[1]. Most plastic pollution in Port Phillip Bay originates from land-based sources. Diverse sources include urban streets, freeways and roadside verges, stormwater drains, wastewater treatment plants, and river and creek runoff. Although plastic pollution has been repeatedly identified as a major threat to Victorian waterways, there has been limited scientific assessment since the Melbourne Water Tagged Litter Study in 1993. The EcoCentre's Yarra and Maribyrnong river trawls commenced in 2014, the Litter Trackers project by RMIT and Melbourne Water was conducted in 2019, and Sustainability Victoria recently conducted a microplastics study on six beaches around the Bay. In this study, they found between 16.7 and 123.2 microscopic microfibres from clothing per kilogram of sand (Sustainability Victoria, 2019).

The Yarra Riverkeeper Association removed approximately 8,000 kg of waste from the Yarra and Maribyrnong between 2017 and 2020 (Kowalczyk and Kelly, 2020), with some of the most common collected items being foam insulation and packaging, plastic bottles and cigarette butts. Both this project and their 2020 polystyrene study, in

[1] *https://www.marineandcoasts.vic.gov.au/grants/port-phillip-bay-fund*

collaboration with Clean Water Group, point to polystyrene being a major waterway pollutant in metro Melbourne (Barmand et al., 2020).

Community groups such as Beach Patrol, Bellarine Catchment Network, various Friends groups and others across the catchments spend countless hours of people power cleaning up beaches and waterways. Over the last few years, the EcoCentre has played a role in shifting the general focus from merely picking up and disposing of the litter, to collecting data on what is found, to be used in advocacy efforts to reduce plastic pollution in the environment. Since February 2018, Scouts Victoria and the EcoCentre have collaborated in the state government–funded **Street2Bay** project, conducting litter audits with particular attention to microplastics on streets in all catchments around the Bay.

Bandalong litter trap in the Yarra.


A close-up of the Balcombe Estuary nurdles.

Policy context

> Australia

From 2018, China's new bans and 99.5% purity standards for uncontaminated recyclables left Australia with large stockpiles of items now needing onshore processing. Extensive ripple impacts of this challenge – from facility fires to paying fees to send recyclable plastics to landfill – have compelled significant rethinking of Australian waste management systems, including materials redesign, reduction, re-use and recycling. Industry bodies and the Australian Government considered plastics and other materials in a range of commitments and aspirations towards an Australian *circular economy,* in which 'waste' and pollution are designed out, and products and materials are kept in use through principles such as repair and maximising use of recycled materials over virgin resources.

Australia's *National Waste Policy: Less waste, more resources* (Commonwealth of Australia, 2018) and *National Waste Policy Action Plan* (2019) apply the 'principles of a circular economy to waste management, to support better and repeated use of our resources.' The targets include reducing Australian waste by 10% per capita by 2030, and to 'phase out problematic and unnecessary plastics by 2025.' Waste policies focus on plastic diversion from landfill; however, plastic uncontained by management systems (e.g. lost as litter, dumping or spillage) becomes pollution of ecological and economic concern due to its persistence in the environment. On 18 June 2015, the Senate referred the threat of marine plastic pollution in Australia for parliamentary inquiry and report by 8 April 2016. The final report, *Toxic tide: the threat of marine plastic pollution in Australia,* was presented on 20 April 2016 (Commonwealth of Australia, 2016). The need for systematic data collection on the extent of plastic pollution was stated in Recommendation 1 of the report:

Blair Stafford conducting a microplastics trawl in the Bay with a manta net.

The committee recommends that any future Australian Government policies on mitigating the threat from marine plastic be underpinned by sound, peer-reviewed research.

> *Victoria*

Plastic pollution is relevant under a range of Victorian policies and strategies to manage waste, and protect human health and biodiversity. In some instances, plastic pollution is discussed explicitly, as in the plastic bag ban (*Environment Protection Amendment Act 2019*) or *Recycling Victoria* 'Key Commitment 3: Address plastics pollution'. Managing plastics can also fall under broader principles such as the goal 'Victoria's natural environment is healthy' in *Biodiversity 2037*; the 'wastes hierarchy' principle of environmental protection in the *Environmental Protection Act Victoria* (1970); and the introduction of General Environmental Duty in the *Environment Protection Amendment Act 2018*. The General Environmental Duty requires all Victorians to manage risks to human health and the environment that their activities create, and becomes active from July 2021.

Studies that quantify the effects and extent of microplastics are necessary to inform policy frameworks that reduce plastic pollution, establish waterway management strategies and assess biodiversity health. Interim results of the Clean Bay Blueprint study have helped inform government documents including:

- *State of the Yarra and its Parklands* (2018) – Commissioner for Environmental Sustainability Victoria
- *Assessment of the Values of Victoria's Marine Environment* (2019) – Victorian Environmental Assessment Council

A written submission by the EcoCentre to the 2018 review of the State Environment Protection Policy (Waters), using the results of EcoCentre microplastics studies, led to 'plastics and microplastics' being added to the list of legally defined waterway pollutants in Victoria.

Prior to the EcoCentre's research, plastic and microplastic pollution were not reported in Victorian State of the Environment reports, nor specifically included in legislated protections.

> *Worldwide*

The United Nations Sustainable Development Goals (SDGs) are 17 interlinked goals to achieve 'a better and more sustainable future for all,' The management of plastic materials relates to several SDGs:

- Goal 12: Responsible production and consumption
- Goal 13: Climate action
- Goal 14: Life below water
- Goal 15: Life on land

The United Nations Environment Programme (UNEP) has produced numerous studies on plastic pollution and prevention in the last five years. Assessing policy efforts in 60 countries around the globe, the UNEP reports *Single-Use Plastics: Roadmap to Sustainability* (2018), includes ten recommendations including (1) target the most problematic single-use plastics by collecting baseline data; (5) raise public awareness; (7) provide incentives to industry; and (9) enforce new measures effectively.

In 2020, Duke University launched a Plastics Policy Inventory[2] as a searchable database of public policy documents targeting plastic pollution. This includes the language, year enacted, location and jurisdictional level. This document is updated quarterly due to the rapidly evolving nature of policy responses to address the health, economic and amenity threats of plastic and microplastic pollution.

[2] *https://nicholasinstitute.duke.edu/plastics-policy-inventory*

3

Melbourne City over the Yarra River.

Microplastics in the Yarra and Maribyrnong Rivers

The first ever litter trawls done in rivers in Australia were conducted by the EcoCentre in 2013. The resulting report, *Pilot study to identify the extent of microplastics in the Maribyrnong and Yarra Rivers and Port Phillip Bay* (July 2014), showed that microplastics were present in Melbourne's two largest rivers. As a result of this pilot study, monthly trawls were continued through the **Turn off the Tap** project (2014–2017), funded by the Victorian Government. The final samples of this study spiked in microplastic litter, which seemed to show an upward trend over time indicating further investigation was warranted. Subsequently, the Port Phillip Bay Fund funded Clean Bay Blueprint (2017–2020) for another three years of continuous research. This report presents analysis of the outputs from both these projects and uses the full 5.5 years of data collected.

Aims of the microplastics study

Within Clean Bay Blueprint, the quantification of plastics and microplastics in Melbourne's two largest rivers was done as a contained research study, which continued from a previous dataset collected between 2015 and 2017. Its aims were the following:

> *Quantifying plastic pollution to inform legislative reform and behaviour change*

When trawls commenced in 2014, there was no reported evidence of the ongoing presence of microplastic pollution in the rivers and Bay, apart from personal observations. As legislative reform and management decisions around litter need to be driven by scientific evidence, the first aims of the study were to confirm the presence and quantify the extent of the pollution.

> *Tracking changes in litter over time and establishing a baseline*

Once presence is established, the next step is to monitor litter loads over time, in order to track if volumes increase or decrease. Continuous monitoring measures a baseline state of the river, which can be used to measure the effectiveness of anti-litter measures taken to reduce the loss of certain items in the environment. In addition, monitoring allows researchers to notice unusual spikes in litter loads or items that may have been the result of mass spills and one-off pollution events, and might otherwise go unnoticed.

> *Identifying the source of litter items*

By tracking and quantifying the different litter items encountered (e.g. polystyrene balls, plastic drinking straws, cigarette butts) it may be possible to identify

FIGURE 3

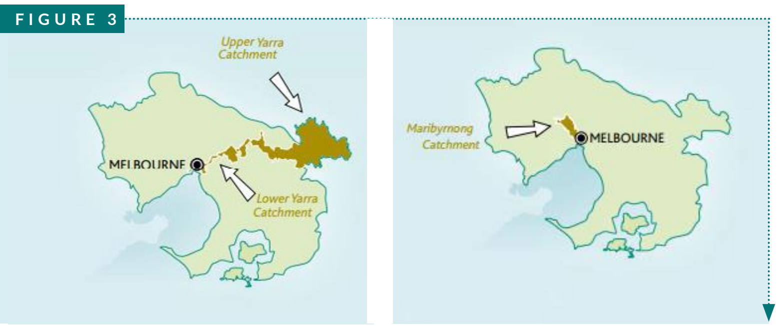
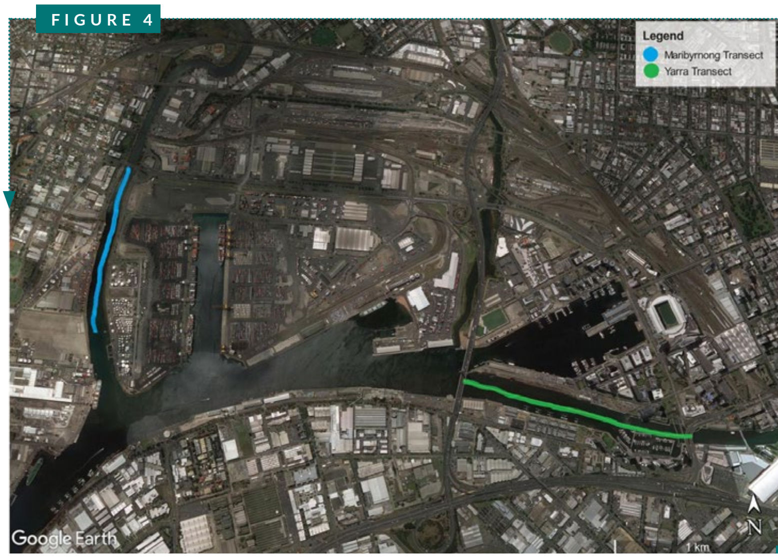


FIGURE 4



their potential source locations. This evidence could be used to inform localised source reduction plans to prevent an item type from entering the environment in the first place. Anecdotally known problem items were analysed as distinct categories, to learn more about their prevalence in the waterways.

Study method

> *Study site*

The Yarra River flows 242 km from its source in the forested Yarra Ranges National Park through to central Melbourne where it enters Port Phillip Bay. More than one-third of Victoria's population lives in the Yarra catchment, which covers about 4,000 km^2 (Barua et al., 2013). The catchment includes 40 rivers and creeks, including the Maribyrnong River, which runs for 160 km from its source on the slopes of Mount Macedon. The Maribyrnong catchment covers 1,408 km^2.

The trawl sites were selected on the basis of being close to the lower reaches of each river and therefore indicative of the total pollution load of each respective catchment (Figures 3 and 4). The Maribyrnong trawls commenced at the Water Canon Jetty extending from the west bank of Coode Island, 300 m upstream from the Yarra. The Yarra trawls commenced underneath Bolte Bridge, 2.5 km upstream of the Yarra and Maribyrnong confluence.

Figure 3: *The locations of the Maribyrnong and Yarra catchments relative to the centre of Melbourne. Images courtesy of Melbourne Water.*

Figure 4: *Approximate trawl location transects in the Maribyrnong and Yarra Rivers.*

> *River trawls*

A manta net designed to collect floating debris off the water's surface was deployed from the side of the boat and positioned outside of the wake zone (picture 4A). Trawling was done according to internationally standardised methods by Galgani et al. (2013): in each river, all trawls commenced at the same place, travelling upstream for 30 minutes with the boat motor operated at a constant 1,000 rpm to operate the net effectively and maintain a consistent speed for all trawls. After 30 minutes the net was retrieved, the collection net (cod end) removed (picture 4B), and placed in a container to be dried in preparation for sorting and categorising the contents.

Between January 2015 and February 2020, a total of 113 monthly trawls were conducted in the Maribyrnong and Yarra Rivers. Both rivers were trawled on the same day. The distance covered in each trawl varied slightly due to the effects of different tides and prevailing wind conditions encountered at the time. While trawls were generally done in a straight line, river boating involves changing course to safely navigate around other watercraft that may be encountered, and the course of the trawls in each river was not rigidly defined.

The 'mouth' of the manta net measures 600 mm wide x 200 mm deep. The net is 3 m long tapering down to a 30 x 10 cm^2 cod end. Both the tapering net and cod end are made of a 330 nm mesh size. The manta net is of the same specifications used by the 5 Gyres Institute to measure microplastics in international studies. In a recent review of methods that measure microplastics in aquatic environments, Mai et al. (2018) confirmed that this collection method is recommended for large-scale surface water sampling.

PICTURE 4A

PICTURE 4B

PICTURE 5

> *Sample analysis method*

Sample sorting was performed by trained citizen scientists (picture 5). Dried trawl samples were analysed by separating litter items from organic matter with the naked eye, using tweezers and supplemental lighting. Litter items were next sorted by item type and the diameter measured with a ruler, after which the item was placed in the corresponding size category. Litter categories included hard plastic fragments < 2 mm, hard plastic fragments 2 mm–5 mm, hard plastic fragments 6–10 mm, hard plastic fragments > 10 mm, polystyrene beads < 4 mm, polystyrene beads ≥ 4 mm, plastic bottle caps, plastic straws, soft plastics < 5 mm, soft plastics ≥ 5 mm, lolly wrappers, cellophane < 5 mm, cellophane ≥ 5 mm, plastic pre-production pellets (nurdles), cigarette butts, twine, sponge (synthetic sponge-like materials) and 'other' items, which included unidentified, non-organic looking items.

Internationally accepted guidelines define plastic pieces smaller than 5 mm in diameter as microplastics (Thompson et al., 2004). In this study, the categories of hard plastic fragments < 2 mm, hard plastic fragments 2 mm–5 mm, soft plastics < 5 mm, cellophane < 5 mm, nurdles and polystyrene beads < 4 mm were grouped into the microplastic category. Plastic items not visible to the naked eye, including microfibres, were excluded from this study due to logistical, technical and funding constraints.

Picture 4:
A. Manta net deployed on side of Yarra Riverkeeper vessel;
B. Removable cod end used to collect microplastic samples.

Picture 5: *Citizen scientists sorting trawl samples at the EcoCentre.*

FIGURE 5

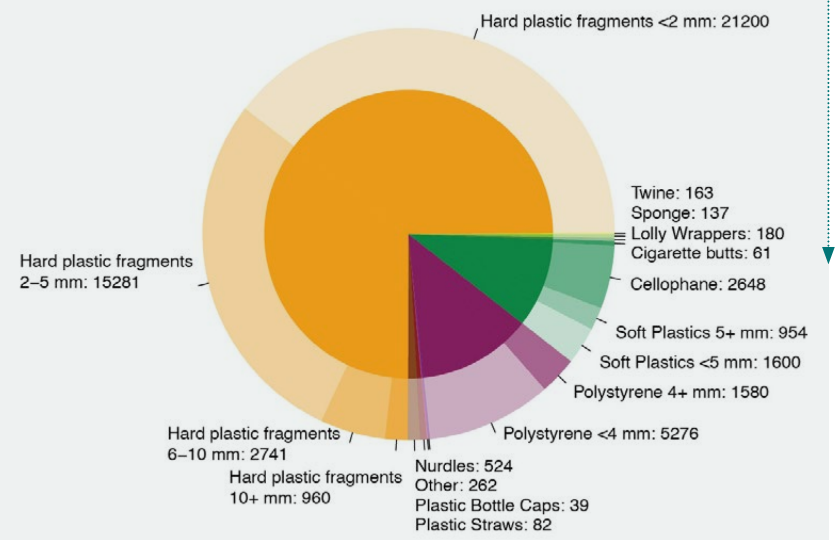


FIGURE 6

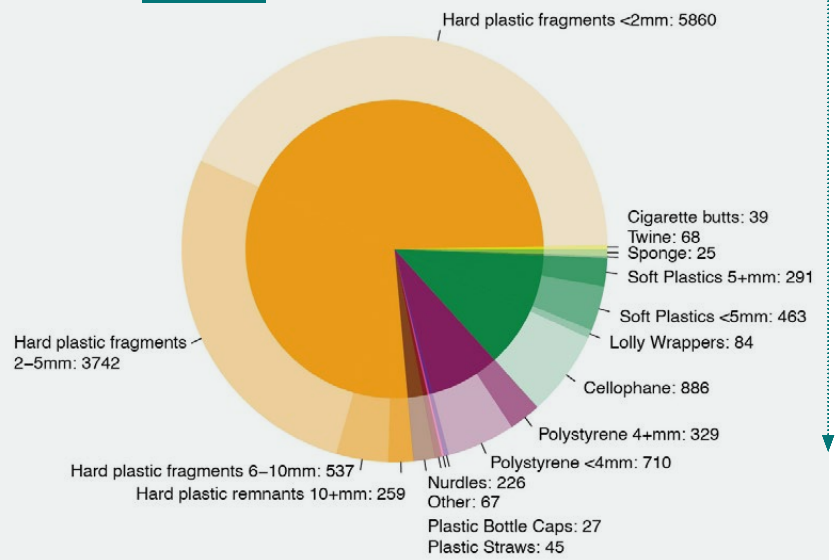
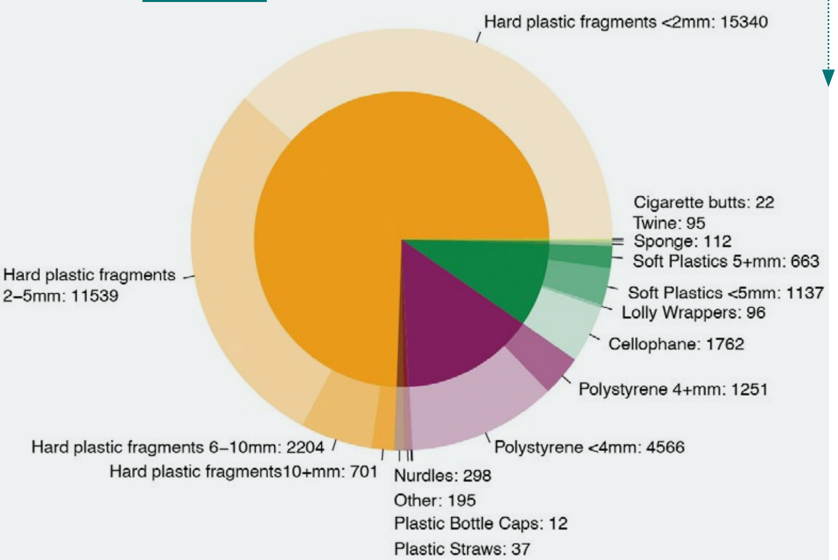


FIGURE 7



Trawl data analysis results

The results of the sample analysis show substantial concentrations of plastic litter present in the Yarra and Maribyrnong Rivers across all months of the year. A total of 40,030 litter items were captured and analysed from the Yarra and 13,658 litter items from the Maribyrnong between January 2015 and February 2020. An average of 690 litter items were collected from the Yarra per monthly trawl, while an average of 248 litter items were collected from the Maribyrnong per monthly trawl.

Because the Yarra's width in the trawl location is more than 160 times wider than the net, and the Maribyrnong's width in the trawl location is 120 times wider, the actual extrapolated volume of litter in both rivers is astounding.

For the Yarra, the rough calculation is:

> *690 litter items x 48 half-hour sessions/ day x 365 days x 160 times net width yielding* ***1,934,208,000 litter items entering the Bay from the Yarra annually.***

For the Maribyrnong, this calculation is:

> *248 litter items x 48 half-hour sessions/ day x 365 days x 120 times net width yielding* ***521,395,200 litter items entering the Bay from the Maribyrnong annually.***

Figure 5: *Relative litter composition of items flowing into Port Phillip Bay from the Maribyrnong and Yarra rivers combined.*

Figure 6: *Litter composition in trawl samples obtained from the Maribyrnong River.*

Figure 7: *Litter composition in trawl samples obtained from the Yarra River.*

These calculations suggest that an average total of **2,455,603,200 litter items flow into Port Phillip Bay annually** from surfaces of the Yarra and Maribyrnong Rivers combined.

It should be noted that since these litter items are only caught in the surface waters (upper 200 mm), this number is likely to be an underestimation of the overall plastic pollution loading in each river. Different types of plastic display different levels of buoyancy, characterised as either: positively buoyant (floating at the surface), negatively buoyant (sinks to the bottom), or, neutrally buoyant (in the water column). It is unknown how many items are present in the water column or the sediments of Melbourne's waterways.

FIGURE 8

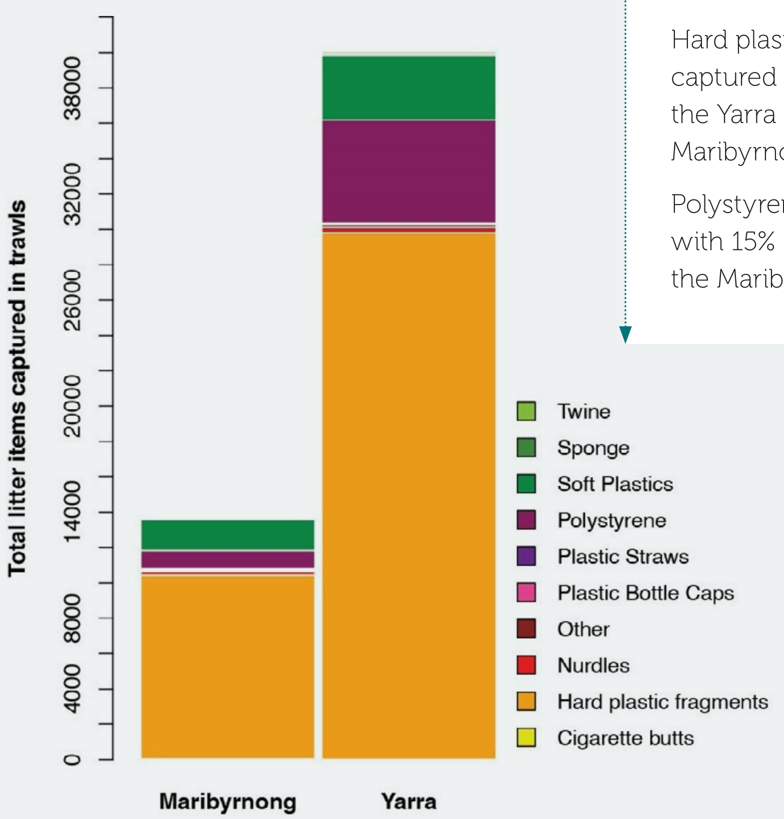


Figure 8: Comparison of number of litter items in Maribyrnong and Yarra rivers.

> Litter reaching Port Phillip Bay

Based on the 53,688 litter items caught and analysed, the composition of litter entering Port Phillip Bay shows that hard plastic fragments are by far the most prevalent litter item (75%), followed by polystyrene (13%) and soft plastics (10%) (Figure 5).

Trawl samples weighed an average of approximately 26.6 g, most of which was organic plant matter. On average, litter comprised 18.4% of the total sample weight, highlighting the pervasiveness of litter in our waterways. Over time, this percentage has stayed quite constant (see Appendix 1).

> Comparing the rivers

Hard plastic fragments, polystyrene and soft plastics were the most common items found in both the Yarra and Maribyrnong (Figures 6 & 7).

Hard plastic fragments made up the bulk of the captured litter items, comprising 74% of capture for the Yarra and 76% of items captured in the Maribyrnong.

Polystyrene was the second most captured item, with 15% of items in the Yarra and 8% of items in the Maribyrnong being polystyrene.

Soft plastics (consisting of cellophane, lolly wrappers and unidentifiable soft plastics) made up 9% of total items captured in the Yarra and 13% in the Maribyrnong.

When comparing the total litter counts between rivers, we found a significant difference between the Maribyrnong and Yarra Rivers (chi-squared = 12954, df = 1, $P < 0.001$), with plastic litter overall more likely to be found in the Yarra than the Maribyrnong (Figure 8).

There is also an overall significant effect of the rivers on distribution of plastics by item category (chi-squared = 747.26, df = 9, $P < 0.001$; Figure 9):

There are no significant differences in proportions of hard plastic fragments in the Maribyrnong or Yarra rivers ($P > 0.05$).

There are proportionally more soft plastics, nurdles, plastic bottle caps, plastic straws, twine and cigarette butts in the Maribyrnong river. Conversely proportionally less of the same items are in the Yarra river ($P < 0.05$), meaning that these items make up a higher proportion of total litter counts in the Maribyrnong than they do in the Yarra (see Appendix 2).

When comparing polystyrene loads to the expected proportions of polystyrene (based on the total counts for the rivers), the proportion of polystyrene is significantly less than expected ($P < 0.05$) in the Maribyrnong, and significantly more than expected in the Yarra ($P < 0.05$); this means polystyrene is more likely found in the Yarra than in the Maribyrnong.

The proportion of 'other' items is significantly above expected in the Maribyrnong ($P < 0.05$) but for the Yarra, the proportion of 'other' items was nonsignificant ($P > 0.05$).

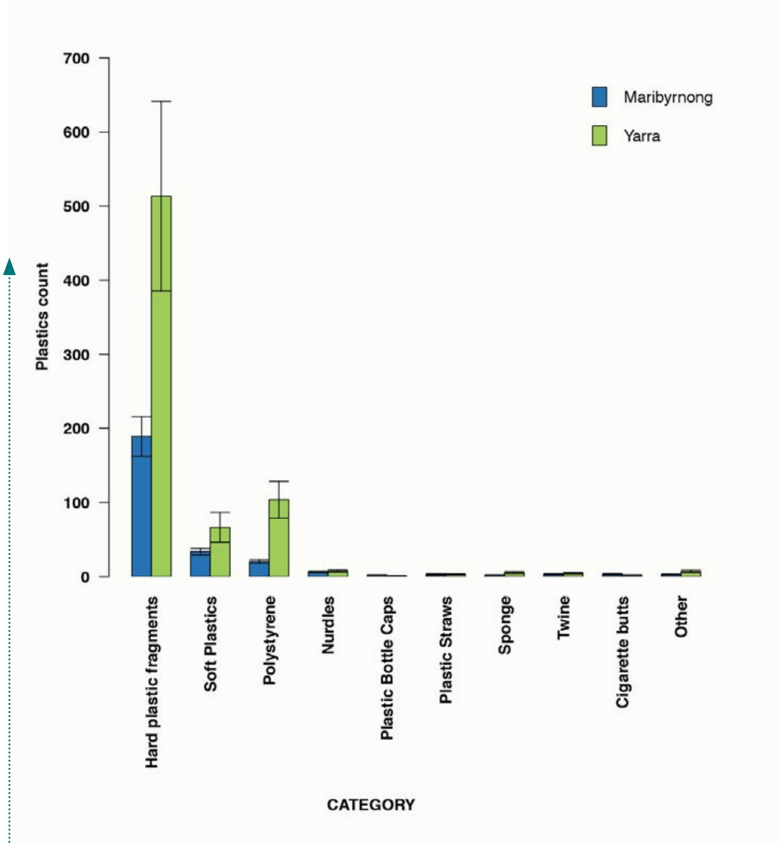


FIGURE 9

FIGURE 10

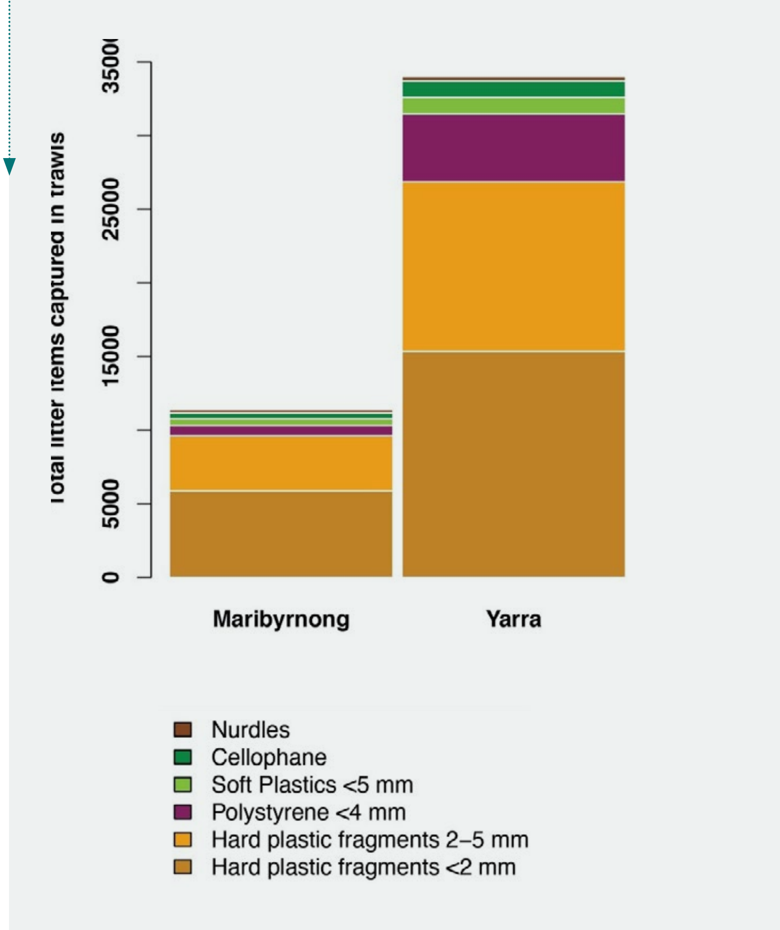


Figure 9: *Comparison of mean monthly number (±SE) of litter items captured by the manta net in the Maribyrnong and Yarra Rivers between January 2015 and February 2020. Note that values shown are means, but statistical tests were conducted on frequency of counts using chi-squared analyses (i.e. the standard errors should not be used to infer anything about statistical significance. They are rough indicators of variation around a mean only).*

Figure 10: *Comparison between rivers of the total number of microplastics captured during river trawls.*

In both rivers, microplastics formed the bulk of litter and accounted for 85% (34,013 pieces) of the total load in the Yarra and 83% (11,388 pieces) of the Maribyrnong load (Figure 10). Hard plastic fragments < 2 mm in length dominated the microplastics category and accounted for 45% and 51% of microplastics in the Yarra and Maribyrnong, respectively.

Of the earlier mentioned total litter items entering the Bay, microplastics make up nearly 85%, which means more than 2 billion (2,076,458,066) microplastics flow from the two rivers into the Bay every year.

> *Analysis of plastic polymer types*

Sorted trawl samples from July 2016 to August 2019 were sent to the Plastics Lab at RMIT, where they were analysed for plastic polymer types, using Fourier Transform Infrared Spectroscopy (FTIR)[3]. There are many polymer types, each of which has varying qualities that align it to typical uses, products or applications. Through FTIR analysis, microplastics or fragments may be grouped according to probable source products.

In both the Yarra and the Maribyrnong rivers, polyethylene (PE) was the most prevalent polymer (48% and 49%, respectively), followed by polypropylene (PP) (22% and 24%, respectively), polystyrene (PS) (15% and 7.9%, respectively).

The Yarra River saw small amounts of 11 other polymers, each of which contributed less than 1%, and 0.67% of samples were of an unknown material. The Maribyrnong saw a small abundance of other polymers, ranging from 1% to 0.05%, and had 0.88% of unknown material (see Appendix 3).

The two rivers showed similar trends over the months for all three of the most prevalent polymers. The abundance of PE and PP did not statistically differ between the Yarra and Maribyrnong (P = 0.67; P = 0.56, respectively); however, PS was statistically lower in the Maribyrnong (P = 0.02).

Interestingly, polyethylene terephthalate (PET) and polyvinylchloride (PVC) are some of the most commonly produced and used plastics, yet were some of the least recorded in both the Yarra and Maribyrnong Rivers.

> *Seasonal differences in litter*

There are significant effects of the seasons and the rivers on the total count of litter (chi-squared = 1242.9, df = 3, P < 0.001). A comparison of total litter by trawl indicates that there is more total litter in the Yarra than in the Maribyrnong in any season. There was more litter in summer in both rivers. However, proportionally, in the Maribyrnong, has more litter in spring and autumn than is expected by chance, whereas in the Yarra the clear peak seasons are summer and winter (Figure 11).

In summer and winter, plastic litter is proportionally higher in the Yarra than the Maribyrnong (P < 0.05 for both seasons). In autumn and spring, plastic litter is proportionally higher in the Maribyrnong than the Yarra (P < 0.05 for both seasons).

FIGURE 11

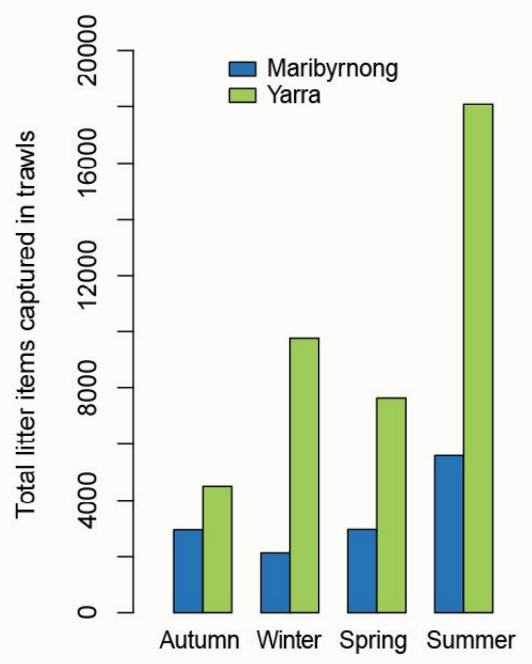


Figure 11: *Seasonal variation in the number of captured litter items in the Maribyrnong and Yarra Rivers between January 2015 and February 2020.*

[3] *This summary of results was used with permission from an unpublished Honours dissertation by M. Pattison (2020).*

FIGURE 12

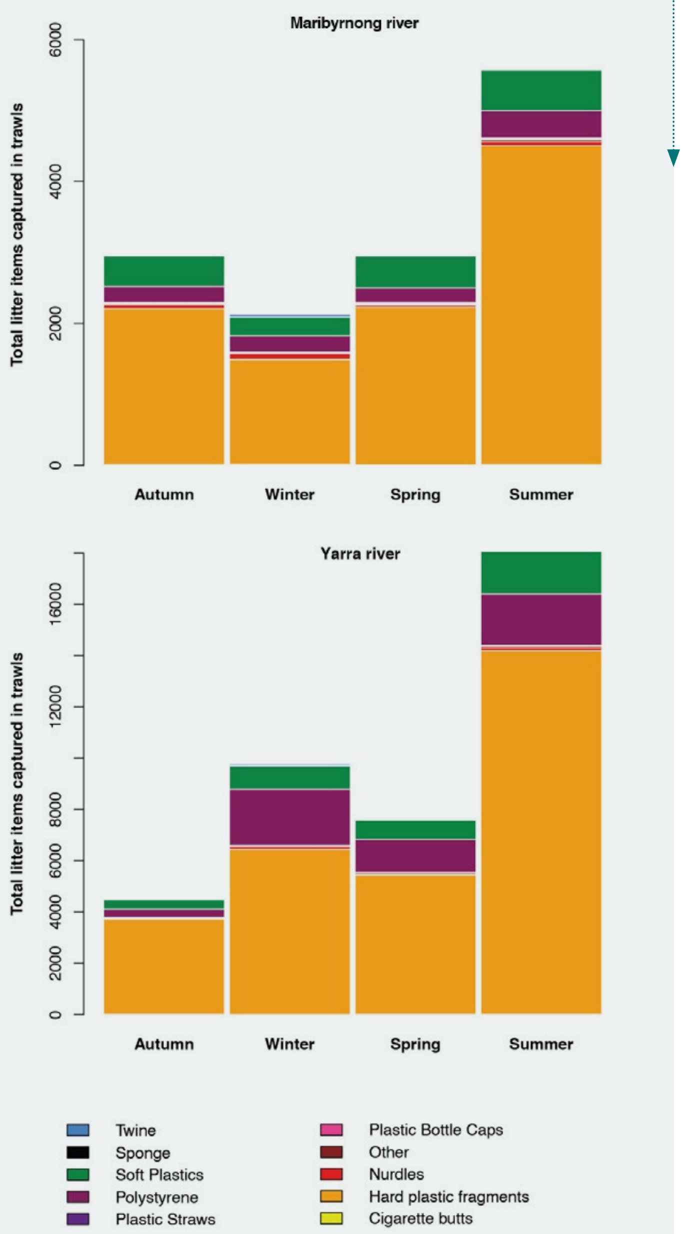


Figure 12 shows more detailed litter item distributions over the seasons for the separate rivers. Hard plastic fragments remain the largest category of items throughout all seasons in both rivers, followed by polystyrene and soft plastics.

Figure 12: *Seasonal variation in the total number of captured litter items in the Maribyrnong and Yarra Rivers between January 2015 and February 2020. Note the difference in total litter items captured on the y-axes.*

> *Changes in litter over time*

The five years of data collection reveal large increases in litter over time (Figure 13). Note the difference in numbers on the y-axes when comparing the rivers.

Both rivers are showing a significant increase in plastics over the sampling period, although the trend is somewhat more pronounced in the Yarra (tau = 0.17, z = 7.45, $P < 0.001$) than in the Maribyrnong (tau = 0.10, z = 4.16, $P < 0.001$) (Figure 14).

Note the differences in percentages on the y-axes of the respective rivers in Figures 15 and 16, which show how much faster the Yarra's litter has been increasing over the last five years. When combining the above litter numbers and percentages, there is a similar increasing trend in litter en route to Port Phillip Bay (Figure 17). It is unclear why there was such an extreme increase in litter in the Yarra in 2017.

The above results warranted a closer examination of the changes in litter item categories over time:

In the Maribyrnong, hard plastic fragments, soft plastics and 'other' are increasing over time ($P < 0.05$) (Figure 18).

Figure 19 shows that in the Yarra, hard plastic fragments, soft plastics, polystyrene, sponge and 'other' in the Yarra are increasing over time ($P < 0.05$). However, plastic straws are significantly decreasing over time (z = -2.34, tau = -0.25, P = 0.019).

All other plastics are steady, showing neither a significant increase nor decrease. See Appendix 4 for more details.

Figure 13: *Total number of captured litter items in the Maribyrnong and Yarra Rivers presented by trawl between January 2015 and February 2020. The labels indicate year, month and trawl number. A total of 62 paired trawls were conducted during this time. Several litter spikes were recorded.*

Figure 14: *Litter trends over time. Litter in both rivers is increasing, with litter in the Yarra increasing faster than in the Maribyrnong.*

FIGURE 13

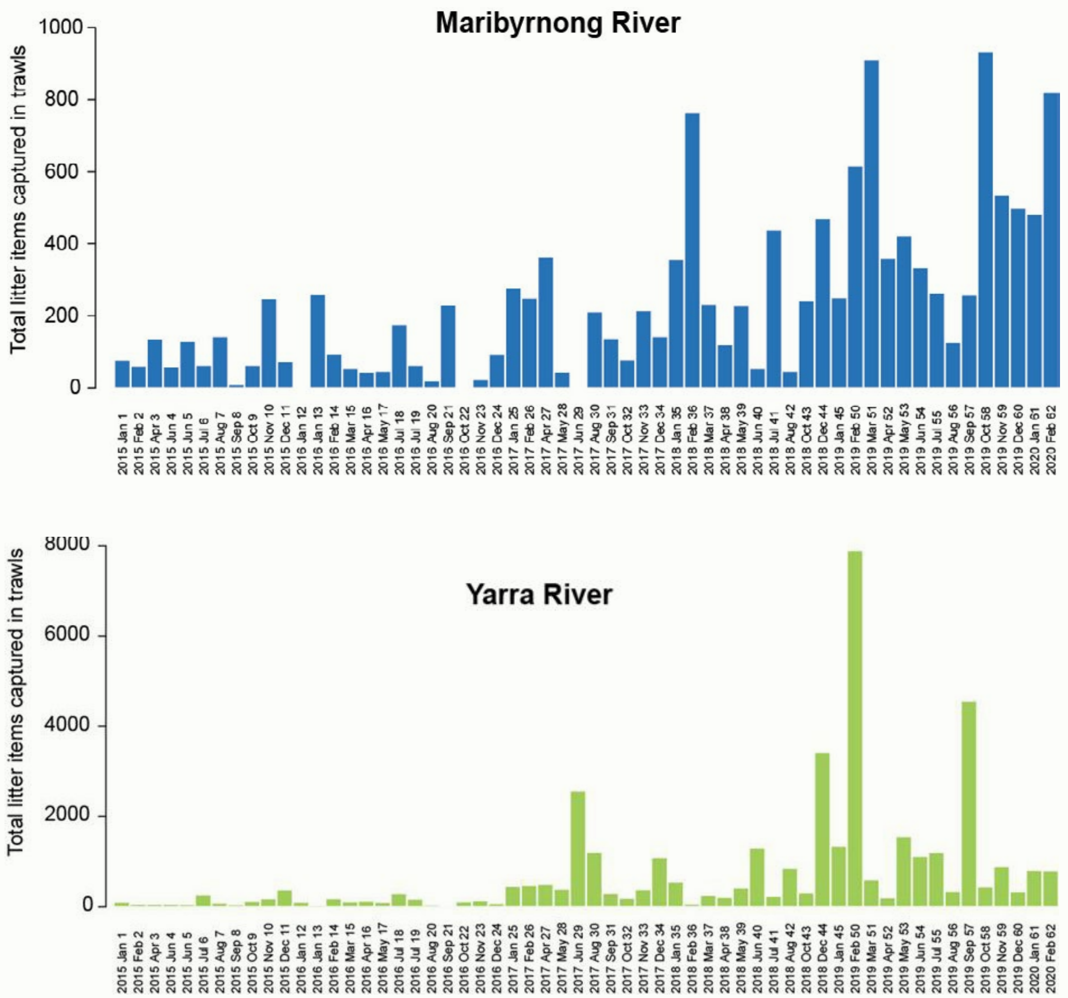
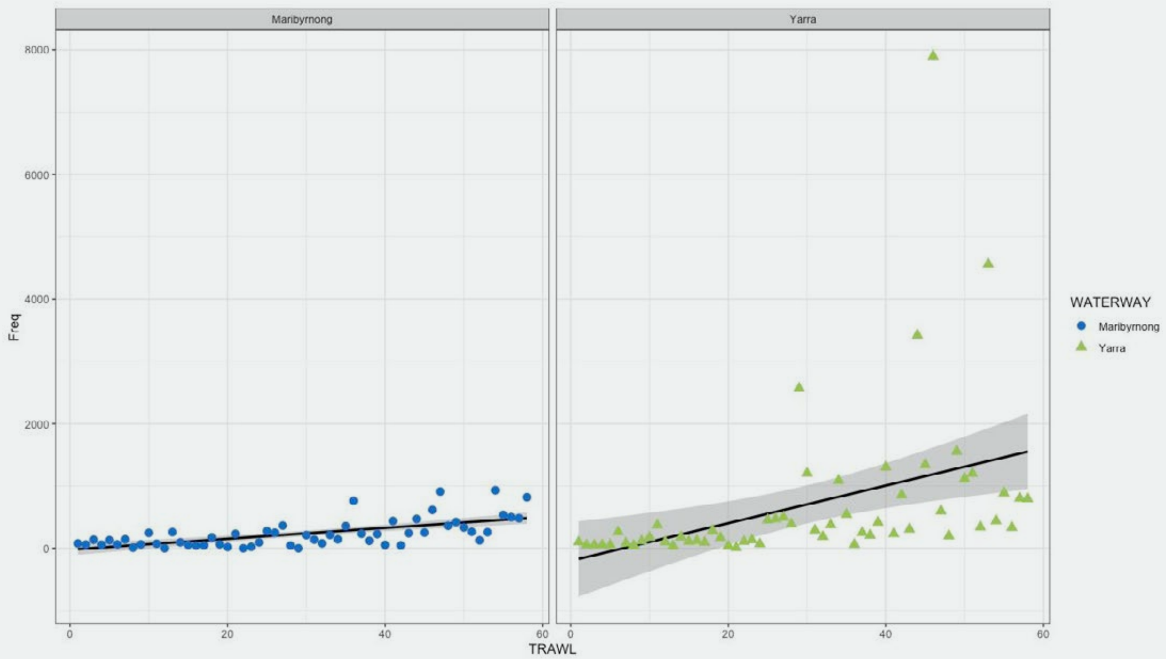


FIGURE 14



CONTENTS ▲

Baykeeper and Riverkeeper trawling for microplastics.

FIGURE 15

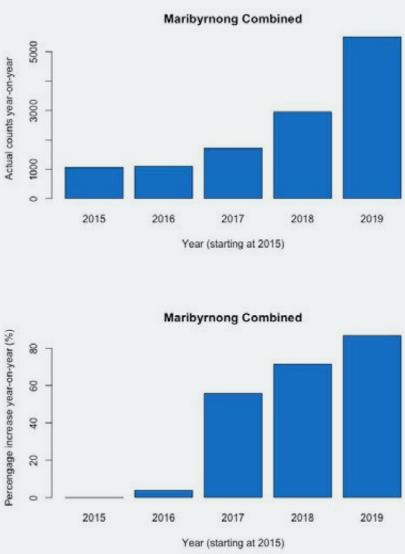


FIGURE 16

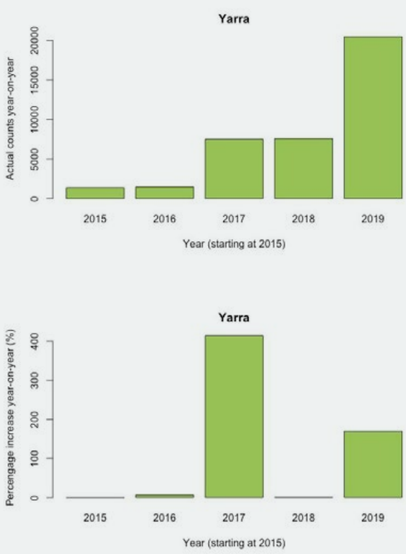


FIGURE 17

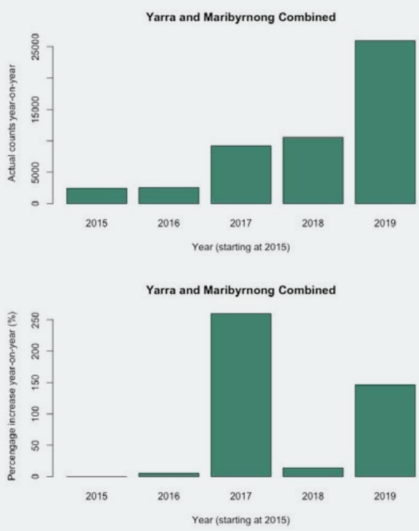
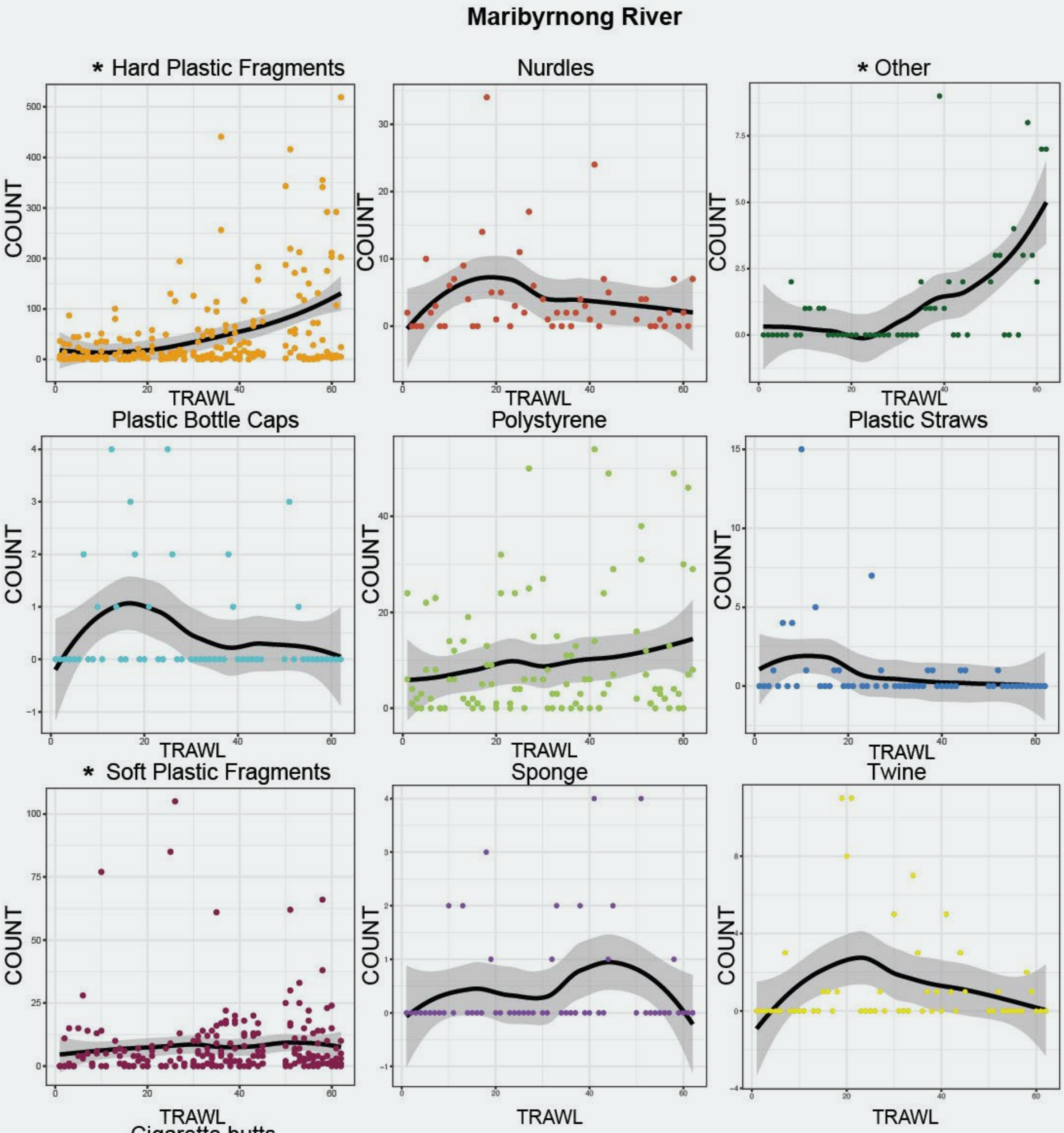


FIGURE 18



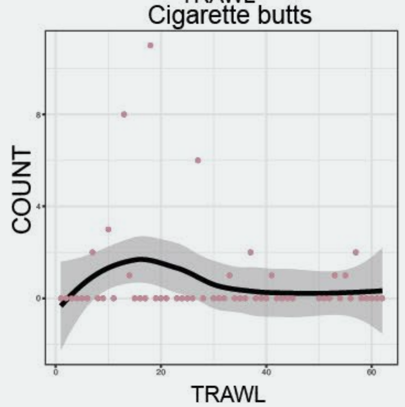


Figure 15: *Above: Actual numbers of microplastics in the Maribyrnong. Below: Percentage increase in microplastics year-on-year.*

Figure 16: *Above: Actual numbers of microplastics in Yarra. Below: Percentage increase in microplastics year-on-year.*

Figure 17: *Above: Actual numbers of microplastics flowing to Port Phillip Bay. Below: Percentage increase in microplastics year-on-year.*

Figure 18: *The number of plastic items by category across time in the Maribyrnong River (measured by trawl number). Note that axis scales are different for each plastic category. Significant relationships are marked by an asterisk (*).*

FIGURE 19

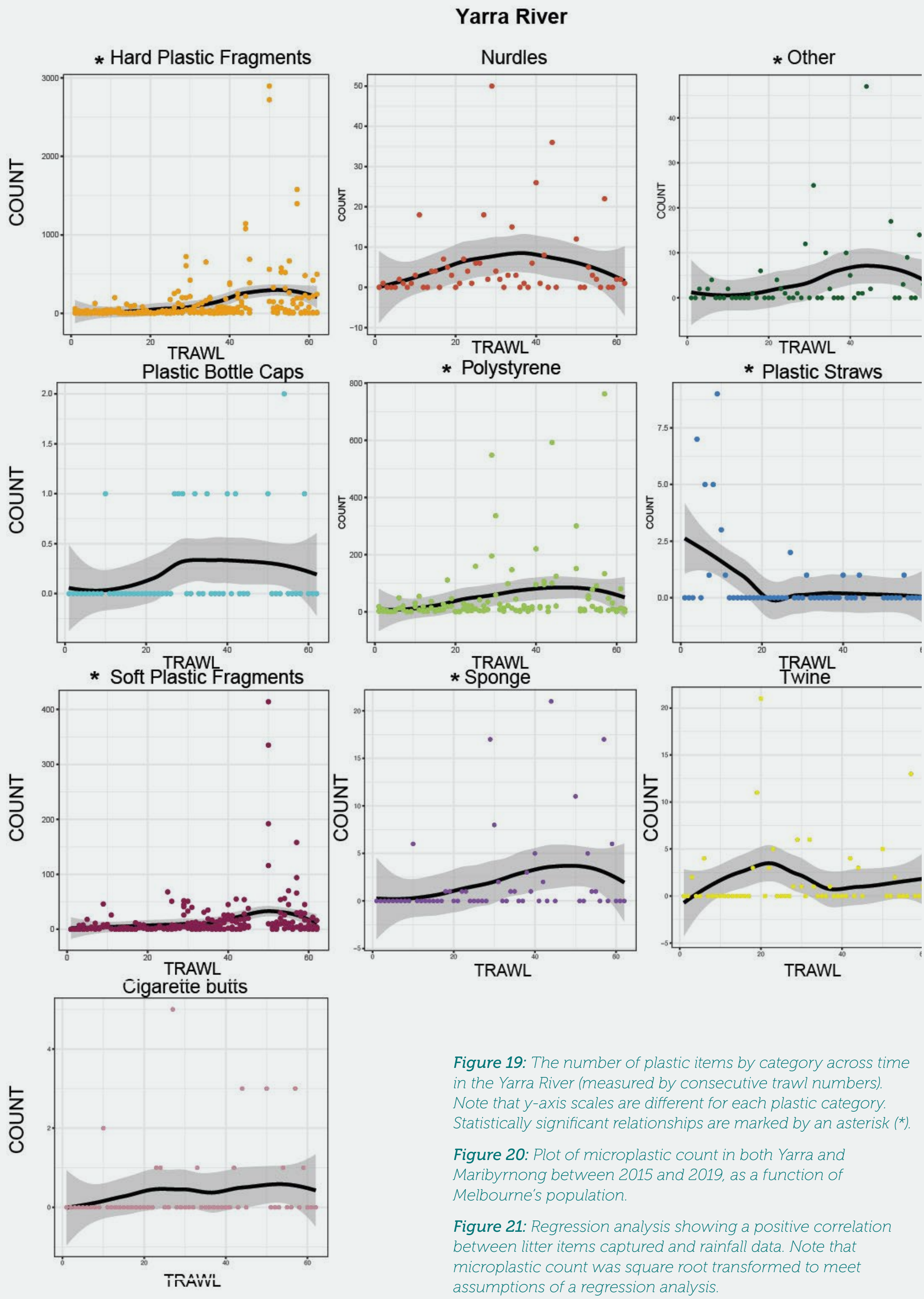
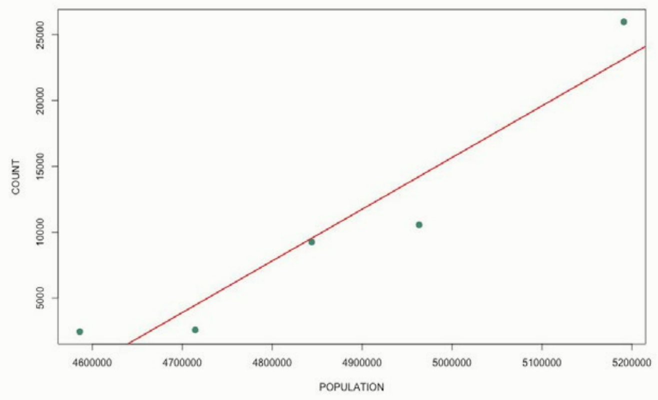


Figure 19: The number of plastic items by category across time in the Yarra River (measured by consecutive trawl numbers). Note that y-axis scales are different for each plastic category. Statistically significant relationships are marked by an asterisk (*).

Figure 20: Plot of microplastic count in both Yarra and Maribyrnong between 2015 and 2019, as a function of Melbourne's population.

Figure 21: Regression analysis showing a positive correlation between litter items captured and rainfall data. Note that microplastic count was square root transformed to meet assumptions of a regression analysis.

FIGURE 20



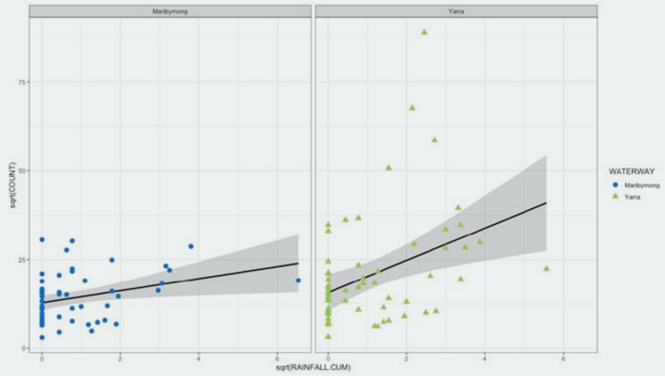


FIGURE 21

> ***Factors driving litter increases and spikes***

A series of regression analyses were performed to see what environmental factors could be driving the increases in litter and some of the unusually high litter counts in some of the trawls.

Worldwide, plastic pollution is usually positively correlated with increases in population. This indeed applied in the Yarra and Maribyrnong as well, with a significant association between population in the Greater Melbourne area from 2015 to 2019 and counts of microplastics ($t = 5.4$, $P = 0.012$). Approximately 87.6% of the variation in microplastic counts was explained by population numbers over this time (adjusted R2 = 0.876; Figure 20), which indicates a very strong correlation.

A regression analysis shows that the count of microplastics was positively associated with total rainfall in the previous 48 hours ($t = 4.1$, $P < 0.001$; Figure 21). Approximately 12.2% of the variation in microplastic counts in the rivers was explained by rainfall (adjusted R2 = 0.122).

Rainfall data for the Maribyrnong was taken from the Bureau of Meteorology's (BOM) weather station at Melbourne Airport. Rainfall data for the Yarra was taken from the BOM's Eltham weather station.

To explain some of the high spikes in litter in the Yarra, two potential factors were tested for:

Bandalong litter traps
The method of emptying the floating Bandalong litter traps is focused on removing larger litter items (gross pollutants) and does not allow for the containment of microplastics. The 2015–2020 dates of the emptying of the traps in the Yarra River were sourced from Parks Victoria. Although there were preliminary indications of litter spikes potentially being caused by litter trap maintenance, there seemed to be no evidence of a correlation with the data available (see Appendix 5). However, additional information sourced from Melbourne Water just before finalising this report, indicates that a more targeted approach to investigating microplastics leakage from Bandalong traps is appropriate. Please refer to the Yarra and Maribyrnong microplastics research discussion below.

There are currently no Bandalong litter traps in the Maribyrnong river.

Environmental water flow releases
In drier periods of the year, environmental water flows are released on a needs basis from the upper Yarra catchment to maintain the ecosystem health of the networks of billabongs and wetlands connected to the Yarra. As these flows have the potential to flush out litter caught in various places along the river, data on environmental water flow releases between 2015 and 2020 were sourced from Melbourne Water. However, a regression analysis showed that there was no significant association between environmental flow events and plastic counts in the Yarra. See Appendix 6 for more details.

Yarra and Maribyrnong microplastics research discussion

Clean Bay Blueprint and the preceding EcoCentre projects are the first studies to investigate microplastic loads in the Yarra and Maribyrnong Rivers and provide the first estimation of microplastic loads entering Port Phillip Bay on an annual basis. Every one of the 113 trawl samples analysed between January 2015 and February 2020 contained plastic pollution, mostly consisting of microplastics. Nearly 2.5 billion pieces of plastic flow into Port Phillip Bay annually from the surface waters of the two major rivers, of which over 2 billion are microplastics smaller than 5 mm in diameter.

These results are expected to be underestimations of the litter volume entering the Bay, as it does not take into account the depth of the river and the fact that high-density particles with additives or other attachments and larger items will sink below the level of trawled surface area (Mai et al. 2018; Pattison, 2020). As the mesh size of the net was 330 nm and sorting and counting of microplastics was done with the naked eye, particles smaller than what could be caught in the net, or observed and confirmed as plastics during sorting (including microfibres and nanoparticles), were not included. It must therefore be emphasised that total plastic pollution numbers in the rivers are likely to be much higher than the numbers in this report and preventative and mitigating actions to reduce plastic pollution are urgently required.

> *Litter increases*

An alarming result of this study is that litter is increasing in both the Maribyrnong and the Yarra, with plastic pollution in the Yarra increasing at a much faster rate. The rate at which plastic pollution in both rivers is increasing is very high: litter in the Yarra increased by 400% in 2017 compared to 2016 and then in 2019 it again more than doubled compared to 2018 levels. The Maribyrnong saw a more gradual increase over time, but still increased by around 57% to 83% year on year since 2017.

Nearly 2.5 billion pieces of plastic flow into Port Phillip Bay annually from the surface waters of the two major rivers, of which over 2 billion are microplastics smaller than 5 mm in diameter.

The Yarra exceeded the Maribyrnong in terms of expected plastic pollution loads in 2016 (Charko et al., 2018). These changes are mostly driven by increases in hard and soft plastic fragments and polystyrene rather than the other categories of litter, meaning these are the litter categories that should be addressed immediately at their source.

As this study shows a very strong positive correlation of plastic pollution with population growth in Melbourne and the population of Greater Melbourne is projected to grow from 5 million to 9 million by 2056 (DELWP, 2019), it is expected that plastic pollution increases will continue until effective source reduction measures are taken.

> *Litter composition in the rivers*

Sample analyses revealed that hard plastic fragments, polystyrene and soft plastics were the most common items captured. Despite the manta net's selectivity to small, buoyant items, the sample results largely align with several other local litter audits.

Litter audits along the Westgate Park foreshore, and along St Kilda beaches between 2015 and 2017, revealed polystyrene packaging and soft plastics (bits of plastic bags, wrap, cellophane etc.) are the second and third most dominant litter categories, after cigarette butts[4]. Hard plastic fragments were the most captured items in manta net trawls in the Bay (see Chapter 4) and the second most prevalent litter items found on beaches around the Bay using the Baykeeper Beach Litter Audit method to monitor for microplastics (see Chapter 5). Polystyrene is the most captured litter item in the Bandalong litter traps in the Yarra River (Kowalczyk and Kelly, 2020). As cigarette butts, much like other heavier items, sink after a relatively short period in water and pass under the manta net, their numbers in the Yarra and Maribyrnong River trawls do not align with general beach clean-up data where cigarettes often dominate. In addition, beach clean-up efforts are typically geared towards the collection of large litter items. Consequently, hard plastic fragments and microplastics are not systematically recorded in litter clean-ups.

In general, trawl findings provide a fairly robust representation of the microplastic pollution issue, providing valuable information about the composition and relative abundance of dominant buoyant litter items entering Port Phillip Bay.

It is worth noting that hard plastic fragments, polystyrene and soft plastics also dominate microplastic pollution in other urbanised catchments around the globe. These items were the most abundant litter types collected in trawls in the New York-New Jersey Harbour estuary, USA, one of the most urbanized estuaries on earth (S. Meola, New York–New Jersey Baykeeper, *pers. comm.*, 2015). Similarly, hard plastic fragments, polystyrene and plastic foil dominated microplastic loads along the length of the Rhine River in Europe (Mani et al., 2015). This is not surprising given that worldwide, the packaging industry, the primary material source of microplastics in this study, is the third largest after food and energy (Moore and Phillips, 2011) and around 11% of plastic waste generated gets lost in the environment (Borelle et al., 2020), where it breaks up into smaller pieces under the prevailing environmental conditions.

It is clear that the Yarra has much higher total litter counts than the Maribyrnong. This is probably because the Yarra's catchment area (4,046 km^2) is larger than the Maribyrnong's (1,408 km^2) and land use between the catchments differs: apart from the Upper Yarra region, the Yarra River catchment includes 4.3 times more of urbanised area than the Maribyrnong. The respective Catchment Region documents from Melbourne Water's Healthy Waterways Strategy state that in the Maribyrnong catchment:

» about 10% retains its natural vegetation (140.8 km^2)

» 80% is used for agriculture (1,126.4 km^2)

» 10% is urban development: Greater Melbourne and larger townships (140.8 km^2)

In the Yarra catchment:

» 55% of the area retains its natural vegetation (2,225.3 km^2)

» 30% is used for agriculture (1,213.8 km^2)

» 15% is urban development (606.9 km^2)

When comparing the other types of litter between the rivers, it was found that the Maribyrnong

[4] *amdi.tangaroablue.org*

(proportionally) has higher counts of soft plastics, nurdles, bottle caps, straws, twine, cigarette butts and 'other' items than the Yarra, whereas polystyrene is more problematic in the Yarra.

> *Investigating litter by item category*

Hard plastic fragments remain the most problematic items in both rivers and have been significantly increasing over the last five years. Due to their small size, it is nearly impossible to trace them back to their individual sources of pollution. They originate from broken-up larger items that are lost from overflowing commercial, household and public bins, littering and illegal dumping of waste, are blown off trucks during transport, or from construction and/or demolition sites.

The plastic polymer analysis showed that most items in the samples were polyethylene (PE), polypropylene (PP) or polystyrene (PS), which are some of the most commonly used plastics in the world. However, other common plastics like polyethylene terephthalate (PET) and polyvinylchloride (PVC) were largely absent from the results. Notably, as per Pattison (2020), degradation of polymers is not uniform, and different polymers break up via a range of processes at varying rates (Gewert et al., 2015). Polymer types such as PE, PP and PS break up faster when exposed to UV radiation than PET and PU, thus potentially increasing the prevalence of these secondary microplastics. The varying densities of polymers may also influence what is collected with equipment such as the manta net, which sits on the water surface.

The lowest density polymers found in the river samples, are most likely to float, were PP (0.90 g / cm^3) and PE (from 0.92- 0.97 g / cm^3) (see Appendix 3A). Some of the higher density polymers included PET (1.38-1.39 g / cm^3) and PVC (1.29-1.44 g / cm^3), which are commonly used worldwide but were only present in study samples in trace amounts (see Appendix 3B). It is therefore likely that denser polymers may be in sub-surface waters, floating underneath the manta net, or have sunken into the sediments, as there is a strong correlation between the number of microplastics found in river sediments and increasing polymer density (Klein et al., 2015).

Further investigation of the water column and the sediments are logical next steps in the process of investigating microplastics pollution in the rivers.

Polystyrene is the second most prevalent litter item in the Yarra and in third place in the Maribyrnong. These findings are supported by litter research conducted between 2017 and 2019 by the Yarra Riverkeeper Association, which found that polystyrene was the most found item on the riverbanks during community clean-ups, as well as in the Bandalong litter traps (Kowalczyk and Kelly, 2020). A subsequent polystyrene pollution research project by Cleanwater Group and Yarra Riverkeeper Association attempted to trace this litter back to the source by surveying 64 manufacturing and distribution facilities (Barmand et al., 2020). Over 80% of surveyed sites were found to have some sort of polystyrene leakage into the environment, even when all reasonable precautions had been taken to prevent this. In addition, more evidence is being collected revealing that building sites are a potential source of polystyrene pollution when using insulation waffle pods[5]. Polystyrene also gets lost in transport, on loading bays and at waste transfer and recycling facilities. The fact that polystyrene loss still occurs even when all reasonable precautions are taken, indicates that the problems lie with the material itself, and how it is handled. It therefore needs to be questioned if this material should still be used for its current purposes; meanwhile, alternatives should be sought.

Soft plastic fragments are steadily increasing over time. Much like hard plastic fragments, soft plastics are difficult to trace back to a single source. Much of it likely comes from plastic littered on the streets, or it blows out of bins and skips due to its light weight, and prevailing wind strength and direction in relation to the bin. Once in waterways, soft plastics carried on rapid flood flows commonly snag on woody streamside vegetation, causing them to shred.

Nurdles are ubiquitous in waterways all over Victoria, as supported by evidence gathered by Tangaroa Blue Foundation and the EcoCentre since 2014 (N. Blake, F. Charko, *pers. comm.*, 2020). Although nurdles have neither significantly increased nor decreased over the life of this project, they are still making up a steady 1% of microplastics flowing into the Bay over time. Chapter 5 of this report shows that nurdles are the number one microplastic type found on beaches around the Bay, indicating that this type of pollution is an ongoing issue.

As nurdles are classed as an industrial pollutant rather than litter, it is relatively easy to identify their source. These pellets can be traced back to the premises of plastic manufacturers, where they are spilled on the loading bays and driveways and are often incompletely or not at all recovered after a spill. Some get lost in road transport on their way to manufacturers and end up in the gutters. Refer to Chapter 7 for recommendations on this issue.

Plastic straws are the only item category that has significantly *declined* over time in the Yarra. This is notably going against the trend of all other items in both rivers that are either increasing or staying constant over time. The most likely explanation for this is that over the last several years, community and business-driven source reduction initiatives such as 'The Last Straw' have gained great traction in Melbourne. Individual behaviour change, as well as community-led advocacy, has led to retailers swapping plastic straws for paper ones, or not offering plastic straws unless specifically requested by their customers. In some instances, entire retail precincts have pledged to cease the distribution of plastic straws, such as the traders on Gertrude Street in Fitzroy (The Everleigh, *pers. comm.*, 2017). The fact that the results of these community initiatives are reflected in the monitoring data indicates two things:

- 1) Individual behaviour change, community-led advocacy and community action to reduce plastic pollution can make a significant positive difference for the environment;
- 2) Ongoing data collection and monitoring of plastic pollution are necessary to evaluate which litter reduction initiatives are effective.

Sponge is a category that has been significantly increasing in the Yarra, and mostly captures artificial 'spongey' substances such as sponge-like household items, building insulation foam and soft packaging material. When speculating where this material comes from, and why it is more prevalent and increasing in the Yarra, the increased residential construction projects in the Yarra catchment may correlate. Further source tracing may provide insight.

Other is a category applied to record items that are not readily identifiable as fitting into any of the other categories, but are obviously not organic. In both rivers, this category is significantly increasing, especially in the Maribyrnong, where the graph's J-curve in Figure 18 suggests an exponential increase. This warrants closer investigation of this category in future research to see if there are specific items that are trending, and if another litter item category should be added for specific monitoring focus.

[5] *Although the Master Builders Association offers a waste minimisation guide that includes waffle pods, it does not outline how this material should be handled onsite to prevent spillage.*

Bottle caps, cigarette butts and **twine** have neither increased nor decreased in both rivers. Although cigarette butts are in the top ten of most littered items in Australia, their plastic filters get waterlogged and most likely pass under the manta net, explaining the low numbers found in this study.

PICTURE 6

> *Seasonal variations*

When examining the seasonal effects on the rivers, the Maribyrnong proportionally has its largest surface litter output in spring and autumn, while for the Yarra, litter numbers are highest during summer and winter. One likely reason for this difference could be related to sports events that draw large numbers of people to the vicinity of the rivers, such as football season for the Yarra in winter and horse racing events at Flemington Race Course in spring for the Maribyrnong. In summer, the Yarra parklands are extensively used for recreation and tourism in Melbourne CBD is at its peak in December–January.

However, both rivers have different land uses influencing them and there are vast differences in the industrial usage and population density along the rivers (Yonkos et al., 2014). Litter hotspots may also play a role. For example, Calder Park Raceway is located near Jacksons Creek, not far upstream from where the creek joins the Maribyrnong River. Road verges in the vicinity of Calder Park are heavily littered (N. Blake, *pers. comm.*, 2020) with plastic items potentially shredded when verges are seasonally slashed. Both rivers are subject to different street cleaning and sweeping schedules and practices by local councils.

> *Other factors influencing litter*

Rainfall There is a positive correlation between rainfall and plastic pollution, which is consistent with research worldwide. Littered items anywhere in the catchment eventually make their way down to the nearest waterway through the stormwater drain system, heavily polluting creeks and streams that lead into the big rivers and the Bay (picture 6).

Litter traps Although no statistical correlation was found between microplastics spikes and emptying of the litter traps, this conclusion was reached through a Wilcoxon rank sum test comparing median litter

Picture 6: *Litter in the Merri Creek, which flows into the Yarra.*

counts when the litter trap was emptied to when the litter trap was not emptied (two days before trawl). See Appendix 5 for more details. Just before publication of this report, subsequent advice was received from Melbourne Water that the average Yarra River current speeds between Burnley and Bolte Bridge is 5.5 km per hour (P. Rasmussen, Melbourne Water Team Leader Flood Preparedness, *pers. comm.*, 2020).

The distance from Burnley to Bolte Bridge is approximately 7.58 km, therefore estimated travel time is about 0.6 to 3.8 hours, with the average approximately 1.5 hours. The shorter duration could be applied during higher flows following rainfall runoff. The longer durations are generally normal conditions. With tides ebbing and flowing for all conditions, the average may be best applied. Accordingly, any spikes in trawl contents attributable to emptying of Bandalong traps could only apply to trawls conducted within just a few hours of the traps being emptied.

Apart from litter prevention measures, gross pollutant traps could be installed on the problematic major drain outlets and catch items before they make it into the creeks. Once it reaches the creeks, plastic pollution mixes in with organic materials and will be more onerous and costly to remove from the waterways due to the much higher volumes presented by these combined materials. To be effective, gross pollutant traps require adequate and proactive maintenance schedules and resources to prevent them from blocking or overflowing.

However, gross pollutant traps do not often catch microplastics. Although the data in this report do not show a direct statistically significant correlation between microplastic capture and the emptying of the Bandalong litter traps in the Yarra, personal observation of the manner in which the traps are emptied confirms that microplastics do escape during this process. More targeted research, specifically designed to test for the effectiveness of microplastics captured by gross pollutant traps during their operation and maintenance is therefore necessary.

Yarra environmental water flow releases No correlation was found between microplastics captured in the trawls and Melbourne Water's regulated release of environmental water flows for the Yarra. There is no evidence that environmental water flows exacerbate plastic pollution in waterways. This supports the result that litter originates from the street, making its way into the rivers through stormwater drains.

> *Implications for marine life in the Yarra estuary and Port Phillip Bay*

Port Phillip Bay is a relatively closed system, due to the distance between the Bellarine and Mornington Peninsulas being only just under 3.5 km. Due to prevailing winds, it is likely the Bay is a sink for a major portion of the plastics that enter it from the rivers. This study found that microplastics form the bulk of items entering the Bay from the surface waters of the Maribyrnong and Yarra rivers. The results of a pilot project of nine Bay trawls showed the presences of microplastics in eight of nine samples (see Chapter 4).

To date, very few studies have assessed microplastic ingestion/interaction rates for faunal species in Port Phillip Bay. However, worldwide, freshwater and marine species at all trophic levels, possessing varied feeding strategies, ingest microplastics (Eerkes-Medrano et al., 2015). In lab-based studies, ingestion has been associated with the retention and accumulation of microplastics in organisms including but not limited to mussels (Browne et al., 2008); lobsters (Murray and Cowie, 2011); scallops (Brillant and MacDonald, 2000); injury and subsequent disrupted feeding/ swimming activity in lugworms, as well as stress, immune response, altered metabolic function and

PICTURE 7

toxicity in lugworms (Browne et al., 2013); and fish and mussels (Rochman et al., 2013). It is also related to tumour formation in fish (Rochman et al., 2013) and brain damage in fish (Mattson et al., 2017).

Smaller sizes of plastic can potentially be ingested by a greater range of species. Plastic ingestion by local wildlife is highly likely, because of Port Phillip Bay's potential for high microplastic concentrations and because these waters are so biodiverse. Faunal ingestion rates and impacts of marine microplastics at the individual, population, and community levels need to be assessed to prevent biodiversity loss in the Bay and to better understand the human health implications of consuming seafood from the Bay. Investing in necessary research will likely require collaboration between departments managing water pollution controls and fish populations, respectively.

> *Further study on microplastics*

The estimations in this study showed that the Yarra and Maribyrnong can transport nearly 2.5 billion plastic pieces – of which more than 2 billion are microplastics – into Port Phillip Bay annually and that this may be an underestimation. Ling et al. (2017) noted that plastic filaments, including highly pervasive clothing microfibre pollution between 0.038 mm and 0.250 mm, formed the dominant categories of microplastic in coastal and estuarine sediments around Australia, including Port Phillip Bay. However, we know little about the downstream movement and deposition of microplastics in rivers. It is not known what portions of riverine microplastics travel downstream, below the surface waters sampled by the manta net, to eventually be released to the Bay or deposited to the river sediments. In the North Shore Channel (Illinois, USA), for example, microplastic concentrations in sediments were up to 15,000 times higher than surface water samples (Hoellein et al., 2017). Some microplastics are likely transported long distances, as several studies report high concentrations of microplastics in estuaries, with rivers implicated as major microplastic sources to these coastal zones (Yonkos et al., 2014; Lima et al., 2014; Sadri and Thompson, 2014). An example of this was revealed during a community clean-up event organised by the Yarra Riverkeeper Association in April 2018, where a vacuum suction device deployed by Ocean Crusaders removed over 4.7 million polystyrene pieces from the Yarra River and its vegetated banks (A. Kelly, *pers. comm.,* 2018).

Consequently, in order to accurately identify the magnitude of microplastic pollution in Port Phillip Bay, it is necessary to better understand microplastic depositional patterns and take into account the water column below the top 20 cm and the sediments.

To advance current microplastics research in this area, the EcoCentre engaged a team of interns from Worcester Polytechnic Institute (WPI) in the USA to design and build a low-cost microplastics sampling device, easily built from hardware store materials, called the 'Microplastics Collector With A Pump' (MCWAP). The MCWAP is a portable, battery-powered pump that takes water samples at various depths in the water column down to a depth of 2 m and runs these through a removable mesh 300 nm filter to capture microplastics (picture 7). The EcoCentre is planning a first trial of depth-sampling for waterway microplastics in 2021.

Picture 7: *The MCWAP: EcoCentre's portable microplastics depth-sampling device.*

Maribyrnong River.

Fishing in Port Phillip Bay.

4

Bay trawls pilot

To gain insight into the relative quantities of microplastics entering the Bay from Bass Strait as compared to the major rivers, a pilot project of nine manta net trawls was conducted at the entrance to Port Phillip Bay, with support from the Blairgowrie Yacht Squadron and the Australasian Ambassador for the 5 Gyres Institute.

Trawls were conducted between April 2018 and February 2020 at Pope's Eye in Port Phillip Bay, during incoming tides and south-westerly winds. Trawl time was 30 minutes, during which the vessel was anchored to the sea bed in the tidal flow. Sample sorting was done in the same manner as the river trawls (see Chapter 3).

Of the nine trawl samples collected at Pope's Eye in Port Phillip Bay, eight contained plastics (Table 1). Of the total 55 items found, 35 (64%) were microplastics. The most prevalent items were hard plastic fragments, which were found in six of nine samples. Samples in which plastic was found contained up to 16 items. The last sample contained a remnant of a party balloon with the balloon string still attached.

Although the sample size is too small to perform meaningful statistical analysis, the findings suggest there may be a worrying amount of plastic floating on the surface waters of the Bay. Given the size of Port Phillip Bay is 1,930 km^2 and plastics were found in 89% of samples collected through 30-minute trawls, plastics are potentially quite ubiquitous.

A proportion of 80% of hard plastic fragments found seems relatively consistent with the 75% proportion that flows into the Bay from the Yarra and Maribyrnong, indicating a probability that many of these items may have originated from the Bay, passed through The Heads into Bass Strait, and then been recirculated back to the Bay by tidal currents and prevailing winds. More samples will need to be taken and analysed in order to further investigate this probability.

TABLE 1

	Hard Fragments <5	Hard Fragments >5	Soft Plastics	Twine/Line	Sponge	Non-Plastic
Apr 18	3	4		1		
May 18	6	2				
Jun 18	8	6			2	
Sep 18						
Oct 18	2			1		3
Dec 18			1			
Jan 19		2				1
Feb 19			1	2		
Feb 20		2		1		1
TOTAL	**19**	**16**	**2**	**5**	**2**	**5**

Table 1: Items caught in Bay entrance trawls. 'Non-Plastic' included paper and a rubber balloon.

Microplastic beach litter.

5

Baykeeper Beach Litter Audits

Development of the Port Phillip Baykeeper Beach Litter Audit method commenced in 2014 in response to international studies confirming the environmental threat of plastic pollution. At that time and to date, there remains no international standard survey method, with various existing data collection methods used by different leading bodies.

While each method provided valuable information, their capacity to accurately record volumes of litter over time – particularly microplastics – was seen to be limited by one or more of the following factors:

- lack of a clearly defined data collection area
- clean-up and/or data collection methods conducted on a scale that was unlikely to be systematically repeated
- data collection recorded in a single area on a beach (as opposed to a set of locations that represented samples of all conditions on the beach)
- data recording conducted from a standing position, reducing the likelihood of recording hard-to-spot microplastics
- data collection without removing litter, eliminating the possibility of clearly measuring change in volumes occurring between surveys.

The Baykeeper Beach Litter Audit methodology was designed to focus on microplastic pollution that poses an immediate threat to aquatic organisms. Key considerations in the design of this method were the need to:

- capture a representative sample of the conditions on the beach
- establish an easily replicated method that can be cost-effectively and consistently applied by different groups around the Bay
- use data field terminology that was consistent with terms used in the Australian Marine Debris Initiative database.

The Clean Bay Blueprint project provided an opportunity to test the survey methodology over several years with a range of user groups.

Methodology

The survey method requires the combined search time of the number of auditors to equate to at least five minutes per quadrat. Noting that some quadrats will have very few, if any, microplastics, this requirement is designed to ensure consistency of search effort, and to enable a small team of two people to comprehensively complete an audit in less than an hour, or two hours on more heavily littered beaches. This relatively small time commitment facilitates regular conduct of audits over the course of a year, to achieve the statistical rigour required to confirm trends in litter volumes and type over time.

> *Transect and quadrat placement*

In order to capture a representative sample of all beach conditions, data is collected from three transects across the beach. In this context 'all beach conditions' is referring to the structure of the beach – shaped by the locally prevailing winds, waves and tidal currents – which transport sand, debris and litter to and from the beach. To capture the influence of these coastal processes over time and to provide a basis for consistent search effort, transects are located at the widest, central and narrowest sections of beach.

In each transect, data is collected from three quadrats: at the top of the beach, mid-beach, and on the last high tide line (Figure 22). The 'top' (inland edge) of the beach quadrats are in the same place for each survey, as locational reference points. Due to changing tidal conditions on the day, the distance between the top of the beach and last high tide line (i.e. transect length) will vary. Hence, the location of the mid-beach and quadrats at the last high tide line differ for each survey. Importantly, the quadrats located at the last high tide line provide a sample of litter arriving on that day.

Each transect starts at the 'permanent landmark' at the top of the beach to ensure transects are in the same place each time a survey is conducted. Transects run roughly at a right angle from the top of the beach towards the closest point at the waterline.

> *Selection of reference beach survey locations*

With a view to gaining insights into catchment sources of microplastics to the Bay, beaches surveyed for Clean Bay Blueprint in various regions of Port Phillip Bay are generally associated with a river or a creek that flows into the Bay. Those that are not directly associated with rivers or creeks (Rye and Geelong Eastern Beach) are included to provide insights into the mobility of litter due to tidal currents and seasonal winds.

FIGURE 22

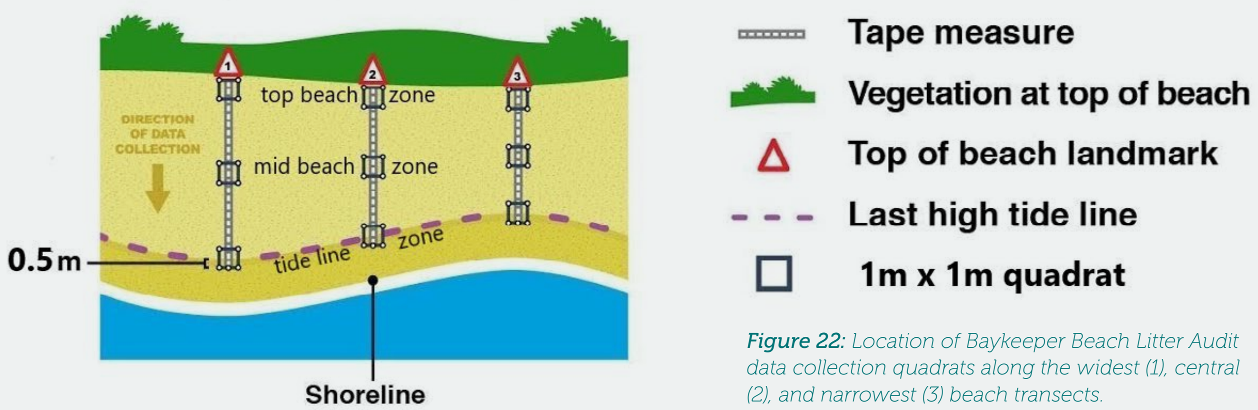


Figure 22: Location of Baykeeper Beach Litter Audit data collection quadrats along the widest (1), central (2), and narrowest (3) beach transects.

Plastics that float in the upper water column are carried in the direction of wind-generated waves and the direction of tidal currents during calm (low-wind) conditions (N. Blake, *pers. obs.*, 2020). Due to the combined effects of tides and varying wind directions, some plastic objects may travel widely in the Bay before eventually being cast upon a beach. A notable example was one of five GPS-tracked PET bottles released in Elwood Canal on 9 May, 2019 by RMIT[6]. After remaining in the Canal for almost two weeks, they ultimately landed on Dromana beach on 25 May due to a prevailing northerly wind. Therefore, in the absence of data collection conducted on a weekly basis, it is impossible to definitively conclude where beach litter on any given day may have originally come from. However, seasonal data collection at multiple (Bay-wide) reference sites does provide some indication of the likely source (the catchment) and ultimately presents a baseline dataset with which to determine if microplastics 'leakage' into the Bay is increasing or decreasing over time.

> *Surveys conducted*

Between July 2017 and March 2020, 117 beach litter audits were conducted in 12 locations around Port Phillip Bay (Table 2) with the help of local community group volunteers, not-for-profits and education institutes. All citizen scientists involved received multiple on-site training sessions by the Port Phillip Baykeeper before independently conducting audits. Regular reference beaches were surveyed every three months (in May, August, November and February), with surveys of all beaches generally conducted within the same fortnight. Only sites that were surveyed on at least six occasions have been given more detailed analysis in this report.

TABLE 2

LOCATION	ASSOCIATED RIVER OR CREEK	# AUDITS COMPLETED
Eastern Beach Geelong	n/a	11
Moorpanyal Beach Geelong	n/a	2
Werribee River Jetty	Werribee River	6
South Beach Werribee	Werribee River	7
West Beach St Kilda	Yarra River	15
Point Ormond Elwood	Elwood Canal	3
Mordialloc Beach	Mordialloc Creek	4
Keast Park Seaford	Patterson River	10
Frankston Beach	Kananook Creek	12
Mothers Beach Mornington	N/A	4
Mount Martha Beach	Balcombe Creek	30
Rye Beach	n/a	13
Total surveys		**117**

Table 2: Beach litter audit sites and number of audits done between July 2017 and March 2020. Beach names in bold are the regularly surveyed reference beaches; the other beaches were opportunistically surveyed.

[6] *RMIT Litter Tracker project: https://www.rmit.edu.au/about/schools-colleges/science/research/research-centres-groups/aquatic-environmental-stress/litter-trackers*

Results and discussion

Figures 23 and 24 show beaches along Port Phillip Bay's eastern shores recorded much higher concentrations of litter than Geelong, Werribee and Rye. The lower counts at Geelong and Rye can be attributed to the fact there is no major waterway entering the Bay in their general vicinity, and

- as Geelong Eastern beach is located near the westernmost end of Corio Bay it has very limited exposure to litter dispersed by wind and tides from wider Port Phillip Bay;
- Rye beach is the southernmost survey location in the Bay, relatively removed from major streams and urban catchment.

The much lower (near negligible) counts at Werribee South and Werribee River jetty are likely attributable to the fact that the Werribee River catchment is much less urbanised (around 20%) than the catchments associated with most of the eastern sites of the Bay. These results suggest that litter makes its way to the Bay from the catchments via the waterways.

The high average counts at Keast Park (Seaford) equate to 42% of total litter collected at all survey locations. Field observations and anecdotal reports of industrial sites in the Mordialloc Creek and Patterson River catchments have identified two particular sites that may be significant contributors to the overall plastic pollution recorded at Keast Park. This result warrants more detailed analysis and investigation.

A total of 11,248 items were recorded in this study. A breakdown of items collected in Figure 25 shows very few gross pollutants (e.g. intact plastic bottles and bags) were recorded, while nurdles (pre-production pellets) and plastic fragments combined comprised 77% of the total records. The volume of microplastics observed in 9 m^2 compared to microplastics reported in typical beach cleans confirms the effectiveness of the methodology in systematically recording microplastics at reference sites around the Bay.

Of all litter recorded, the quadrats within the 'last high tide line' recorded the greatest percentage of items (45%), followed by the 'top beach zone (38%) then the 'mid-beach zone' (18%). However, this order did not apply to all beaches, with several of the less littered beaches recording the greater amount in the top beach zone (Figure 26). Mt Martha is notable in this regard among the more heavily littered beaches in that the 'top beach' quadrats had the highest amounts in all three transects. However, this result was skewed significantly by the top beach of the central beach transect, which averaged 27.8 items per survey – almost as much as the totalled averages for all other quadrats combined (33.8 items).

Keast Park has the distinction of having the highest percentage of nurdles (59% of items recorded), compared to St Kilda West beach (47%), Frankston (34%), Rye (22%) and Mt Martha (17%). Nurdles were virtually absent from beaches on the west side of the Bay.

Examination of plastic fragments by type and size also found Keast Park distinguished from other beaches, with 53% of fragments being hard fragments < 5 mm. Frankston ranked next highest for hard plastic fragments with 37%, followed by Mt Martha with 34%.

The significantly higher counts of nurdles and hard plastic fragments < 5 mm may be due to a combination of factors such as:

- the broader range of wind directions that might affect the site: prevailing winds are acknowledged as a primary agent for litter dispersal, and Keast Park is located at the easternmost point of Port

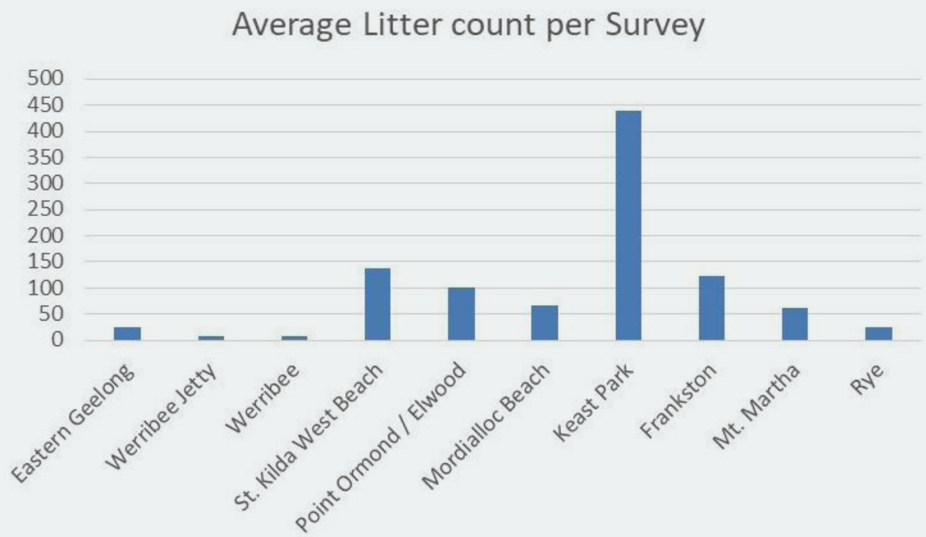


FIGURE 23

Figure 23: Average litter per survey for all beaches surveyed.

Figure 24: Visualisation of total litter counts on sampled beaches around Port Phillip Bay; larger circles represent higher counts. Image source: Port Phillip Sea Pilots.

FIGURE 24

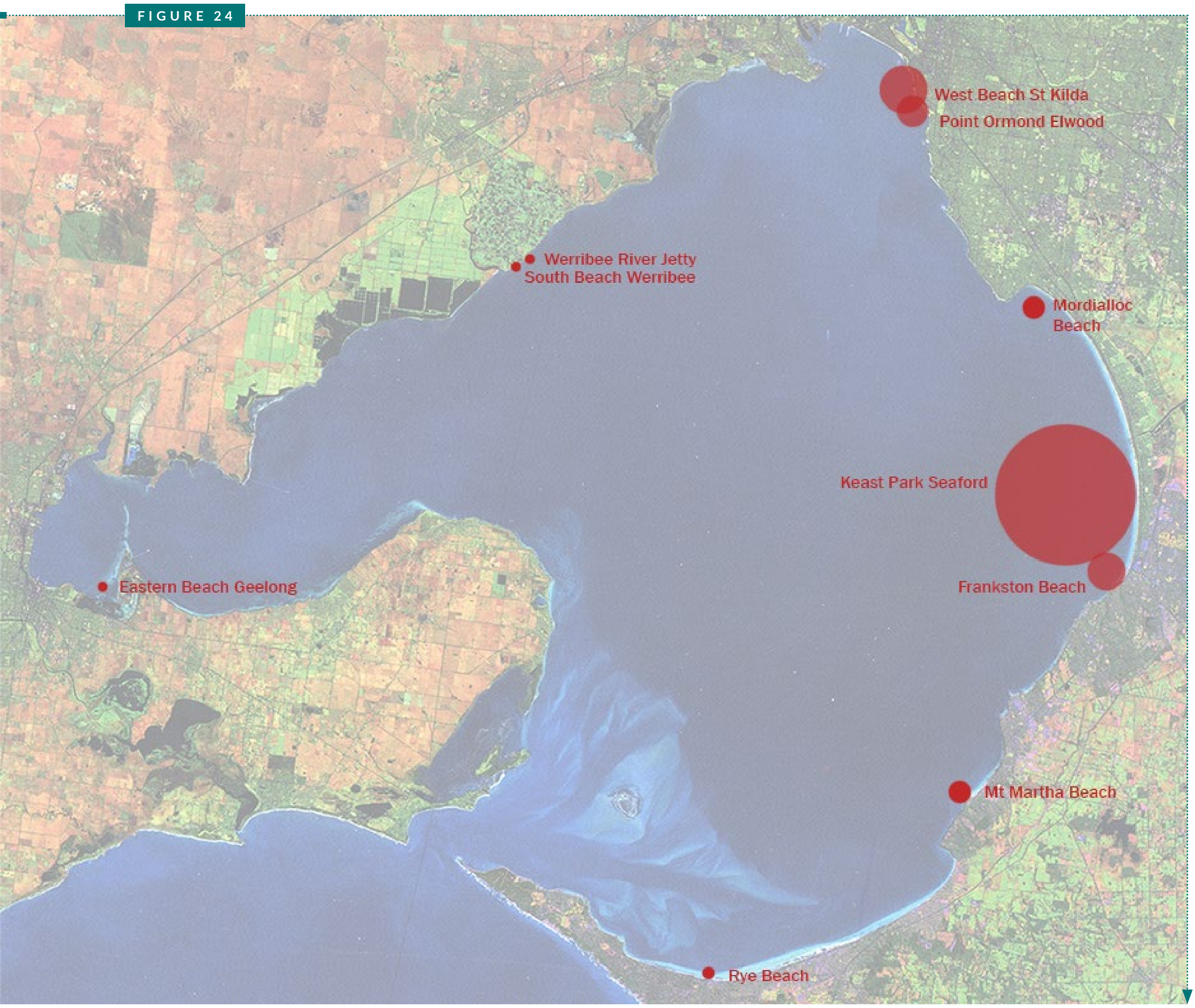
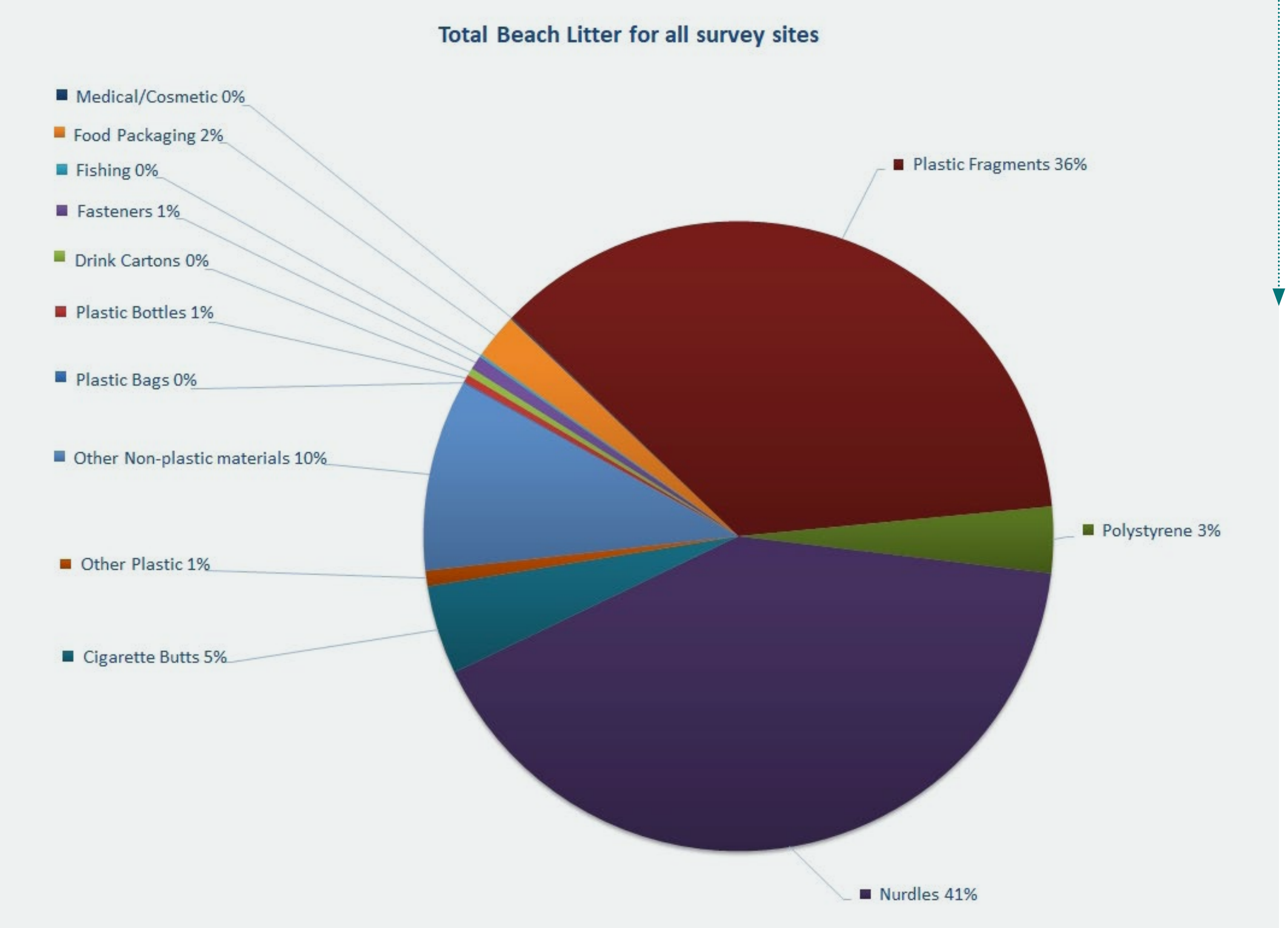


FIGURE 25



Phillip Bay, and subject to winds from south to north (the widest range of all sites surveyed)

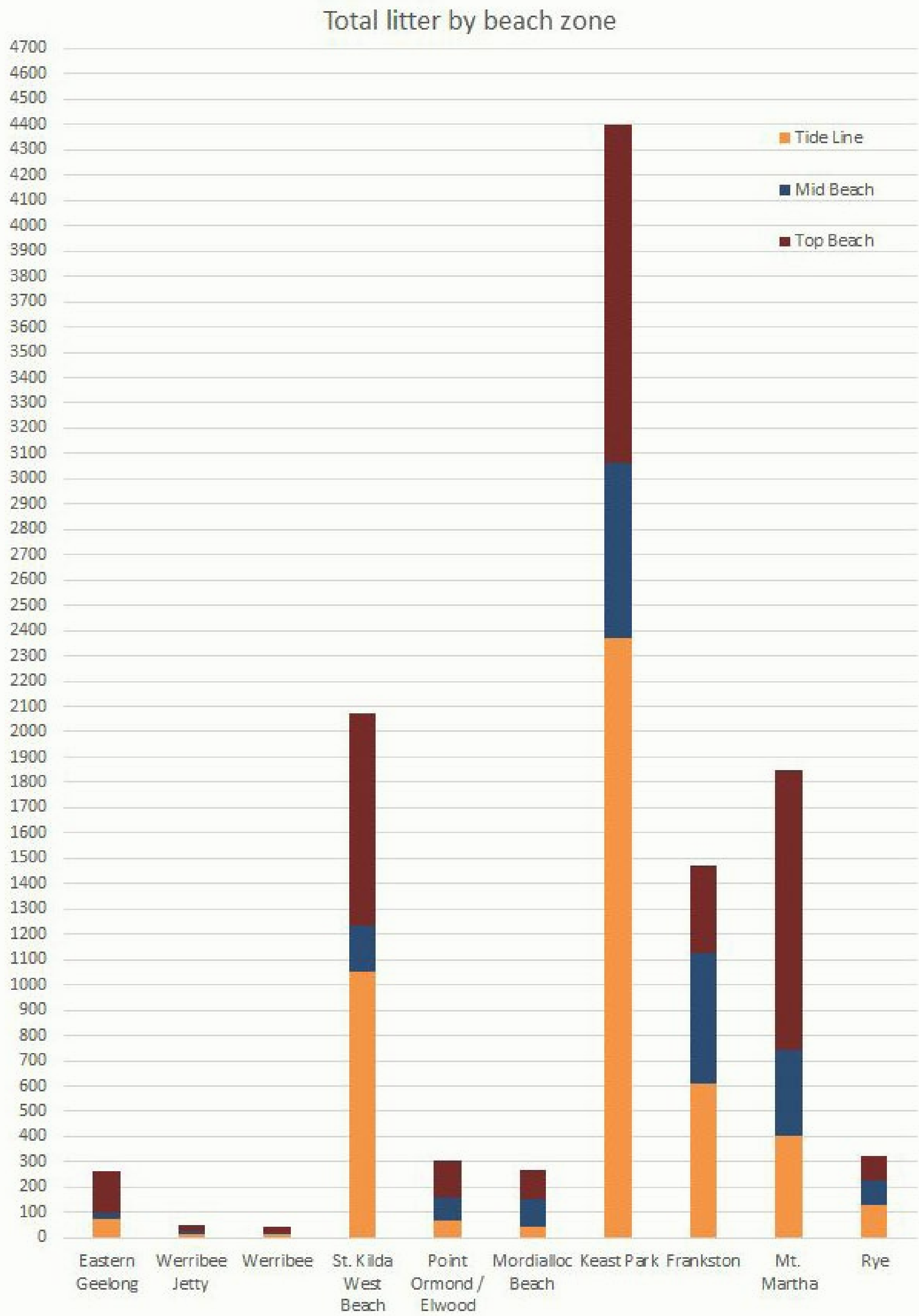
- orientation of the beach (near North-South at Keast Park)
- physical infrastructure impeding wave action on this particular beach (the Riviera stormwater outfall projects into the Bay at a point around 20 m south of the survey area)
- presence of plastics manufacturing and re-grind industries within the catchments
- proximity to industrial sites in local river and stream catchments (Mordialloc Creek and Patterson River) to the north of the survey beach (tidal currents that run clockwise around the Bay would carry plastics generated by these streams towards Keast Park).

The Frankston beach survey site is oriented NNE to SSW, which is not dissimilar to the orientation of Keast Park (NNW-SSE). The two sites are just seven kilometres apart. Despite this proximity, the Frankston site (located just to the south of Kananook Creek mouth) recorded considerably fewer nurdles and hard plastic fragments than Keast Park (which is to the south of Mordialloc Creek and Patterson River). These findings suggest that close scrutiny of the Mordialloc Creek and Patterson River catchments for nurdles and hard plastic fragments is warranted.

Figure 25: *Litter category percentages of total litter recorded across all sites. The numbers above the percentages are the total items collected.*

Figure 26: *Comparison of results for tide line, mid-beach and top beach zones.*

FIGURE 25


Total litter by beach zone
4700
4600
4500
4400
4300
4200
4100
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Tide Line
Mid Beach
Top Beach
Eastern Geelong
Werribee Jetty
Werribee
St. Kilda West Beach
Point Ormond / Elwood
Mordialloc Beach
Keast Park
Frankston
Mt. Martha
Rye

Port Phillip Bay on a windy day.

6

Related litter investigations

Over the life of Clean Bay Blueprint, the EcoCentre collaborated with many other organisations. Other investigative litter projects enabled by the Port Phillip Bay Fund, with the primary aim of data collection for pollution prevention, include:

» Yarra Riverkeeper Association's **Litter and Flows** and **polystyrene** projects - analysing litter in the Yarra.

» RMIT University's **Plastics Lab** project – analysing plastic fragment samples to identify polymers and adsorbed contaminants

» Tangaroa Blue Foundation's **Let's Strain the Drains**[7] – trialling stormwater pit filtration devices to document the captured contents in a range of municipalities and for four different street usages

» Scouts Victoria's **Street2Bay**[8] project – auditing litter in six different street usages in all catchments around the Bay

» RMIT University's **Litter Tracker**[4] project – GPS tracking and on-line reporting of the mobility of plastic bottles released into streams in catchments leading to Port Phillip Bay

» Beach Patrol Australia and Love Our Street have also compiled considerable data with the mobile **Litter Stopper phone app**[9]

Interactive litter maps

It is essential to provide data access and report back on research results to citizen scientists and those advocating for and designing change. Data collected from the beach audit sites have been entered into an interactive Tableau data visualisation platform and is hosted on the EcoCentre website, with potential for visualising street litter data collected by other groups. Consequently, the Tableau platform appears to be a useful means of engaging with schools and the wider community in relation to the high mobility of microplastic pollution.

The EcoCentre was also part of the community reference group that helped design and test the State Government's **LitterWatch**[10] database, which collects and collates litter data from all over Victoria, visualises this on a map, and makes it publicly accessible. This is the first attempt to gather all litter data, no matter which data-collection methods were used, and bring this together in one accessible repository.

Incident reporting

During the course of the study several materials that have been noted as of ongoing concern were reported to relevant authorities. These included Telco wire offcuts discarded at telecom sites on streets, polystyrene waffle pod waste leaking from a building site, and AstroTurf fragments leaking from a sportsground demolition.

All of the complementary initiatives represent major advances in our understanding of plastic pollution and warrant careful consideration as a whole body of information as opposed to in isolation, particularly with a view to adopting the optimum suite of data collection methods for the future and to set targets for local source reduction plans.

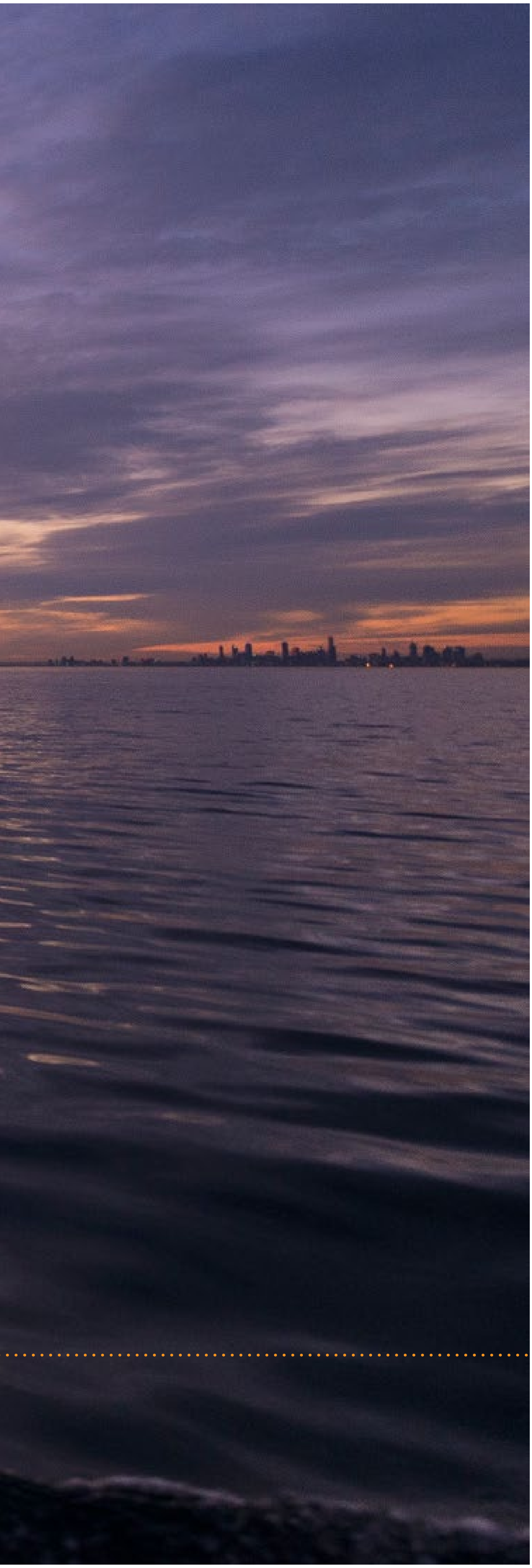
[7] *tangaroablue.org/lets-strain-the-drains-port-phillip-bay-region-vic*
[8] *https://scoutsvictoria.com.au/activities-events/activities/environment/street2bay-project*
[9] *https://www.beachpatrol.com.au* [10] *https://litterwatchvictoria.org.au*

7

Recommendations

Over the life of the Clean Bay Blueprint project, microplastic pollution has stopped being an 'emerging issue'. The irrefutable evidence of its unacceptable impact on the environment is well-documented all over the world.

Sunset over Port Phillip Bay.



Many governments are acting on the recommendation from the science community that society should not wait for any more quantification of damage before taking action to reduce marine plastic pollution impacts (Lavers and Bond, 2017; Gall and Thompson, 2015). In their report *Marine Plastics Debris and Microplastics,* the United Nations stated there is a moral argument that we should not allow the ocean to become further polluted with plastic waste, and that marine littering should be considered a 'common concern for humankind' (UNEP, 2016).

The high quantities of litter and microplastics in the Yarra and Maribyrnong rivers highlight the large contribution of these rivers to marine plastic pollution in Port Phillip Bay. Recent research by Borelle et al. (2020) projected the future of plastic pollution in our oceans, and concluded that the predicted growth in plastic waste in the next 10 years far exceeds the impacts of mitigation efforts currently deployed. Therefore, significant changes and investments need to be made to counter the rising tide of plastic pollution in the oceans.

Recommendation 1:

> *Improve product stewardship*

Plastic and microplastic pollution are everybody's problem. Over the 'lifecycle' of a plastic item, it travels through the fossil fuel and petrochemical industries, transport and shipping, plastic product manufacturers, retailers, community, local councils, waste contractors and the recycling industry. However, whereas every link in this user chain has some level of responsibility, not everyone should be expected to have the same level of accountability for plastic waste. The current responsibilities for the fate of plastic products are not well-defined and are often passed on to the next group down the line, putting a disproportionately large strain on communities and local councils. There is very little meaningful manufacturing industry accountability for the end-of-life destination of plastic, whether for waste management or pollution of the environment. The plastics industry is set to grow 40% by 2030[11], yet hardly any producer responsibility is taken for the waste and problems its products cause. Only 9.4% of manufactured plastic is being recycled in Australia (O'Farrell, 2019), which is consistent with 9% world-wide[9]. An astonishing 11% enters the oceans (Borelle et al., 2020). Currently local councils and the community are expected to deal with the consequences of unregulated production of a material that lasts in the environment forever.

As Victoria is moving from a linear to a circular economy model, this is the perfect time to change and define the responsibilities of the plastics industry, and their accountability. Federal and state governments play a key role in leading and managing this change. Some of the changes that the EcoCentre believes should be made in the short and long term are:

1.1 Transition to a circular economy model. *Product recovery schemes (such as the container deposit legislation) that are part of a circular economy model should be funded by the industries which produce the product, and managed by an independent government agency to prevent perversion of the initiative.*

1.2 Invest in implementing alternatives to plastic. *Plastic is not the right material for the majority of functions it performs, e.g. using a material that lasts forever for single-use packaging. The ever-increasing monetary and environmental costs of dealing with plastic's end-of-life stage are too high. Many alternative, truly biodegradable materials have already been invented, but have not been taken up for large-scale use. Industry needs to be given incentives to transition towards producing large-scale alternative packaging solutions, e.g. through new legislation or stimulus measures such as innovation grants or tax incentives.*

1.3 Set limits on virgin plastic production. *This includes avoiding investments in waste-to-energy schemes that burn plastic, as it perpetuates our reliance on a product that should not be burned in the first place.*

1.4 Ban broad-scale groups of problematic single-use plastics[12]*. Examples such as South Australia's ban on single-use plastic items, will provide some of the incentives driving innovation and transformation. Bans may be premised on design qualities rather than product type, for example banning oxo-*

[11] *https://www.plasticsoupfoundation.org*

[12] *The Australian National Waste Policy Action Plan commits to banning 'problematic and unnecessary single-use plastics' by 2025 and delegated the Australian Packaging Covenant Organisation to lead all governments to 'Identify problematic and unnecessary single-use plastic packaging to provide an evidence base for industry to take coordinated action' by 2019. The resulting report identified four priority categories (including expanded polystyrene and non-certified compostable packaging such as oxo-degradable) and three materials for further investigation. https://www.packagingcovenant.org.au/documents/item/3183*

degradable plastics (that merely break into microplastics faster rather than biodegrade to natural component materials) or non-recyclable/non-compostable packaging.

1.5 Make the Operation CleanSweep[13] program mandatory *instead of voluntary for any manufacturer using nurdles and have this enforced by EPA Victoria.*

Recommendation 2:

> *Cultivate effective partnerships*

It is critical that conversations and true working partnerships are forged and maintained with a long-term vision of collaboration and tangible, positive outcomes. In the case of an issue as big as plastic pollution, cross-sectoral collaborations are essential to ensure effective changes. Industry, local government, state government agencies (such as EPA Victoria, the Catchment Management Authorities and Melbourne Water and others), research institutes, community organisations and businesses all need to engage in ongoing dialogue about responsibilities and, most importantly, to reach clear agreement on which group is accountable for delivery of each defined outcome that is necessary to the success of the overall enterprise. This might be achieved through stakeholder working forums similar to the Victorian Department of Environment Land Water and Planning's Integrated Water Management Forums.

Recommendation 3:

> *Support local councils in waste management*

Until larger systemic changes in waste management are made, the end-of-line responsibilities councils have for plastic waste need to be adequately supported and resourced. The costs of this should not be transferred to the community via rate increases, nor by reliance on ad hoc, manual volunteer clean-ups.

Measures should include effectively resourcing councils to:

3.1 Install and maintain pollutant traps in drain outlets that discharge into creeks and rivers. *This could be a collaboration with Melbourne Water. Care should be taken to not just install gross pollutant traps, but also traps that catch microplastics such as Drain Buddies.*

3.2 Enforce litter and illegal dumping law.

3.3 Run effective litter prevention and education programs *in the community, and especially with local businesses and industry. This may be best done by partnership with trusted business or community organisations supporting the outreach.*

3.4 Review and improve current street sweeping schedules*, and where necessary adapt these to be more effective at the occurrence of large sporting events and seasons when litter peaks occur.*

[13] *Operation CleanSweep is a best-practice manual for plastic manufacturers that employs cost-effective ways of preventing nurdles leaking into the environment.*

Recommendation 4:

> *Continue monitoring (micro)plastic pollution*

Existing waste management and anti-litter initiatives are not effective enough to stop plastic and microplastic pollution from reaching Port Phillip Bay. The research in this report has established a baseline data set that shows that the problem is getting worse over time.

The river trawls and beach litter audit methods described in this report are both demonstrated to be scientifically valid means of ongoing data collection, and the multiple years of data gathered represent a benchmark of plastic pollution in the major rivers and Port Phillip Bay. The street litter audit method applied by Scouts Victoria in the Street2Bay project has also proven to be an effective and replicable means of monitoring plastic pollution on streets in Port Phillip Bay catchments. Continued data collection using these methods can provide a means of evaluating any future strategies to reduce plastic pollution in waterways.

Picture 8: *Industry messaging on plastic bag.*

Recommendation 5:

> *Increase education and 'plastic literacy' of all plastic users*

As part of cultivating a shared responsibility for plastic use and disposal, education of plastic users is essential. The general public has become much more aware of the issues of plastic pollution in the environment thanks to a boom in scientific research, followed by mainstream film documentaries and social media and community campaigns over recent years.

However, there is still much confusion about how plastic can be avoided, or what plastics are more preferable to others. An example of this is the actual meanings of the words 'biodegradable', 'degradable', 'oxo-degradable' and 'compostable' for plastic bags. People generally try to do the right thing and want to invest in better products, but industry uses the terms in misleading ways (picture 8). Recommendations are, therefore:

***5.1 Set standard legal definitions** for degradability labels.*

Not-for-profit organisations as well as local councils play a key role in educating the community and implementing education programs in schools. Organisations that specialise in this should be adequately resourced. It is likely the reduction in plastic straws in the Yarra can be attributed to education efforts and community behaviour change projects, showing that these approaches work. The community and NGOs are not significantly mentioned in Recycle Victoria (February 2020), whereas community and cross-sector collaborations are mentioned in the Port Phillip Bay EMP, but funding for joint activities is unclear after the conclusion of the Port Phillip Bay Fund in 2020.

***5.2 Develop project grants, forums and strategic ongoing partnerships** that integrate community, government, research and industry efforts.*

5.3 Adequately resource groups who educate and facilitate action on plastic pollution.

Recommendation 6:

> Conduct further research

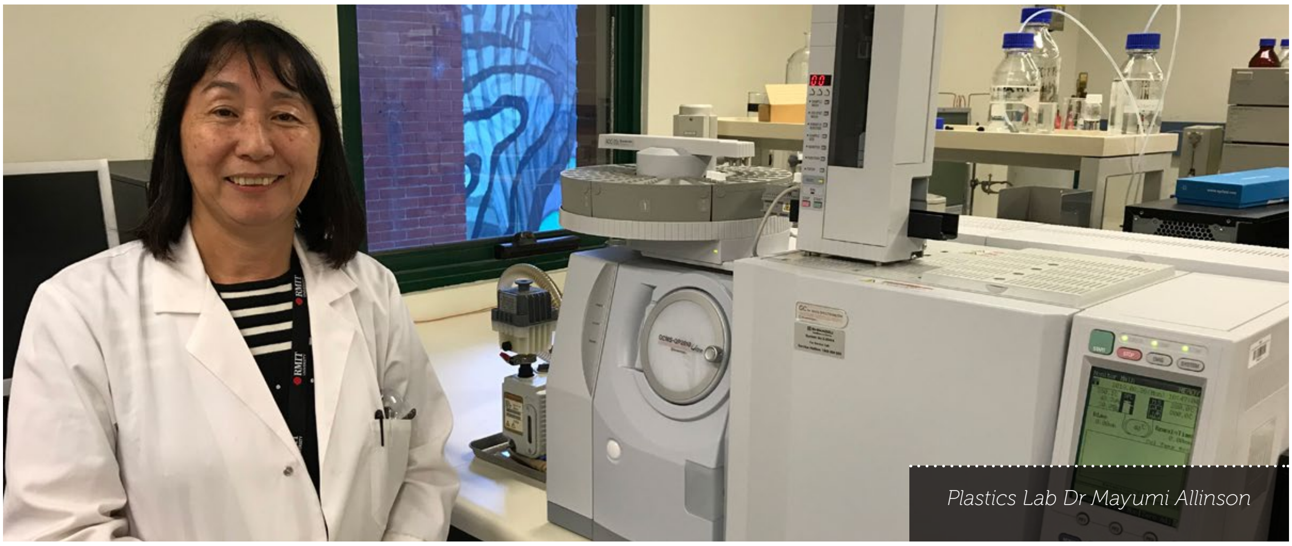
As highlighted in the study discussions above, additional research is needed to adequately monitor microplastics in Melbourne's waterways and Port Phillip Bay. Ongoing monitoring of surface waters is necessary to track the quantities and movements of microplastics and can serve as a baseline for source reduction action. Given the high numbers of microplastics reaching the Bay from surface waters, it is also important to conduct further research into the water column and the sediments. Recommendations for further research are:

***6.1 Conduct depth-sampling studies.** The EcoCentre will pilot the MCWAP to start monitoring microplastics in the water column. If successful, the device and methodology could be rolled out for use across creeks and rivers of Victoria.*

***6.2 Conduct sediment studies.** Sediment research is necessary to identify where the heavier polymers end up, according to Schwarz (2019), river sediments act as a plastic sink and CSIRO estimated that based on their samples taken in the South Australian Bight, 14.4 million tonnes of microplastics reside on the seafloor worldwide (Barrett et al., 2020).*

***6.3 Prioritise understanding the contaminants carried by plastic in waterways, and associated human health risks.** Continued analysis of plastic polymer types and chemical contaminants carried by plastics in waterways is necessary to strengthen our understanding of the potential ecological and human health impacts of plastic pollution.*

***6.4 Conduct on-ground investigations for major sources** of hard plastics fragments and nurdles within the Mordialloc Creek and Patterson River catchments.*



Plastics Lab Dr Mayumi Allinson

8

View of St Kilda Beach.

A note on citizen science

The research conducted in this study strongly relied on the collaborations with volunteer citizen scientists. Citizen science has received increasing recognition over the last decade and rightly so: without more than 8,800 hours contributed by volunteers for data collection, sample sorting and analysis, Clean Bay Blueprint could not have produced such robust results.

This project is hardly an exception these days, as volunteers, both individually and via community groups, put countless hours of their time and expertise towards environmental projects that rely on large datasets and labour-intensive analyses.

It needs to be recognised that the contributions of citizen scientists to science and environmental change-making are both invaluable and essential, and that collaborations between research institutions and community provide a powerful opportunity to build understanding of complex issues of Victorian, Australian and global significance. Resourcing the professional coordination of such collaborative studies often provides funders with a multifold return on the investment through generating new knowledge, inspiring extensive in-kind contributions, and activating community-led conversations and action on topics that might otherwise be uncommon around dinner tables, classrooms and clubs.

Little Penguin in Port Phillip Bay

Acknowledgements

One of Clean Bay Blueprint's main goals was to build partnerships with other organisations that target litter and improve Bay health.

Many new collaborations and ongoing partnerships were formed and many existing relationships were leveraged during this project. This was made possible by the funding from the Port Phillip Bay Fund of EcoCentre projects as well as those of other organisations. We therefore thank the State Government of Victoria for its support.

Our sincere thanks goes out to the many **volunteers**, including work placement students and interns, who have donated hours of their time and expertise to the project to make it a success. We acknowledge your great passion for the environment and deep dedication to making positive change for the future of our waterways. This project would not have been possible without your support.

We thank the following organisations, groups and individuals for their contribution and collaboration (in no particular order):

- Balcombe Estuary Reserves Group Mt Martha
- Beach Patrol Mt Martha
- Frankston Beach Patrol
- Rye Beach Patrol
- Beach Patrol Australia
- Seaford Beach Patrol
- Werribee Beach Patrol
- Werribee River Association
- Yarra Riverkeeper Association
- David Flew (Karringal boat skipper)
- Blair Stafford, Australasian Ambassador of the 5 Gyres Institute
- Blairgowrie Yacht Squadron
- Metropolitan Waste and Resource Recovery Group
- Melbourne Water
- Parks Victoria
- 3CR Community Radio
- 3RRR Community Radio
- Sacred Heart Mission
- Bellarine Catchment Network
- RMIT Plastics Lab: Prof. Graeme Allinson, Dr Mayumi Allinson, Marinda Pattison and students
- Scouts Victoria
- Worcester Polytechnic Institute
- Dolphin Research Institute
- Sustainability Victoria
- Victorian Litter Action Alliance
- Gordon TAFE
- Dr Christopher Johnstone and Emma Barnett of Monash University
- Victorian National Parks Association
- Federation University
- Australian Citizen Science Association
- *The Age*
- Department of Environment, Land, Water and Planning
- Ying Quek
- Port Phillip Men's Shed

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- Madison Healy - Worcester Polytechnic Institute
- Nick Sorensen - Worcester Polytechnic Institute
- Cameron Collins - Worcester Polytechnic Institute
- Samantha Comeau - Worcester Polytechnic Institute
- Brendan Gallagher - Worcester Polytechnic Institute
- Gina Visser - Worcester Polytechnic Institute
- Katie Donovan - Worcester Polytechnic Institute
- Spencer Hoagland - Worcester Polytechnic Institute
- Thomas Lipkin - Worcester Polytechnic Institute
- Eric Stultz - Worcester Polytechnic Institute

Microplastic.
Image: Josie Jones

Appendices

> Appendix 1

FIGURE 28

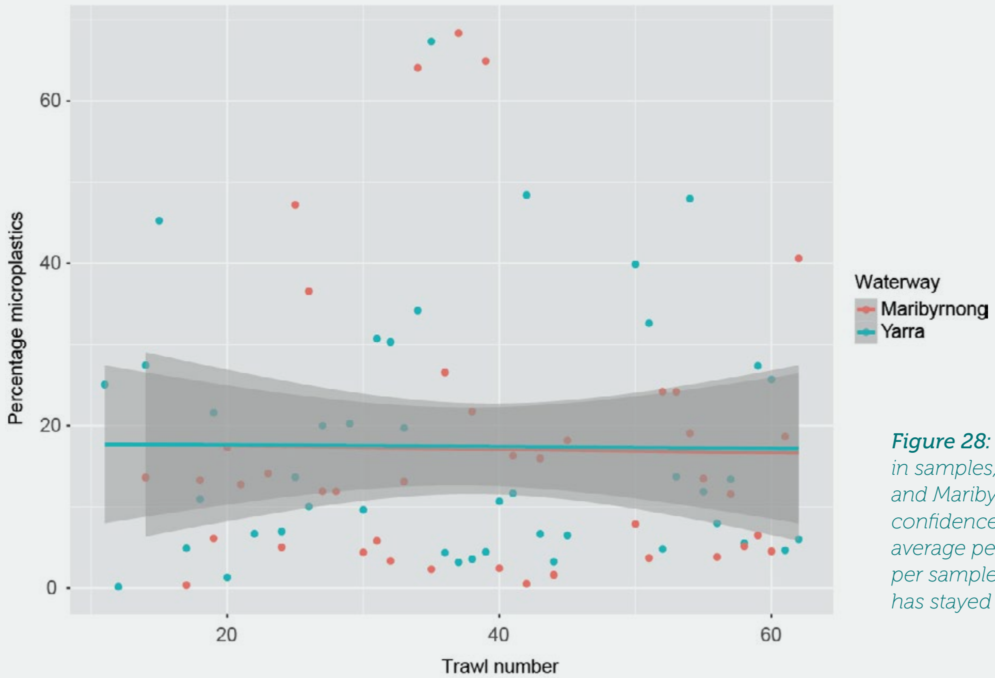

Figure 28: Percentage of microplastics in samples, per trawl in the Yarra (blue) and Maribyrnong (red) rivers with 95% confidence intervals shaded grey. The average percentage of microplastics per sample was 18.4%. This number has stayed constant over time.

> Appendix 2

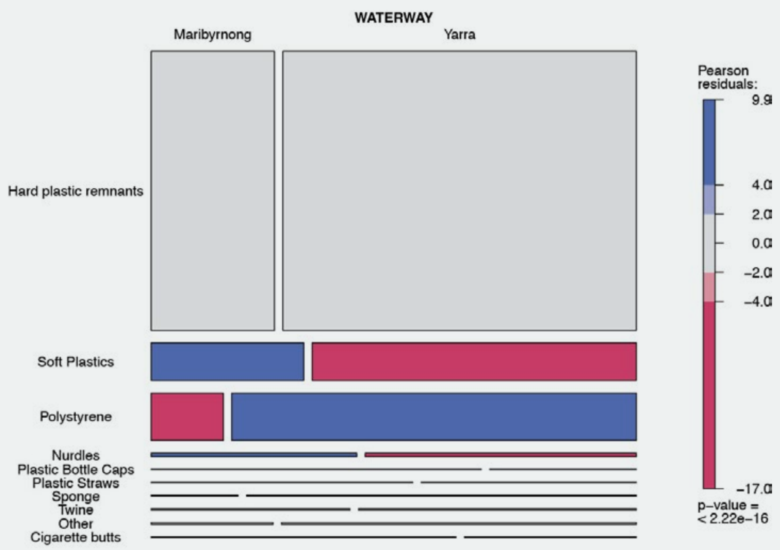

FIGURE 29

Figure 29: Mosaic plot showing the Chi-Square test results (in Table 3 below). The statistical test looks at whether proportions are different than what is expected by chance, considering both the Yarra's and Maribyrnong's total litter. The width of the boxes show the proportion of litter in the Maribyrnong compared to the Yarra. The height of the boxes shows the proportion of litter for each litter item. The colours represent significance. Boxes coloured red have lower proportions than expected by chance and those in blue have higher proportion than expected by chance. The boxes for hard plastic are grey, meaning there are no significant differences in proportions of expected hard plastic fragments in the Maribyrnong or Yarra rivers ($P > 0.05$). The boxes for nurdles, bottle caps, straws and soft plastics are blue for the Maribyrnong and red for the Yarra, meaning there are proportionally more nurdles, bottle caps, plastic straws and soft plastics than expected in the Maribyrnong river and fewer than expected in the Yarra ($P < 0.05$).

TABLE 3

	MARIBYRNONG	YARRA
Hard plastic fragments	1.74	-1.02
Soft plastics	**9.59**	**-5.60**
Polystyrene	**-16.88**	**9.86**
Nurdles	**8.03**	**-4.69**
Plastic bottle caps	**5.42**	**-3.17**
Plastic straws	**5.29**	**-3.09**
Sponge	-1.67	0.97
Twine	**4.12**	**-2.41**
Other	0.04	0.02
Cigarette butts	**5.96**	**-3.48**

Table 3: Residuals from Chi-square test for plastics count as a function of waterway and plastics category. Significant values are in bold red.

> Appendix 3

Plastic polymer analysis

A.

B. The below Table 7 is used with permission from the unpublished Honours dissertation *Analysis of Microplastic Polymers in the Yarra and Maribyrnong Rivers* (May 2020), by Marinda Pattison, under supervision of Associate Professor Graeme Allinson.

TABLE 6

	Plastic Resin	Density g/cm^3 at 70ºF
POLYOLEFINS	PP (polypropylene, #5)	0.90
POLYOLEFINS	LDPE (low density polyethylene, #4)	0.92
POLYOLEFINS	LLDPE (linear low density polyethylene, #4)	0.92
POLYOLEFINS	Mid-density polyethylene	0.94
POLYOLEFINS	HDPE (high density polyethylene, #2)	0.94-0.97
	Water	1.0
	Nylons	1.02-1.14
	ABS (acrylonitrile-butadiene-styrene)	1.05
	PS (polystyrene, #6)	1.05
	Polycarbonate	1.20
	PVC (polyvinyl chloride, #3)	1.29-1.44
	PET, polyester (polyethylene terephthlate, #1)	1.38-1.39

Table 6: Plastic polymer density (Stelray Plastic Products, 2020)

TABLE 7

	YARRA RIVER		MARIBYRNONG RIVER	
	Percentage (%)	Std Dev.	Percentage (%)	Std Dev.
Total PE	47.50	11.13	49.16	15.62
PP	22.04	10.24	23.61	8.67
PS	15.30	11.95	7.91	8.71
PU	0.88	2.17	0.35	0.67
Nylons	0.27	0.64	1.04	2.41
EVA	0.43	0.62	0.49	1.01
PVC	0.21	0.65	0.08	0.23
Latex	0.02	0.08	0.05	0.19
PE & PP mix	0.23	0.39	0.21	0.55
PET	0.02	0.08	0.00	0.00
Nitrile	0.00	0.01	0.00	0.00
PMMA	0.02	0.09	0.00	0.00
PTFE/ FEP	0.00	0.00	0.00	0.00
CA	0.01	0.05	0.00	0.00
PC	0.01	0.06	0.07	0.27
ABS	0.12	0.46	0.00	0.00
Unknown	0.67	0.96	0.88	1.13

Table 7: Mean abundance (percentage) of polymers in Yarra and Maribyrnong Rivers.

> Appendix 4

Changes in individual litter items over time

TABLE 4

MARIBYRNONG RIVER

Plastic	Kendall's tau	Z	P-value
Hard Plastic Fragments	0.26	5.52	**<0.001**
Nurdles	-0.04	-0.44	0.657
Other	0.43	4.16	**<0.001**
Plastic Bottle Caps	-0.13	-1.25	0.21
Plastic Straws	-0.21	-1.95	0.051
Polystyrene	0.09	1.4	0.161
Soft Plastics	0.13	2.79	**0.005**
Sponge	0.07	0.64	0.524
Twine	0.04	0.42	0.671
Cigarette butts	-0.03	-0.31	0.755

YARRA RIVER

Plastic	Kendall's tau	Z	P-value
Hard Plastic Fragments	0.33	7.41	**<0.001**
Nurdles	0.08	0.86	0.391
Other	0.23	2.29	**0.022**
Plastic Bottle Caps	0.16	1.46	0.146
Plastic Straws	-0.25	-2.34	**0.019**
Polystyrene	0.22	3.46	**0.001**
Soft Plastics	0.27	5.78	**<0.001**
Sponge	0.25	2.48	**0.013**
Twine	0.07	0.72	0.470
Cigarette butts	0.17	1.64	0.102

Table 4: *Kendall's tau test results. Change in counts of plastic over time, by category, for the Yarra and Maribyrnong rivers. Kendall's tau, the Z value and P-values are presented. Significant values are in red. These results are important for interpreting the scatterplots in Figures 18 and 19. A positive tau indicates an increase in litter over time. A negative tau indicates a decrease over time. Kendall's tau is a non-parametric correlation value.*

> Appendix 5

Bandalong litter traps

In the Yarra River, multiple outliers were recorded for the total litter items captured per trawl date. Litter traps were emptied over 24 of the trawl days. Six of those days showed higher than average litter counts. On 35 trawl days, litter traps were not emptied and we saw five higher than average total litter counts.

FIGURE 30

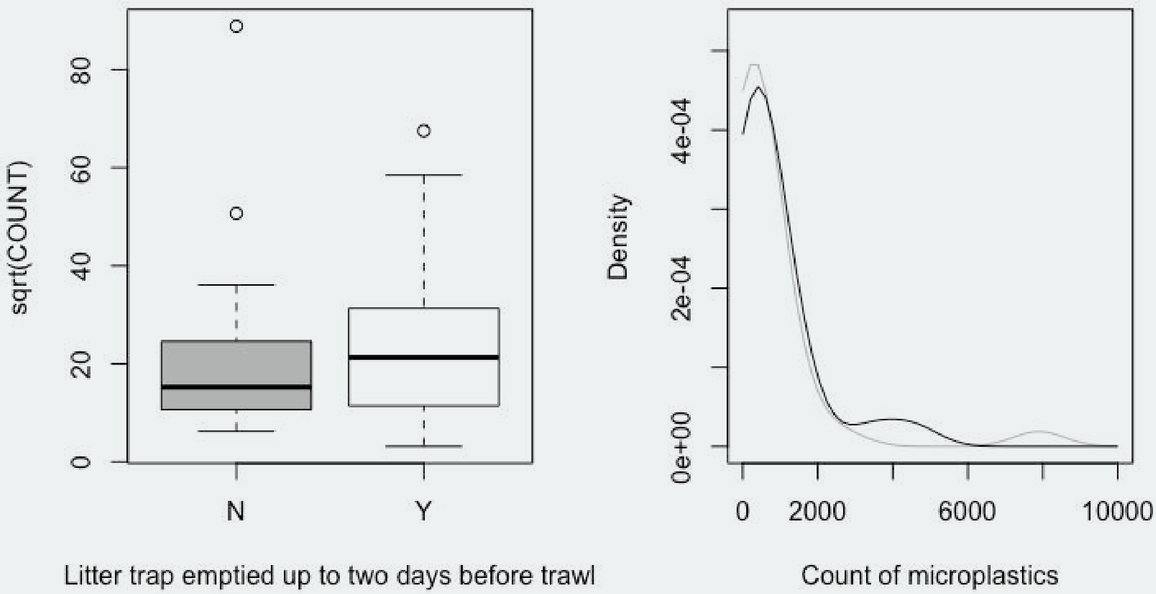

Figure 30: A Wilcoxon rank sum test compared median litter counts when litter trap was emptied to when litter trap was not emptied (two days before trawl). We did not find any effect of litter trap emptying on the total number of litter items captured (W = 289, P = 0.162).

> Appendix 6

Yarra Environmental flows

There was no significant association between environmental flow events and plastic counts in the Yarra (t = -0.3, P = 0.768). The amount of variation in microplastic counts explained by environmental flows was close to zero (adjusted $R^2 < 0.001$). Note that microplastic count was square root transformed to meet assumptions of a regression analysis.

FIGURE 31

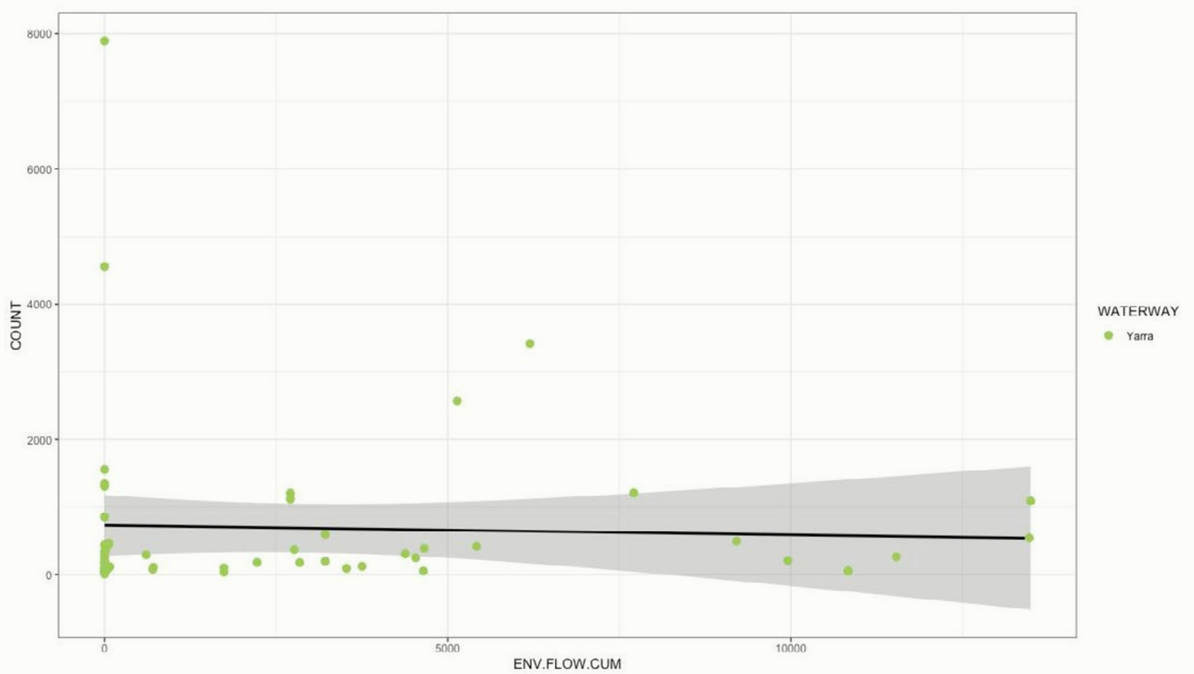

Figure 31: Count of microplastics per trawl as a function of environmental flows in the Yarra River.

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