Long Term Plastic Rubbish Study in Port Philip Bay

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The topic of plastic in our oceans has been getting more and more international attention in the last 10 years. To solve this problem is going to involve taking a lot of action at local and international levels. Having a baseline size of the problem recorded would be very helpful before any meaningful action can be taken.

The city of Melbourne sits at the top of a large bay, Port Philip Bay. The amount of plastic rubbish in Port Phillip Bay had not been a subject of serious study prior to 2015. Different groups had been undertaking beach cleans to remove the plastic that washed in[1]. The various groups in BeachPatrol Australia (BPA) were also recording basic items such as plastic bottles to monitor their count over time at numerous locations around the bay on a monthly basis. The State government had never monitored the issue and were considering introducing some plastic restraint measures[2]. Without a base line of the current situation it would be difficult to tell if any measures were being effective after they had been introduced. Monitoring litter on our beaches has become more necessary as our population grows and our modern “convenient” lifestyle results in increasing usage of disposable plastic items. The potential harm of these items to wildlife is significant. The closer the plastic litter resembles naturally occurring food, the greater is the threat of harm to wildlife, particularly seabirds. It is important to find efficient ways to monitor the amount of plastic in our oceans to be able to quantify potential consequences this pollution has on the marine environment, and ultimately, us. Collecting good quality data is paramount to providing impetus for action to reduce the influx of plastic into our oceans[3].

In the large oceans, plastic litter can travel many thousands of kilometres. Identifying the origin can be difficult, due to weather and currents. Affecting legislation to stem the tide of plastic entering the oceans is hampered by complicated international relations, politics and cultures. These facets can make it very hard to bring the importance of the problem to the source.

In March 2016, two BPA volunteers in the suburb of Port Melbourne in Melbourne, started surveying the plastic that washed ashore every day on a specific beach. They selected two fixed lengths along that beach to survey to get an average for that beach. (See Appendix1) . Their goal was twofold. They wanted to identify the top or most common item types that were washing out of the bay. This would support any potential upcoming legislation on plastic items. The second goal was to use the data and develop a model that would allow the extrapolation of how many plastic pieces were washing out of the whole bay perimeter every year. This would essentially show how many items of plastic were washing into the bay each year.

Background Port Phillip Bay is a large bay approx. 30 km across. It has narrow heads making the bay a near captive source of water. It has a coastal perimeter of 260 km. The city of Melbourne lies at the top. The bay is fed by a number of rivers, of which the Yarra river that runs through the city of Melbourne is the largest. It enters at the Bay's northern most point. Studies by the State of Victoria's EPA[4] show that very little in the way of debris that gets into the bay washes out through the heads to the ocean. Hence, what debris flows into the bay will either stay in the bay waters or wash out somewhere along the coast. The area is often windy and the wave action pushes most floating plastic rubbish ashore at some point.

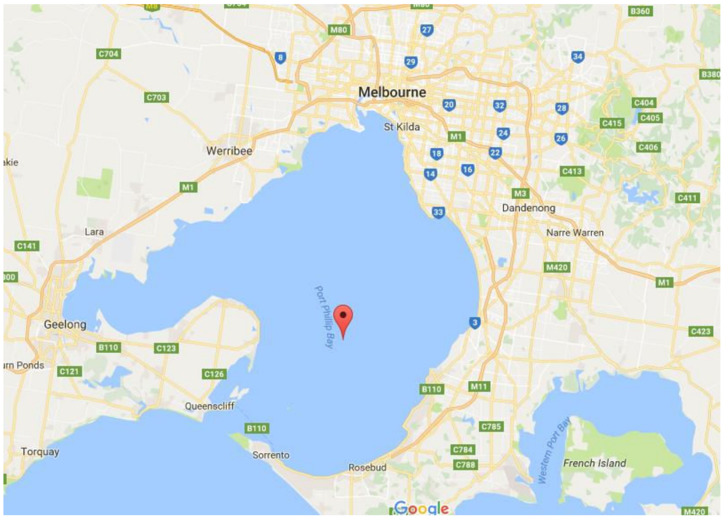


Figure 1, Port Phillip Bay

Related Work

Melbourne Water[5] performed a litter distribution experiment in 1991. They released 1307 tagged items into the upstream waterways that drained into the bay. The items had a note for the finder so they could call and report the ID number, as well as when and where the item was recovered. Their study estimated 4-5 million pieces of plastic entering Melbourne waterways per year. It was not clear from their paper how they arrived at this number. This was 30 years ago. No other work on this topic has been published since.

A concurrent study to the study in this paper, performed by the Port Philip Ecocenter[6] focusing on microplastics using manta nets and performing 113 trawls through the two largest river inlets to the bay collecting 53,688 pieces of plastic. Their findings predicted nearly 2.5 billion pieces of plastic entering the bay, of which 2 billion were microplastic (smaller than 5 mm) and 0.5 billion were larger than that. This report also stated this was still probably an under estimation due to other river inlet sources into the bay and very small plastic pieces that would pass through the manta net.

Other Survey Methods. Other survey methods encountered, employ a fixed sized small area on a beach and count items per square meter and extrapolate that over the whole beach. Another method uses a transect in which a fixed width section of one to two meters is survey starting from the water's edge going all the way up to the top end of the beach. This method is chosen to cover the different zones on a beach. It reaches from the tidal zone at the water's edge, through the beach visitor zone at mid-section, up to the wind catchment areas around bushes or fences at the top. These results are then extrapolated over the length of the whole beach. These methods provide information on the type of debris on a beach at that instant in time. They cannot provide any information like history of when the debris came ashore, what the beach was like the day before, has it recently been cleaned or had big wind just come though and blew some items away? They do not show seasonal effects to cause debris variations ending up on the beach. Any of these could make the snapshot image quite distorted. Conducting a yearlong daily survey that provides information on the rate of the debris loading onto the beach every day is of much more interest than a snapshot of the beach condition at a single point in time.

Survey Details

This survey started with recording of how many pieces of plastic were washed ashore every day. They were sorted into 15 different categories. If a lot of one distinct type were being encountered, that were subset of the 15 categories, then it was made into a new category the next year. The list was expanded each year based on the previous year's observations. In the last two years there were 28 categories of different plastic items that were counted.

The issue of obtaining accurate litter data is further complicated for urban beaches for two reasons: Firstly, many local councils regularly sweep beaches with cleaning machines that skim the dry sand to remove most of the non-sand items. If such cleaning has occurred prior to an audit, then the audit results will underestimate the litter. These machines cannot get down to the tide line however, as the wet sand clogs their workings. Secondly, people often walk for exercise or walking their dog in the morning and many of these people casually pick up some litter when they see it. This would then also contribute to an under-estimation of true quantitative litter data. The survey described in this paper was done early in the morning to avoid the above two factors.

Further survey procedure details can be found in Appendix A.

Overall Data Results

The most interesting result of the survey is to look at how the total plastic items count varied over each of the five years and also within a year. Over 530,000 pieces of plastic were picked up over the 5 years and divided and counted for their respective categories.

Figure 2 Cumulative pieces of plastic collected each year

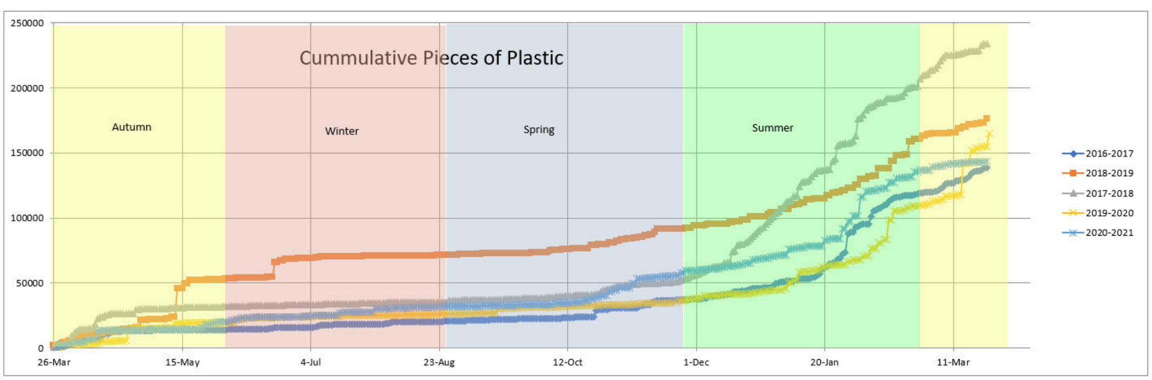


Figure 2 shows some interesting points.

1) It shows how many items were collected off just 55 m of beach each year. The worst year 2017-2018. Nearly ¼ of a million pieces were picked up off that short tide line length for that one year. When you consider the bay is 260 km around it paints a dire situation. We calculate, factoring in wind directions and speed as per Appendix B, this predicts over 500 million pieces of macro plastic washing out of the bay per year. What washes out must have entered the bay somewhere. The year 2017-2018 has high values in every category compared to other years. In looking at the chart it suggests it may have possibly been a hotter year with a lot of people outside

compared to other years. (This could be verified by a more detailed review of weather records that summer).

2) It shows the variation throughout the seasons of the year. The winter rate can be seen to be climbing very slow as it is cold, and people are not outside having food and drinks. Then in spring with the warmer weather and higher winds, more people are outside, and the plastic rubbish rate climbs fast through summer and leveling off in late autumn.
3) It shows that over all there is no decrease in the amount of plastic over the 5 years. The curves are somewhat close, indicating that in spite of all the news of plastic pollution around in recent times, not much change is happening overall. This means we need regulation to supplement education. The Victorian State government has announced[7] some upcoming bans on some items effective in 2023. This is a good first step, however further action is needed. The Federal government has been silent on this issue for many years in spite of mounting evidence presented to them[3]. They are just starting to introduce the voluntary National Packaging Targets[8] for plastic packaging. This may alleviate some items classed as packaging, but not many of the items found in the survey will be covered by these new requirements. Food wrappers would be the main category and if industry classes them as recyclable, then no change would be expected here either.

Detailed Analysis

In order to extrapolate the results for the whole bay, two factors were needed. One was to extrapolate from the survey length to the full bay perimeter. This is 260 km for the entire bay, extrapolated from the 55 m survey length. However, this factor alone would overestimate the amount of rubbish as the wind speed, duration and direction play a big factor. A strong on shore wind or a lighter onshore wind for a longer time would wash more plastic on to the beach. Conversely, an offshore wind would reduce the plastic washing ashore. For port Phillip Bay, as it is a nearly enclosed bay, then an offshore wind direction on one side, would result in an onshore wind direction on the other side of the bay.

The concept of a "wind-day" was developed to account for wind strength and time duration. This assumes a strong wind for a short time and a lesser wind for a longer time would have the same effect of washing rubbish ashore. 1 wind-day is defined as a 1 km/hr wind blowing for 1 day (24 hours). Therefore, for example, a 10 km/hr blowing for 1 day is 10 wind days. A 20 km/hr wind blowing for 6 hrs then stopping is 5 wind-days. See Appendix B for further details.

Rainfall clearly effects the amount of plastic washing into the bag after any rain event as the runoff surface water washes street rubbish into drains which flow into the bay. The effect of the rain is however to cause spikes in the influx of plastic into the bay[5]. It does not change the total amount of litter washing into the bay over a year.

Table 1 shows the counts for all categories. This is the average per year for the five years. If an item was counted for less than that time, it is the average of its respective yearly count. The table then shows the estimate of how many of each of the items wash out of the entire bay every year based on the methodology shown in Appendix B.

	Bottle Glass	Bottle Plastic	Cans Drink	PPE*	Hard piece > 5 cm	Hard piece < 5 cm
Survey Amount	28	157	43	75	3,499	12,984
Whole Bay Estimate	85,276	478,844	130,715	227,641	10,668,319	39,585,891
	Soft piece>5 cm	Soft Piece < 5 cm	Microplastic	Wrappers	Food Containers	Bags
Survey Amount	35,283	46,874	28,590	23,499	810	782
Whole Bay Estimate	107,568,733	142,907,581	87,165,560	71,641,920	2,470,763	2,383,284
	Ziplock Bags	Straws	Bottle Tops	Bottle Labels	Coffee Cups	Cups Other
Survey Amount	476	1,551	1,435	1,577	137	242
Whole Bay Estimate	1,449,893	4,729,819	4,376,284	4,808,925	416,157	738,649
	Balloons	Cutlery	Polystyrene	Fishing Items	Cig Butts	Cig Other
Survey Amount	703	149	5,721	271	2,373	243
Whole Bay Estimate	2,144,341	455,740	17,442,860	826,948	7,234,584	739,835
	Syringes	Construction Items	Nurdles	Totals		
Survey Amount	29	320	7,412	175,263		
Whole Bay Estimate	87,028	974,590	22,597,271	534,337,450		

Table 1 predicts that over half a billion pieces of plastic wash out of the bay onto surrounding beaches every year. This is very disturbing when it was only 50 years ago this would have been almost zero. The rapid rise in the unconstrained use of plastic has brought about this very large change within a person's lifetime. By 2050 it is estimated that four times as much plastic will be dumped into the ocean per year[9] compared to now, unless strict and enforceable regulations can be implemented to change this trend.

* PPE items were added in late October of 2020. This was the time of high Covid 19 incidence in Melbourne and it had 'all of a sudden' become a new type of litter which had not been seen prior to this. Hence it only reflects 5 months of collection. Once Covid has been eradicated, it is expected this item count will drop down considerably again.

Table 2 shows the percent of each item that was picked up. It can be seen that of all the plastic picked up, that 72.6% of the count was the bits of plastic hard, soft and microplastic pieces. These are not attributable to any specific item.

Item	Bot Glass	Bot Plastic	Cans	PPE	Hard Pl>5 cm	Hard Pl<5 cm	Soft Pl>5 cm
Percent	0.02%	0.09%	0.02%	0.04%	2.00%	7.41%	20.13%
Item	Soft Pl <5 cm	Microplastic	Wrappers	Food Containers	Bags	Zip Lock Bags	Straws
Percent	26.74%	16.31%	13.41%	0.46%	0.45%	0.27%	0.89%
Item	Bottle Tops	Bottle Labels	Coffey Cups	Other Cups/Lids	Balloons	Cutlery	Polystyrene
Percent	0.82%	0.90%	0.08%	0.14%	0.40%	0.09%	3.26%
Item	Fishing	Cig Butts	Cig Packs	Syringe	Construction	Nurdles	
Percent	0.15%	1.35%	0.14%	0.02%	0.18%	4.23%	

Table 2 Percent of each item of total plastic collected.

What is also of interest is to consider what the percent of each specific item category is of the total specific items, i.e. excluding the bits of plastic mentioned above, as they dominate the count. This allows a clearer consideration of the magnitude of each specific item and a better guide as to what items to target for any plastic rubbish reduction programs. In table 2, balloons are only 0.4% of total plastic rubbish, yet in table 3 this can be seen to be 1.46%. Table 3 is dominated by food wrappers and then nurdles.

Item	Bot Glass	Bot Plastic	Cans	PPE	Wrappers	Food Containers
Percent	0.06%	0.33%	0.09%	0.16%	48.92%	1.69%
Item	Bags	Zip Lock Bags	Straws	Bottle Tops	Bottle Labels	Coffey Cups
Percent	1.63%	0.99%	3.23%	2.99%	3.28%	0.28%
Item	Other Cups/Lids	Balloons	Cutlery	Polystyrene	Fishing	Cig Butts
Percent	0.50%	1.46%	0.31%	11.91%	0.56%	4.94%
Item	Cig Packs	Syringe	Construction	Nurdles		
Percent	0.51%	0.06%	0.67%	15.43%		

Table 3. Each specific item's percent of all specific items.

Individual items Review.

The following graphs show the counts per year of each individual item. As noted above, some items were separated out and counted on their own part way through the 5 years hence do not have data for all of the 5 years.

Non Specific Items

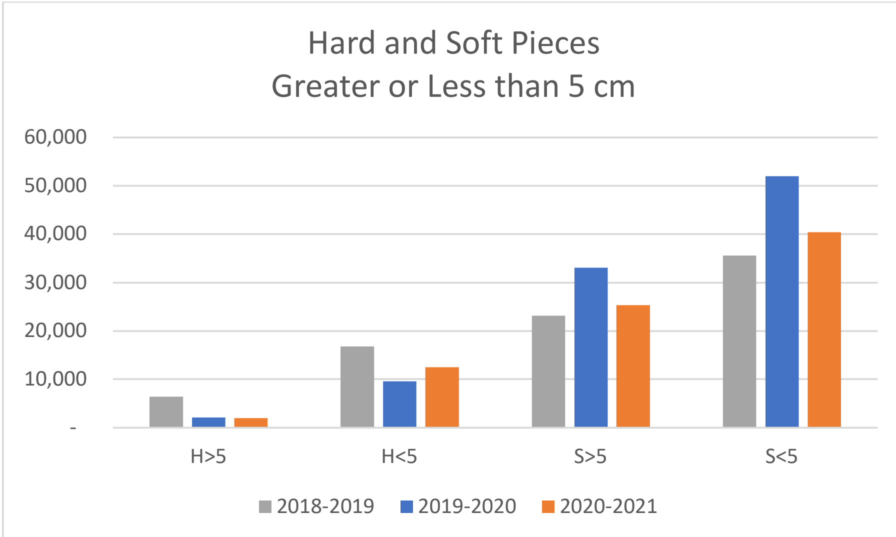
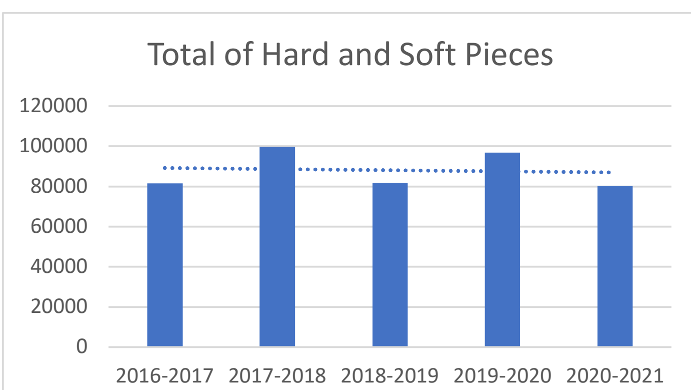


Figure 3 Hard and Soft pieces of plastic that do not fit into any of the specific categories.

These items were separated into those greater than 5 cm and those less than 5 cm. The purpose of this was to see if any understanding of the amount of breakup of plastic due to wave action in the bay could be ascertained. If a lot of break up was occurring, then small items would be a lot more prevalent than larger items. While this is indeed for hard pieces where small pieces were approximately 400% more than hard pieces, it is less so for the soft pieces. For soft plastic, small pieces were approximately 150% of large plastic pieces. Reference [5Tagged] showed that up to 87% of plastic items entering the bay are washed out with in the first 4 months, indicting the plastic does not spend a lot of time in the water compared to big ocean waters. Soft plastic being more flexible, can bend and flex with agitation, hence it would be expected to break up less. Hard pieces are stiffer, heavier and would be prone to more flexural stress during wave action.

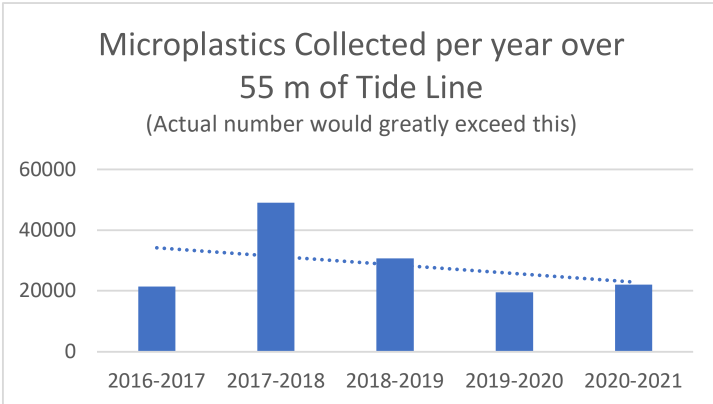
Comparing hard piece to soft pieces, the soft pieces were approximately 425% more prevalent than hard pieces. This probably reflects use by industry. Soft packaging is used extensively for food items and is the largest application of plastic[8ElleMc].

Figure 4 Total of Hard and Soft Pieces



The total of all the hard and soft pieces per year is shown in Figure 4. No significant trend is seen. The count in the fifth year is the same as the count in the first year with little variation in between.

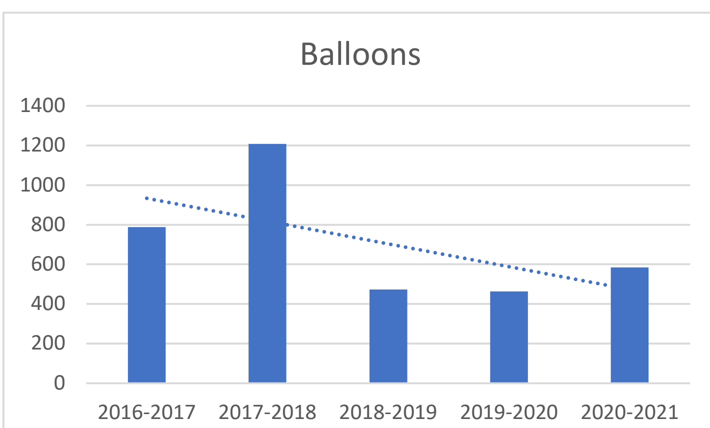
Figure 5 Microplastics



Microplastics are shown here to again show there is no obvious trend. While the trend line shows a decreasing slope, it is influenced by the 2017-2018 year. Year 5 has the same count as the first year which may be a better indicator. The microplastic counts in this survey were limited to obvious pieces of plastic to the naked eye and that could be picked up by hand. The actual amount of microplastics would be 1000's of times greater than this shown. There were many days where 100,000s of tiny blue, white and red flecks were on the sand at the water's edge or floating in the water ready to wash in. It was impractical to count these. The method used in reference 6 *(clean bay)* is a more detailed way to estimate microplastics.

Specific Item Results

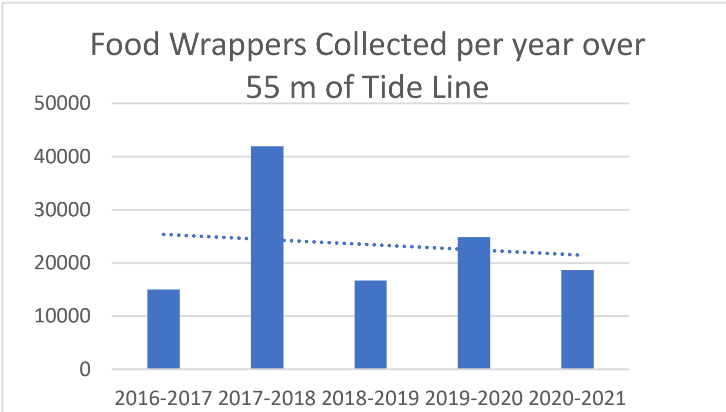
Figure 6 Balloons



This group includes balloons and balloon associated items such as the balloon sticks and clips.

This year shows again the year 2018-2018 was higher than any other year. Apart from that, the trend for the last three years would indicate an increase in balloon littering in spite of many anti balloon release campaigns [10 zoo] or balloon release ban programs by local jurisdictions[11council].

Figure 7 Food Wrappers

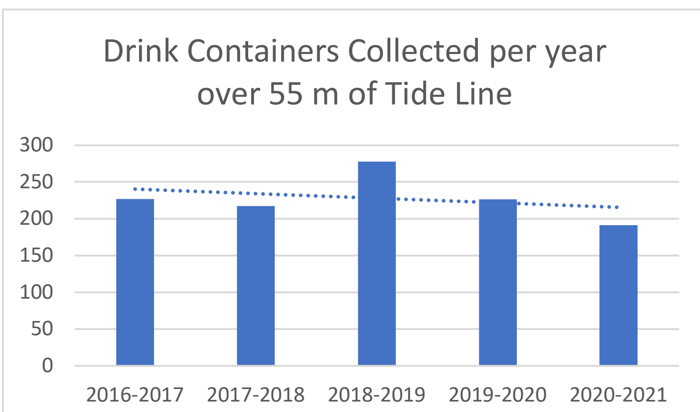


Food wrappers had the largest count in the specific category items. They made up 13.4% of all plastic picked up. After a period of high on shore winds, the seaweed washed ashore would have a high concentration of food wrappers and other pieces of plastic.

Drinkware

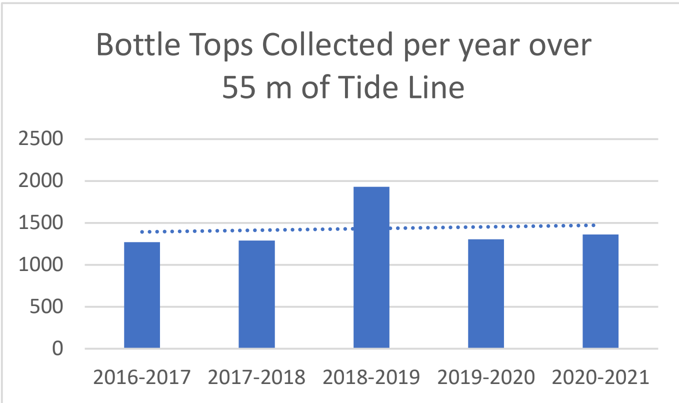
Drinkware items can be looked at as a subgroup as they are closely related items with many littered at the same time. These include, bottles and cans, bottle tops, bottle labels and straws.

Figure 8 Drink Containers



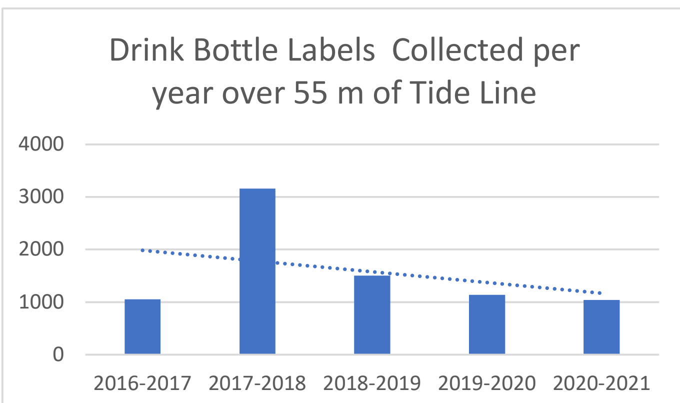
Drink containers comprised glass bottles, plastic bottles and drink cans. There are some unusual factors for this category.   Compared to the components that make up a complete bottle package such as bottles top and bottle labels, the count of containers was understandably low.   For metal cans and glass bottle, they sink in water and do not wash in on a tide unless there is a large storm. Similarly plastic bottles are made of PET material, and this also has a specific density greater than water, so they too sink to the bottom. Only if the littered bottle has its top screwed on would it float and then wash ashore. Once ashore however, for plastic bottles as they are comparatively big, round with little weight, they easily blow up off the beach.

Figure 9 Bottle Tops



Almost 5 times as many plastic bottle tops were found per year as drink containers. Some days over 100 tops on the 55 m of tide line. The tops float and easily wash in with the tide. Their bright colour allows them to stand out against the sand background. A simple and low cost change to a tethered cap as trialled in a European study[12] would near eliminate this prolifically littered item on our beaches and other public spaces.

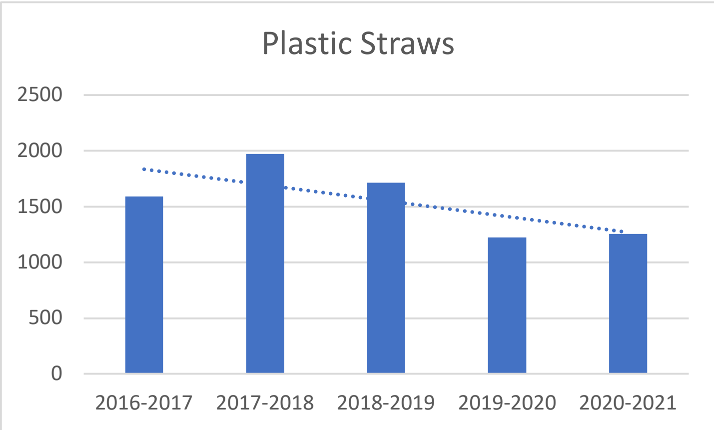
Figure 10 Drink Bottle Labels



These are plastic labels that come from plastic drink bottles. They are found in similar quantities to bottle tops. There are many problems associated with this one item. They are all caused by their design considerations being only for the bottle use and its sales and no provision for the littering situation. The labels are spot glued to the plastic bottle. Affixing one piece of plastic to another with a glue is a very technologically challenging and expensive problem to achieve a successful durable bond. The drinks industry with their very large output volumes, adopt a much lower cost and less robust method. Reputedly the labels are designed to come off when the bottles are recycled and put into wash tanks. However this means too that the labels readily come off when the bottle ends up in the ocean being agitated around with the waves.
The labels are also a composite label made of more than one layer of plastic. Layers for bonding, layers for strength and layers for printing on. Hence not only does the label come off a bottle in the

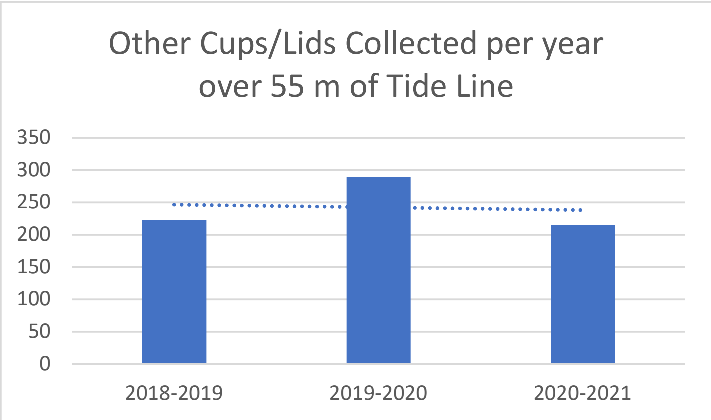
ocean, the layers separate as well, making multiple pieces of plastic litter.
Their downward trend is skewed by a high number collected in the second year.

Figure 11 Plastic Straws



Plastic straws were one of the most prolific items collected. Many were attributable to fast food chains with their characteristic stripped patterns.   In 2018 Buckingham palace banned straws[13] in their royal estates. This caused a ripple effect around the world and many food service businesses followed suit over the next 24 months to phase out plastic straws. Figure 11 does show a declining trend line for straws being found on the beach. This trend line shows an approximate 9% reduction on average per year.   Plastic straws are a simple item to replace as there are many substitutes to plastic straws available. This would help in their steady decline in usage. They are also one of the key items to banned in the Victoria State Plastic items ban in 2023[7]

Figure 12 Cold Drink Cups and Components



These items were only separated out for the last three years. A slight declining trend is observable.

Figure 13 Coffee Cups and Lids

In many times, it is not obvious that a remnant piece of plastic is actually the remains of a disposable coffee cup. Sometimes it would just be a cloudy piece of plastic film.   On some other times, the cardboard bottom would still partially be there to give away its identity. Hence it took some practice to more closely examine the plastic fragment to establish it was the remains of a coffee cup.   These items were only separated out for the last three years after gaining this experience. Perhaps the presence of Covid in 20-21 year exacerbated the use of disposable coffee cups.

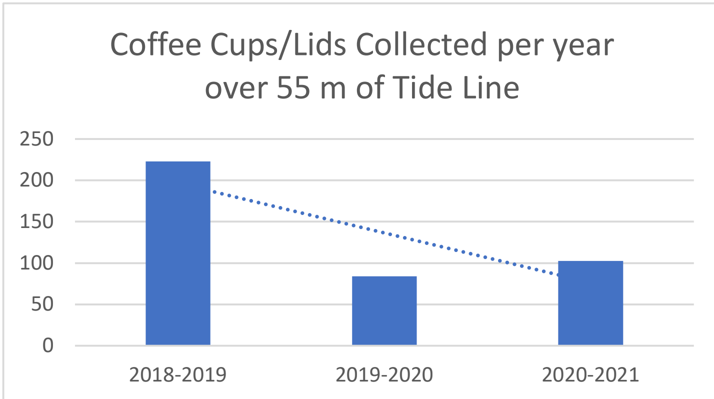
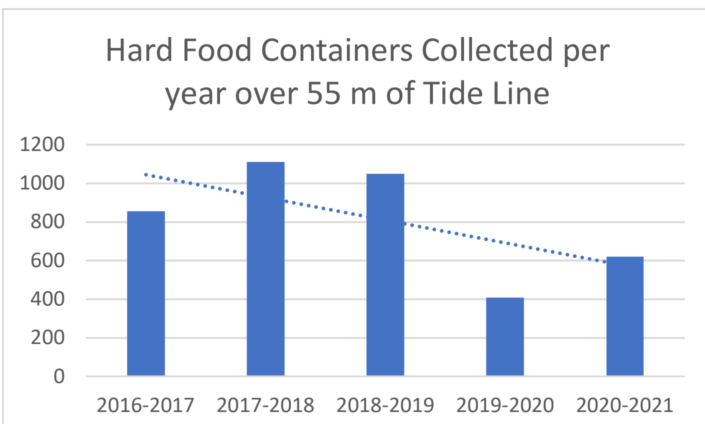


Figure 14 Food Containers

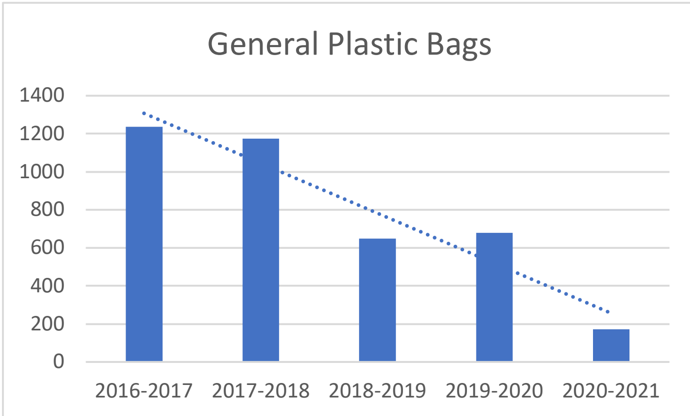


This group contained hard plastic take away food containers from take away shops, packaging for store brought food and sauce packets. It thus covered a range of hard plastic products. The trend was down until the last year which was the first covid 19 response year.

Plastic bags

Plastic bags were also a large grouping. In this group they were separated into general plastic bags, zip lock bags and Fishing equipment which was predominantly bait bags.

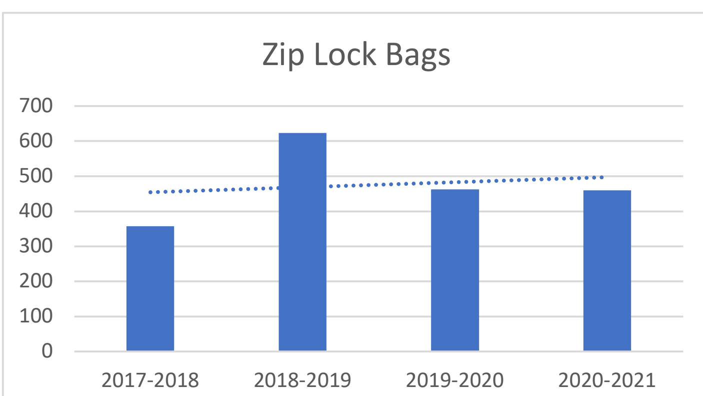
Figure 15 General Plastic Bags



This category included the store hand out tee shirt style bags and any other nonspecific bag. Plastic bags are a unique item for collecting from a beach. They are generally not lying on the sand like a piece of plastic film. Having a sealed bottom, they float at the water's surface and fill with water. They move through the water like an iceberg, with almost all of the bag just under the surface, hanging down 200-300 mm. As they approach the shoreline they run aground in shallow water of that same depth. There they fill with sand from the waves and settle to the bottom. Most plastic bags therefore are found in this shallow water partially filled with sand and buried. In the calm days are a storm with on shore winds, then that is when the plastic bag population is at its highest.

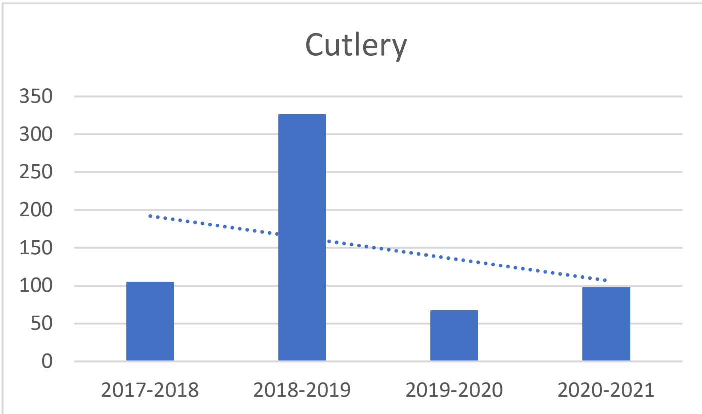
On 1 November 2019, the State of Victoria banned lightweight shopping plastic bags[14]. The consequence of this can be seen in figure 15 above. A steep decline in bags. It may be that the again sudden drop on in 2020 was due to people being outdoors a lot less due to Covid 19 restrictions for most of that year. The trend line shows a steep decline in plastic bags of 262 bags per year for this stretch of beach which is approximately a 25% decline per year from the 2016-2017 year supporting the concept of government ban regulations are very effective.

Figure 16 Zip Lock Bags



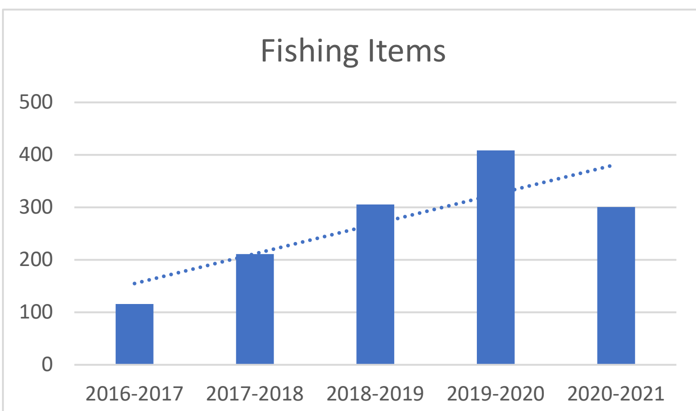
The high number of zip lock bags collected in the first year made it worth recording them thereafter. They are a significant portion of total plastic bags. Their frequency is trending up each year.

Figure 17 Cutlery



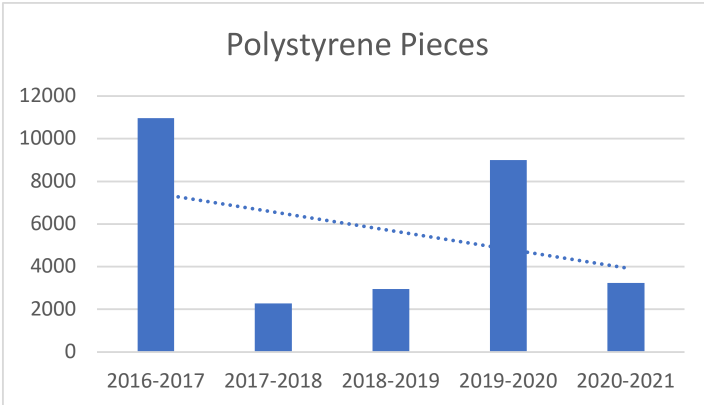
Plastic cutlery was not found in any significant quantities. Figure 17 shows typically only around 100 per year were picked up. Except for the 2018-2019 year, their quantity found per year did not change very much. This is one of the items listed to be banned under the State of Victoria ban in 2023[7].

Figure 18 Fishing Gear



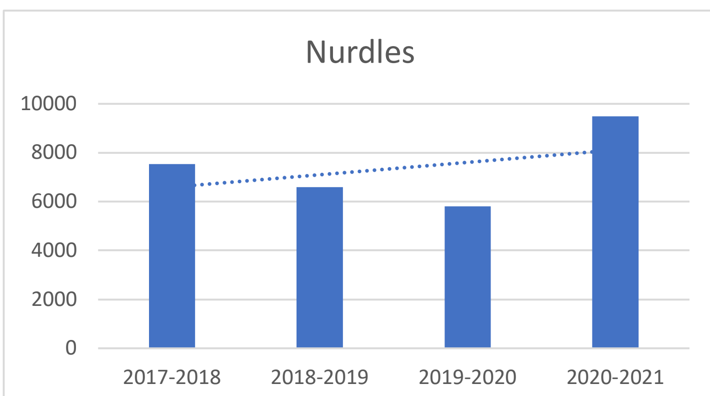
Fishing gear picked up was all most all bait bags. The steep increasing trend line shows the negative effect of a government plan to increase recreational fishing in Port Philip Bay[15]. More fishermen result in more littered bait bags. The drop off in 2020-2021 was attributable to the total fishing ban during the 2020 Covid-19 restrictions. The way bait is packaged and sold is not the best method for the application. They are a non resealable bag.   This means once opened the fishermen cannot close them off again to take home. They could spill out and smell out their car.   The contents are more likely to be dumped and this leads to a high amount of bait bags ending up in the water. If these bags were a resealable container, then possibly this could lead to less bait bag littering. Further research and consultation with the industry is needed.

Figure 18 Polystyrene



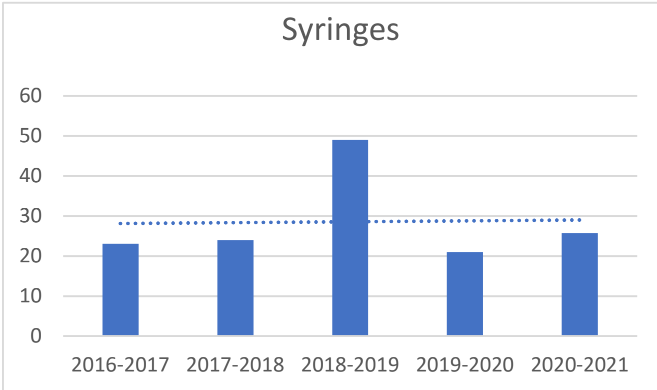
Polystyrene includes chunks of polystyrene down to the individual little polystyrene balls 3-4 mm diameter that are liberated as the chunks break up. The above graph trend is a little skewed as in 2016 there was a storm that washed 1000's of polystyrene balls up on to the beach over just a few days. Otherwise the trend would show an increase.

Figure 19 Nurdles



Nurdles are the little plastic beads made by the raw plastic manufacturers and sold to the plastic product manufacturers. Often called pre-production pellets. They are typically coloured cream, and 2-3 mm diameter with a cylindrical shape. If accidents happen during their transport or use, they get dumped in the 1000's, often washing down drains or waterways to get to the oceans.   It takes an experienced eye to spot then as they can look like large grains of silica sand. The continuing rapid rise in plastic production will inevitably result in increasing spillage of nurdles unless some government regulation on their handling and use is introduced.

Figure 20 Syringes



Syringes are an unfortunate item found washed on to beaches. Measures to address their reduction would need to be quite different to the measures taken to address the other above common general consumer items. The trend line shows a slight increase per year.

Change in Plastic Littering Rate Over the 5 Years

A breakdown of the change in litter type per year is show in table 4. Using the slope of the trend line for each items yearly graph, an estimate can be made of the percent reduction for each item per year. For balloons shown in table 4, the trend line showed balloons were reducing at 15% per year. This can be expressed as a percent of total littler reduction by multiplying the annual percent decrease by the ratio of balloon litter to total litter. This is shown in column 6 of Table 4.

At the bottom of Table 4 is shown the overall trend of litter is reducing 4.5% per year. While some readers would say plastic litter is decreasing, that is good, it shows that, with no other changes, it would take another 16 years to get plastic litter down by 50%. Given the high rate of plastic in the oceans now and the rate that it is entering the oceans, this would appear to be too slow of a change.

Item	Trend Rate	Value First Year Recorded	Percent of first year value	Average per year	Percent of total litter
Balloons	-115	787	-15%	703	-0.061%
Straws	-141	1590	-9%	1551	-0.081%
Bottle Labels	-204	1051	-19%	1549	-0.178%
Wrappers	-968	15051	-6%	23460	-0.891%
Butts	-182	2688	-7%	2358	-0.094%
Containers	-6	227	-3%	228	-0.004%
Bit >5	-4410	39064	-11%	37382	-2.491%
Bit <5	1901	42459	4%	54664	1.445%
Micro	-2820	21412	-13%	28577	-2.222%
Food Con	-117	856	-14%	809	-0.065%
Bags	-262	1237	-21%	782	-0.098%
Zip Lok	14	358	4%	476	0.011%

Bot Tops	19	1273	1%	1432	0.013%
Bot Labels	204	1051	19%	1576	0.181%
Coff Cups	-60	223	-27%	137	-0.022%
Cups/Lids	-4	223	-2%	242	-0.003%
Cutlery	-28	106	-26%	149	-0.023%
Poly	-872	10958	-8%	5683	-0.267%
Fishing	56	116	48%	271.24	0.077%
Syringe	0.22	23.06	1%	29	0.000%
Nurdles	508	7532	7%	7352	0.293%
				Net Change in Plastic Items Count	-4.479%

Table 4 Change in each littering rate for each item by year.

Conclusion

The 5 year survey data has yielded deep insight into not only the litter rate, but also the types of plastic litter being released around Melbourne's Port Phillip Bay. Using wind data, a model was developed to predict the total count of plastic littering washing out from the whole of the bay every year. The survey showed significant variations in littering over the different seasons, emphasising the importance of surveying for the full year not just at a few times within a year. The results also showed the importance of sampling at a high frequency as many short-term events can greatly influence the count on anyone day. For example, a storm washing litter in or blowing litter away, or another group had just recently performed a clean, removing litter before the survey.

The 5 years of survey showed a slight decrease in the amount of plastic litter per year on average. However, the decreasing rate is very small and shows that more strong action on the reduction of plastic use is required.

Appendices

Appendix A

Survey Method.

For the first 2 years, every day the survey counted and removed every bit of plastic that washed ashore in the previous 24 hours along two sections of a beach in Port Melbourne. For the following three years, due to the time it took to do the daily survey, the same method was used but only for 3 days a week. Date from the first two years of daily surveying showed that, if the surveys were sampled at 3 days a week, and the results extrapolated to obtain an equivalent every day of the week survey, the 3 times per week would be expected to be within 17% of the everyday survey number.

One section length was in a rock groyne corner which could act as an over valued concentration point or an undervalued location depending on the wind directions in the last 24 hours. The other section length was in the middle of the beach away from any corner effects. Combined they would provide a more average situation of the plastic loading washing out on the beach.

The first section in the corner was 35 m along the tide line. The midsection section was 10 m long for the first year and extended to 20 m long for years 2-5. The 35 m length was chosen based on how much tide line could be cleaned of plastic without taking undue time. It could take anywhere from 5 minutes for clean days to 5 hours on heavily loaded days.

Appendix B

Data Extrapolation to the whole of Port Phillip Bay.

Port Phillip Bay perimeter data

Port Phillip Bay is a bay with an area of 1950 km^2 and a perimeter of 264 km. Using a map of the bay, the coastline was divided into successive straight sections. For each section, the length was determined from the map scale and its orientation relative to north was tabulated. A minor linear adjustment was made to ensure the total lengths of the sectors added up to the actual coast length of the bay perimeter (264 km). From this, components were calculated for each sector to ascertain the respective North, East, South and West facing directions and the component lengths. Adding up these length components, the total distance of the bay coast facing each of the 4 compass points was determined (Table 1).

Table B1: Length of Bay Shore facing each of the four Compass directions.

South facing beach	86,091 m
North facing beach	87,827 m
East facing beach	77,731 m
West facing beach	84,882 m

Table 1 shows there are not a lot of variations between compass directions in net lengths of each of the beach facing directions.

For the duration of the experiment, the wind speed and direction for the previous 24 hours measured in 10 minute intervals were down loaded every morning from a weather website[5]. Seasonal variations in wind are a large factor, hence the need to conduct this experiment for a year to cover multiple month-long term variations in wind-days.

Wind-day data

Wind-days were separated into each of the compass directions (Table 2). Onshore winds were deemed the primary winds to blow litter onto a beach. Off-shore winds or parallel-to-shore winds were deemed to not blow litter onto a beach. For example, a south facing beach with a south wind of 20 kph for 24 hours, would be allocated a positive wind-day value of 20. A south facing beach with a north or east or west 20 kph wind vector was assigned a zero value.
Table 2 shows wind-day values allocated for each compass direction for the 365 days.

Table B2: Wind-days for the 365 days of the experiment for the 2016-2107 year.

Wind-Day Direction	Value, kphDays 2016-2017
North wind day	2107
South wind day	1143
West wind day	866
East wind day	321

Table B2 shows that the prominent winds for the experiment are northerly winds. Year on year is quite close as would be expected. This was verified by performing the same wind recording for the second year. Northerly winds would be expected to blow litter onto the north facing beaches, which are primarily at the south side of the bay.

Litter Data Extrapolation to the Whole Bay Coast Line

A shorter 30 day survey was also performed on a beach section at the bottom of the bay, a long way from any northern inlets. These results were then able to be compared against the beach at the top of the bay and used to calibrate the model. For each beach section surveyed, their tallies are shown in Table 3

Table B3 Plastic Items count on North and South Beaches

Beach Location	Pieces collected	Number of days of survey
North Beach	138,792	365
South Beach	1452	30

The total counts for each beach were then divided by the respective beach length surveyed and the number of onshore wind days for that beach to arrive at a value of the pieces of plastic per meter per wind day (Table B4).

Table B4: Determining pieces of plastic per meter per wind-day on a beach for 2016-2017 year.

Beach Location	**Total pieces counted**	**Beach Length surveyed**	**On shore wind-days**	**Pieces/meter/ wind-day**
North,	138,792	45	1143 South wind-days	2.7
South, 30 days of data	1452	50	270 North wind-days	0.11

As can be seen in Table B4, the number of plastic items washing ashore on the southern beach is significantly less than that recorded at the northern beach. Not only are these southern beaches a long way from the river inlets, but the population level also down that side is far less than the northern end Melbourne city and surrounding suburbs.

Since we have no litter collection data from any west or east facing beach sections, we have assigned the mean value of pieces/meter/wind day of the north (2.7) and south beach (0.11) to the west and east facing beaches. This is 1.4 pieces of litter per meter per wind day for those orientations.

Finally, we can perform an estimation of the total number of plastic litter pieces washing onto bay shores for each of the four compass directions and shown in Table B6.

Table B6.1: Estimation of the number of plastic Items washed ashore over the 2016-2017 year.

Beach Facing Direction	**Beach Length Facing wind [m]**	**On shore wind-days 2016-2017**	**Pieces/meter/ wind-day**	**Extrapolated Plastic items washed ashore per year**
North wind	87,827	2107	0.11	19,798,233
South wind	86,091	1143	2.7	265,528,466

West wind	84,882	866	1.4	103,109,023
East wind	77,731	321	1.4	34,934,999
			Total	423,370,720

As a check, the same analysis was performed for the second year, 2071-2018 using that year's wind-day data.

Table 6.2 2017-2018 Data: Estimation of the amount of plastic Items washed ashore over the 2017-2018 year.

Beach Facing Direction	**Beach Length Facing wind [m]**	**On shore wind-days2017-2018**	**Pieces/meter/ wind-day**	**Extrapolated Plastic items washed ashore per year**
North wind	87,827	1,532	0.11	14,398,961
South wind	86,091	1,238	3.43	366,165,163
East wind	77,731	803	1.77	120,705,470
West wind	84,882	386	1.77	53,085,294
			Total	554,354,888

Table B6.1 predicts 423 million items of plastic being washed up on Port Phillip Bay beaches per year. For the second year of the survey, Table B6.2 predicted 554, million items of plastic to wash up per year. Which, while the 2017-2018 year result is significantly larger, it is still well within the same order of magnitude, showing consistency in results

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