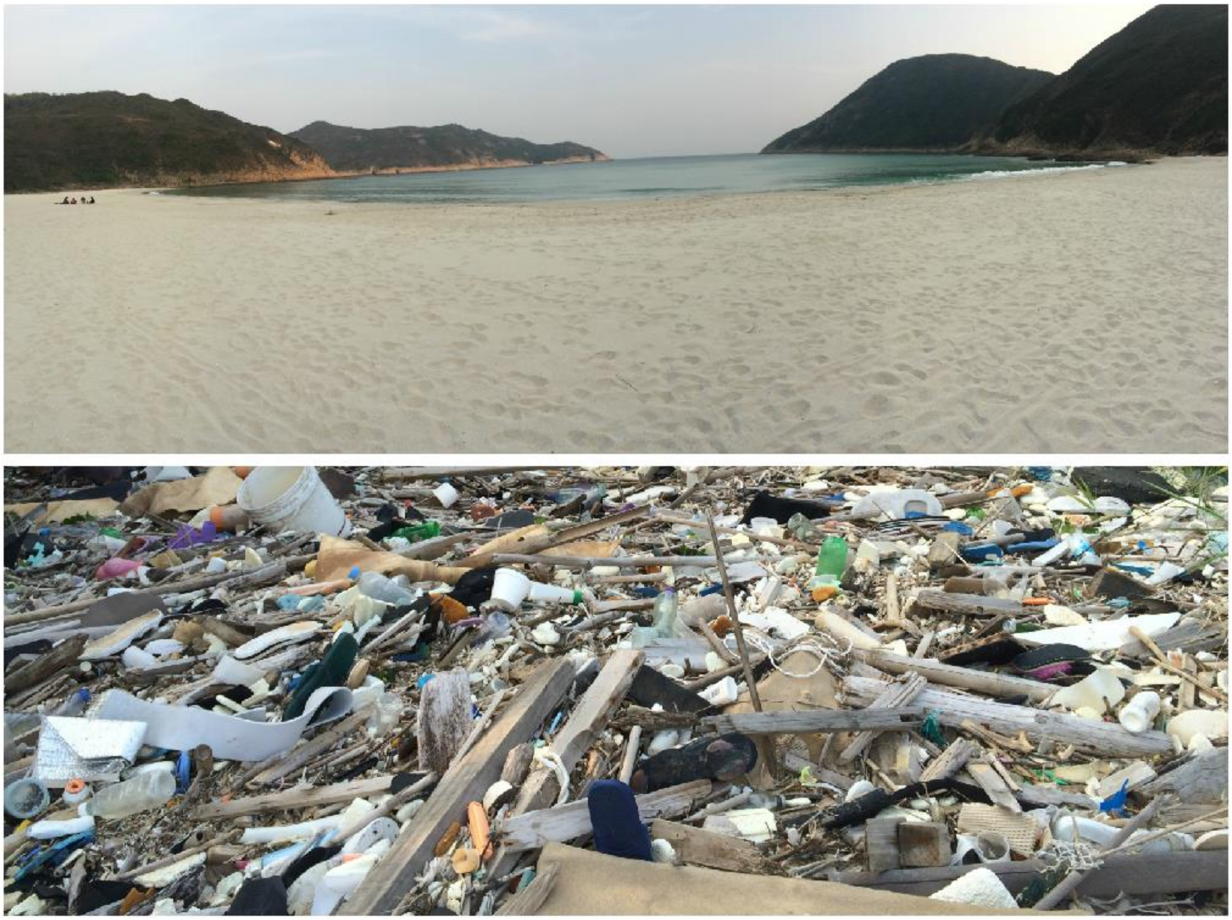

A picture of plastic free Long Ke Wan in comparison with extremely polluted Fan Lau Tung Wan.

MICROPLASTIC POLLUTION IN LITTORAL ENVIRONMENTS

MARCH 6, 2015

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Microplastic Pollution in Littoral Environments

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Abstract

This project presents an assessment of the composition and severity of microplastic pollution on the beaches surrounding Hong Kong. Through comparison with similar data collected in summer months, and by surveying members of the HKIEd community, we identified the abundance, types and locations of microplastics and gauged the public's awareness of the problem. These data sets allowed us to draw conclusions and make recommendations for the public of Hong Kong on how to better manage microplastic pollution.

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Authorship

While completing the project Ozan Akyıldız, Paul Calamari, Zachary Sellman, and Stephanie Symecko all assisted with beach sampling, sorting, analyzing, and surveying. Ozan Akyıldız, Paul Calamari, Zachary Sellman and Stephanie Symecko each put particular emphasis on background research, report conclusions, data analysis, and report revisions respectively.

Table of Contents

Table of Figures

Table of Tables

Executive Summary

The invention of plastic has revolutionized the way we package and manufacture goods. The reality of plastics can be summed up by the fact that they are inexpensive, easy to manufacture, and do not degrade naturally in the environment. The problem, most importantly, is that they do not break down chemically, but will keep breaking into smaller and smaller pieces. This breakdown happens when plastics get into bodies of water and are subject to mechanical erosion and photodegradation. This results in very small pieces of plastic of the order of millimeters, which scientists call microplastics. These microplastics have the potential to harm the environment they exist in because of their small sizes that allow ingestion and the ability to adsorb persistent organic pollutants (POPs). POPs are known to be harmful chemicals that can eventually cause cancer as well as other health problems after prolonged exposure to them. Microplastic pollution is a problem that needs to be addressed for exactly this reason.

The main reason behind the lack of action towards limiting microplastic pollution is the fact that there is not a lot of information on the subject. The only known preventive measures have been limited to those preventing plastic microbeads from being used as an ingredient in health and beauty products. This happened when research was done showing the extent of the microbead pollution in the Great Lakes region of the US and Canada. However, this kind of successful action is not a global norm as the actual extent of microplastic pollution is unknown. Therefore, more information needs to be known about the severity of microplastic pollution.

The main goal of this project was to accurately obtain the information that is needed to propose solutions to the microplastic problem. Our first objective was to sample enough of the Hong Kong coastline to accurately quantify the extent of the microplastic pollution there. By sampling the beaches in Hong Kong, we were able to completely analyze the beach samples to identify what plastics can be found on Hong Kong's shores. We also obtained information on the public's perceptions of microplastics by using a survey to gauge the public's awareness of this problem.

Our data indicated that microplastic pollution was more severe on the beaches nearest to the Pearl River Delta. We determined that the majority of the microplastics were in the form of expanded polystyrene (EPS). Comparing our results which were obtained in the winter season to the results that were obtained by other researchers in the summer, we found that many more microplastics were present on the beaches in the summer than in the winter. From our survey results, we were able to conclude that not many people had heard of microplastic pollution nor were they aware that it was a problem.

Our final objective was to identify ways to change how plastics are handled in Hong Kong. We have concluded first that awareness of microplastic pollution needs to be raised throughout Hong Kong to show the dangers of this type of pollution. The awareness campaign can also show the extent of microplastics in the environment and show how people can contribute towards preventing this spread. This campaign could also encourage people to recycle EPS and to create ways to prevent microplastics from entering the waters around Hong Kong. A comprehensive awareness campaign would be the obvious start to effective action mitigating microplastic pollution.

Our project was successful in quantifying the extent of microplastic pollution in Hong Kong and in studying the perceptions of the people living there. Our recommendations can bring about change that is needed to limit the amount of microplastic pollution in the waters around Hong Kong. We hope our project is the first of many to bring about increased global action towards creating solutions to the problem of microplastic pollution.

1. Introduction

Studies on plastic pollution in the oceans of the world were published as early as the 1970's but have generally received insignificant reaction to their results (Andrady, 2011). The studies of plastic debris in bodies of water were mostly limited to results coming from animal entanglement statistics until the scale of the plastic pollution was revealed to be extending well up into the Arctic regions (Moore et al., 2001a; 2001b; 2002). Although the awareness has increased in recent years, marine pollution was deemed negligible compared to the vastness of the Earth's oceans for a long time (Andrady, 2011). Because of this presumption, the full impact of plastic pollution in the world's oceans is mostly unknown. Therefore, there is not enough data to understand the extent and severity of this problem.

There is little knowledge of the extent of microplastic pollution in Hong Kong, much like the rest of the world. Experts in Hong Kong are worried that the toxins in the microplastics could be harming people as well as marine life in general (L. Fok, personal communication, December 11, 2014). Hong Kong residents have a diet containing a lot of fish and seafood (Sterling et. All, 2001). If fish are living in polluted waters and ingesting toxic microplastics, then humans eating the fish could be exposing themselves to these toxins as well. People in Hong Kong are currently unaware of this risk that they are taking daily, and experts do not know how big this risk is since so little research has been done on the types and amounts of microplastics present in nearby waters.

Experts have started to understand the threat of plastics in our oceans. They know that plastic debris in the Earth's oceans consists mostly of microplastics, small particles formed by degradation of plastic materials (Teuten, Rowland, Galloway & Thompson, 2007; Hidalgo-Ruz et al., 2012). Direct discharge of these materials by various plastics industries has caused the greatest concern because consumer products are increasingly made of plastic polymers, such as polyethylene (PE) and polypropylene (PP) that degrade into microplastics. The surface of these substances represents a lipophilic medium that attracts hydrophobic contaminants in water, some of which are persistent organic pollutants (POPs), causing further toxicity (Teuten, Rowland, Galloway & Thompson, 2007). Many types of industries discharge POPs into water that ends up in our oceans. While generally in low concentrations in the water, POPs become concentrated on the surface when absorbed by microplastics (Fok, personal communication, January 22, 2015). Since these types of marine pollution are from relatively recent causes, the collection of studies looking at such pollution is limited mostly to studies from the previous decade (2000-2010). Recently Dr. Lincoln Fok, a scientist at the Hong Kong Institute of Education, has been researching this topic and more specifically the levels and types of microplastics in Hong Kong.

Dr. Lincoln Fok (personal communication, 2014) believes that data available to assess the nature and origins of microplastics in Hong Kong is extremely limited. He has identified this specific research gap in Hong Kong and he hopes to use his research to close it. So far only a small amount of research has been started. There are no published data showing amounts and locations of microplastic pollution in Hong Kong. In the summer of 2014, Dr. Fok and his team gathered data on microplastic pollution in a number of Hong Kong's littoral environments. However, there is no data from the winter season, which is expected to have very different results due to reduced waste discharge from the Pearl River in the dry season and the lack of typhoons (Zhou et. All, 2011). Previous efforts to measure microplastic contamination have not been very effective because the technology has not been capable of analyzing such small material until recently.

Our project aimed primarily to determine the scope of the microplastic pollution in the waters around Hong Kong. This included determining the microplastics present in the beach sand, the differences in the pollution levels among beaches, and the differences in levels in the winter compared to summer. We determined the types of plastic by analyzing microplastic samples from the sand on selected beaches in Hong Kong using attenuated total reflectance - Fourier transform infrared spectroscopy, or ATR-FTIR. This method provided us with comprehensive results because the sand contained the microplastics gathered by waves, drifts and precipitation. As a result, we were able to identify the types and abundance of microplastics. Once identified, we were able to compare our winter results to the data collected in the summer. Additionally, we were able to evaluate the public's knowledge, behavior and awareness of the problem as well as their willingness to pay (WTP) to address the problem through a survey given to people at the Hong Kong Institute of Education. Using the data we obtained, we were able to propose an effective way for Dr. Fok to present both the public's willingness to contribute to mitigation efforts and the severity of the problem to the government and public of Hong Kong.

2. Background

This chapter discusses the current extent and characteristics of plastic and microplastic pollution in the marine environment. We examine the extent of plastic pollution and its distribution, the classes of microplastics, their effects on the food chain and health, and methods used to sample and analyze the microplastics found on beaches or the water column. We also review the prevention and mitigation policies around world and in Hong Kong that have been put in place to try to control and reduce the amount of plastic pollution entering the world's oceans.

2.1. Plastics

As the use of plastics has become greater and greater, so has the problem of plastic pollution. With no proper management systems in place, the increased use of plastics will continue to create a significant pollution problem worldwide. Plastics are human-made polymers that may contain other substances to improve performance and/or reduce costs (Vert et al., 2012). Natural polymers such as wool, shellac or even natural rubber, which can be considered the closest relatives of plastics, are prone to degradation. On the other hand, plastics are synthetically produced from the distillation of petroleum and additional petro-chemical procedures. Therefore, complete breakdown of a plastic polymer into Carbon Dioxide (CO_2) and compounds of Nitrogen (N), Fluorine (F), Chlorine (Cl), etc., does not occur in nature since this requires an oxidative reaction that needs a temperature of at least 70°C to take place. Even in the case of complete breakdown, most of the released chemicals, such as ammonia from nylon, will be toxic (Andrady, 2011).

As of 1988, 50 billion pounds of plastic were being produced each year in the United States alone (Andrady, 1989). In 2012, 128 billion pounds of plastic were produced in the US (EPA, 2014). Alarmingly, plastic's share in the solid waste stream has increased from less than one percent to thirteen percent. Only twelve percent of the plastics from bags, sacks, and wraps were recovered by recycling. The rest of plastic waste goes into a landfill or is littered and makes its way to water or land deposits.

2.2. Marine Environments

In the late 1940s, plastic began entering the oceans (Andrady, 1989). It started as fishing gear evolved towards being made of plastics instead of natural fibers. Plastic ends up in the marine environment through a variety of sources including passenger, freight, military, and research vessels. Beach users also introduce plastics to the marine environment. Even plastic pollution on land can make its way to the ocean (Blomberg, 2011). This transpires when plastic bags or bottles that are dropped in the street are washed into sewers, then into a river and down to an ocean. These littered plastics eventually are broken down mostly by mechanical wear and photodegradation, which is the result of the waves and the sun's UV rays. This breakdown of plastics may take hundreds of years to complete.

The long biodegradation timeframe leads to a buildup of plastics in the oceans. Common flow patterns and gyres, or vortexes, have caused large islands of garbage to form in the oceans (Blomberg, 2011). For example, the Great Pacific Garbage Patch is found in the North Pacific Gyre and covers an area two times the size of Texas. Eighty percent of the North Pacific Gyre is made up of plastic. One common misconception is that the Great Pacific

Garbage Patch is made of whole plastic bags and bottles, but it is also made of dispersed plastic waste particles, or microplastics.

2.3. Microplastics

Even though some plastics are marketed as biodegradable, in reality they end up breaking into smaller strands of polymers (Thompson et al., 2004). Eventually, these particles will reach the scale of micrometers and be grouped as microplastics. In 2004 Thompson et al. was the first to use the term (Hidalgo-Ruz et al., 2012).

Multiple research projects have been done to assess the abundance of microplastics in oceans (Hidalgo-Ruz et al., 2012). Those studies indicate which types of microplastic can be commonly found. In Table 2.2, we list these substances with the number of reports that included them. Moreover, as mentioned in Table 2.1, many plastic products we use in daily life such as bottles, plastic bags, and cups are made of these materials (Andrady, 2011). These plastics also make up a big portion of the world's plastic production (Thompson et al., 2004).

Table 2.1: Classes of microplastics found in the marine environment (Andrady, 2011, p. 1597).

Plastic Type	% in Production	Used in
Low-density polyethylene	21	Plastic bags, six-pack rings, bottles, netting, straws
High-density polyethylene	17	Milk and juice jugs
Polypropylene	24	Rope, bottle caps, netting
Polystyrene	6	Plastic utensils, food containers
Foamed Polystyrene		Floats, bait boxes, foam cups
Nylon	<3	Netting and traps
Thermoplastic Polyester	7	Plastic beverage bottles
Polyvinyl Chloride	19	Plastic film, bottles, cups, window frames
Cellulose Acetate		Cigarette filters

2.3.1. Measuring the extent of the problem

Understanding the role of microplastics in marine life requires us to analyze the distribution, variety and abundance of these pollutants, both in habitats and in the organisms that live in these habitats. However, these analyses are suspected to underestimate the amount of microplastics as sampling microplastics presents a challenge (Hidalgo-Ruz et al., 2012). For example, microplastics denser than water will evade surface sampling with neuston nets. Meanwhile, some substances such as high density polyethylene (HDPE) can change density due to exposure to seawater and might partially appear in results, clouding the data. Table 2.2 shows that many microplastics have a varying density and only two classes of them, polyethylene and polypropylene, are less dense than freshwater (1 g/cm^3) and seawater (1.035 g/cm^3).

Table 2.2: Densities of Microplastics Found in Previous Research (Hidalgo-Ruz et. Al, 2012, p.3063).

Polymer Type	**Abbreviation**	**Density(g/cm^3)**	**No. of studies**
polyethylene	PE	0.917−0.965	33
polypropylene	PP	0.9−0.91	27
polystyrene	PS	1.04−1.1	17
polyamide (nylon)	PA	1.02−1.05	7
polyester		1.24−2.3	4
acrylic		1.09−1.20	4
Poly oxymethylene	POM	1.41−1.61	4
polyvinyl alcohol	PVA	1.19−1.31	3
polyvinylchloride	PVC	1.16−1.58	2
poly methylacrylate	PMMA	1.17−1.20	2
polyethylene terephthalate	PET	1.37−1.45	1
alkyd		1.24−2.10	1
polyurethane	PUR	1.2	1

*Out of 42 studies in total

Most of the studies have focused on measuring the amount of microplastics in order to close the research gap that exists because of a lack of data on microplastics. However, the topic is very recent, and microplastics have a broad range of physical and chemical characteristics. Consequently, a standard technique for analysis to find out what type of plastic the microplastics are is yet to be defined. Hidalgo-Ruz, Gutow, Thompson, and Thiel (2012) reviewed the methodology and outcomes of sixty-eight studies on microplastics found in the marine environment.

Forty-four of those studies took samples from sedimentary areas such as beaches, while thirty-three of them collected samples from water. In both groups, sampling area, depth, and time of day differed (Hidalgo-Ruz et al., 2012). Sand samples were picked up with numerous items including buckets and tablespoons. Conversely, neuston (surface-floater organisms) and plankton samplers such as nets were used to sample layers of water. In net sampling, nets with different mesh sizes designed for different depths were used. For example, neuston nets are produced for collecting surface-floating microorganisms. Microplastics that happen to be the same size can easily be picked up from the sea-surface with these nets. The term plankton is used for every marine organism that can only swim vertically; therefore the nets to sample them differ in mesh size. Plankton nets with micrometric mesh sizes can be used to sample microplastics from many depth levels of the ocean.

The sorting process for the beach samples can be divided into four stages: density separation, filtration, sieving and visual separation (Hidalgo-Ruz et al., 2012). The first step is to separate certain density plastics by flotation. Filtration and sieving is used to isolate smaller and bigger particles, respectively, with different pore or mesh sizes. Finally, visual separation is used to confirm collected substances. These four steps solely consist of physical separation methods, which means they cannot be completely accurate. For example, samples can be left at the edges of containers or other test materials. This causes underestimated results by loss of part of the samples. Furthermore, microplastic samples can get contaminated if not sealed, in which case overestimation may occur.

Hidalgo-Ruz et al. (2004), mentions that R.C. Thompson minimizes this “noise” in the data by scanning the sample containers and the equipment and tracing the remaining microplastics with Focal Plane Array (FPA). Focal plane array is an optic imaging device. It consists of an array of photoreceptive cells placed on the plane that passes through the focus of a lens. When used for infrared imaging, FPA can detect, and therefore map, molecules such as microplastics. However, these efforts may not be necessary, as the recovered amount is usually negligible. If every sample in an experiment is handled similarly, the data will be congruent enough to be able to evaluate results.

2.3.2. Identification

The sorted material needs to be classified to finalize data collection. Emission spectrum is the most reliable property of matter for identification. Any material will absorb photons with energy levels that match their electrons’ (Griffiths, 1986). The absorbed photons will excite the atoms, causing them to eventually release a photon. This concept causes materials to have unique electromagnetic absorption and emission spectra, which can be used to determine material types.

Scientists realized that spectroscopy can be adapted to the analysis of organic material at the end of 20th century (Schmitt, 1998). Harrison, Ojeda, and Romero-González (2012) discuss and confirm that ATR - FTIR can effectively be used to determine the microplastics present in the marine environment. FT-IR stands for spectroscopy done in infrared wavelength range (700 nm $<\lambda<$1 mm). Fourier transform data is converted to the domain of frequency instead of time, creating a convenient graph. Spectrometry was used on gases first, but Attenuated total reflectance, ATR, an additional sampling module, enabled the samples to be analyzed in a solid or liquid state (Harrick, 1967). This development predates the topic of microplastics and environmental scientists can precisely identify the content of the samples by attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR) (Hidalgo-Ruz et al., 2012).

2.3.3. Formation

A number of studies show that microplastics are abundant in locations near plastic factories and also public beaches (Moore, 2008; Teuten et al., 2009). This indicates that there are two main sources of the pollutant: waste runoff from factories and plastic debris resulting from commercial use. The plastic industry uses the raw material in the form of very small pellets. These tiny particles are classified as microplastics, and when the excess matter is discarded, they cannot be filtered out from the sewage due to their small size.

Although plastics remain in the environment for a very long time, they will eventually disintegrate into smaller strands of polymers (Thompson et al., 2004). This disintegration can occur mechanically, in which case the process gets slower as the particles get smaller. Alternatively, light can cause photodegradation, oxidizing the litter slowly and releasing chemicals while breaking down (Shang, Chai, & Zhu, 2003).

2.3.4. Effects on Marine Life and Human Health

Plastics, in their macro form, harm marine life physically (Teuten, Rowland, Galloway, & Thompson, 2007). Laist (1987) states there are reports of entanglement and ingestion concerning 260 marine species. In their smaller form, microplastics can be ingested by organisms without causing suffocation (Hidalgo-Ruz et al., 2012). As synthetic polymers, they are bio-inert since organisms don't have enzymes to digest them (Andrady, 2011). Having a few microplastics inside the body can cause abrasion to organs. Additionally, large amounts of microplastics can accumulate in the body and cause blockage.

Table 2.3: Some Chemicals Released from Plastics and Their Effects (Garrison, 2010, p. 496)

Name	Major Health Effects
Aldicarb (Temik)	High toxicity to the nervous system
Benzene	Chromosomal damage, anemia, blood disorders, and leukemia
Carbon tetrachloride	Cancer; liver, kidney, lung, and central nervous system damage
Chloroform	Liver and kidney damage; suspected cancer
Dioxin	Skin disorders, cancer, and genetic mutations
Ethylene dibromide (EDB)	Cancer and male sterility
Polychlorinated biphenyls (PCBs)	Liver, kidney, and lung damage
Trichloroethylene (TCE)	In high concentrations, liver and kidney damage, central nervous system depression, skin problems, and suspected cancer and mutations
Vinyl chloride	Liver, kidney, and lung damage; lung, cardiovascular, and gastrointestinal problems; cancer and suspected mutations

The threat comes from what microplastics carry with them. Plastics contain many additives including adhesives, colorants and plasticizers (to make plastics pliable or malleable) (Andrady, 2011). Most of these additives are released very easily into the environment (Teuten et. al, 2007; 2009). Table 2.3 shows that plastic additives can cause severe health problems such as endocrine disruption, cancer and other system failure related health problems.

The most common additives are phthalates, which are used as plasticizers to soften PVC in a wide range of products (U.S. EPA, 2007). Phthalates are classified as endocrine disruptors or hormonally active agents (HAAs). They cause the most damage (skeletal malformations, fetus deaths and reproductive system failures) before maturity, a shocking fact considering phthalates are also used in toys. Radicals are a very vast group of highly reactive and unstable molecules, which makes most of them dangerous for organisms with varying effects.

Even if a plastic product is “clean” of toxic additives, it is possible for plastic material to become bio-hazardous. Many persistent organic pollutants (POP) adhere to plastics. These pollutants include insecticides, pesticides such as DDT, polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons (PAHs, molecules consist of multiple benzene rings), organophosphates (fertilizers) and organochlorides (Cole, Lindeque, Halsband, & Galloway, 2011; Teuten et al., 2009; Wurl & Obbard, 2004). Since plastics are petroleum based, their molecules are mostly lipophilic (Teuten et al., 2007). Thus, plastics act as a medium for POPs to concentrate. POPs are generally hydrophobic. This can be perceived as plastics filtering water, but in the long term, their impact on marine environments will be negative since they can be ingested by organisms.

An experiment presented by Teuten et. al (2007) compares the absorption rates of PE, PP, PVC and two sediment samples. In the experiment, equal amounts of Penanthrene (PHE, Figure 2.1) were added to the seawater that contained the samples. PHE was then recovered from each medium. The "solid" column in

Table 2.4 presents the PHE absorbed by the three microplastic and two sediment samples. The data show that the PE absorbed most (80%) of the pollutant, while PP and PVC contained approximately 30% of PHE, and the sediment samples were almost not contaminated. This experiment proves that microplastics absorb the most toxins in seawater.

Table 2.4: Comparison of Absorbed Penanthrene Percentages (Teuten et. Al, 2007, p. 2)

	total PHE recovered in each phase (%)[a]			
	liquid	glass wall	solid	total recovery (%)
		In seawater		
polyethylene	4.6 ± 0.5	0.6 ± 0.3	80.5 ± 6.4	85.7 ± 6.5
polypropylene	37.4 ± 0.7	1.2 ± 0.4	35.6 ± 0.9	74.1 ± 1.2
$PVC_{200-250}$	67.6 ± 8.6	1.3 ± 0.2	27.3 ± 3.8	96.3 ± 4.8
Plym sediment	73.8 ± 2.0	2.4 ± 1.1	3.3 ± 0.5	79.5 ± 2.2
Mothecombe sediment	88.1 ± 3.9	2.0 ± 0.4	0.4 ± 0.1	90.5 ± 4.5

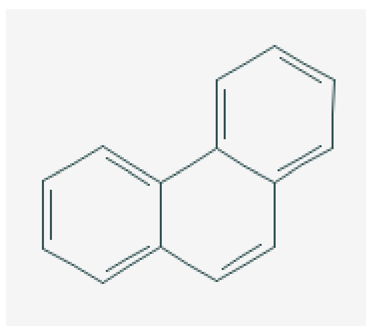

Figure 2.1: Penanthrene, a POP

Microplastics have drastically more surface area than macroplastics due to their particle size (Teuten et. al, 2007). This leads to an increased rate of absorption and release of chemicals for plastics of the same weight. As a result, contamination is maximized in some layers of water. Low-density microplastics float at the sea's surface where hydrophobic pollutants are 500 times more abundant than the rest of the water body. This means that the low-density microplastics have a high chance of absorbing many pollutants.

Another problem occurs when plastic polymers hydrolyze into their monomers (Andrady, 2011). These monomers are no different from POPs or plastic additives with respect to toxicity. For example, the primary building block of polycarbonates, bisphenol A (BPA), is an estrogen-like endocrine disruptor that can leak into organic material (Yang, 2011). BPA causes insulin resistance, which can lead to inflammation and heart disease (Alonso-Magdalena, Morimoto, Ripoll, Fuentes, & Nadal, 2006). Notice how each molecule structure (an additive, a toxin and a monomer) in Figure 2.2 contains benzene links (modeled as hexagons). Benzene is one of the most fundamental petrochemicals, it can be naturally found in crude oil. Due to its easily modifiable structure, it is usually used to create other petrochemicals. However, this nature of benzene makes it very hazardous as a monomer with many irreparable effects on organisms (see Table 2.3).

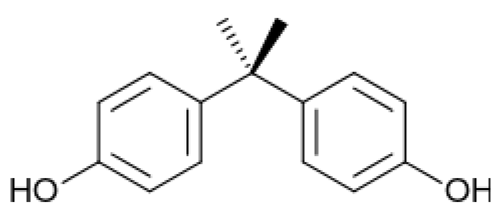

Figure 2.2: Structure of Bisphenol A

Due to their small size, microplastics can start being incorporated into organisms from the base of the marine food chain (Thompson et al., 2004). The accumulated material in plankton and filter feeders will be transferred through their predators without being digested and continue to release chemicals. Cole et al. (2011) lists the microplastic uptake of some marine species in Table 2.5 below. If microplastics are traced, this information could be used to further analyze at what point the microplastics start to disrupt the food chain. Cole et al.

(2011) has shown that there could be a reduction in organism's appetites when microplastics are added to their environment.

Table 2.5: Microplastic Uptake of Some Marine Organisms (Cole et. Al, 2011, p.7).

Organism(s)	Microplastic (μm)
Copepods (*Acartia tonsa*)	7–70
Echinoderm larvae	10–20
Trochophore larvae (*Galeolaria caespitosa*)	3–10
Scallop (*Placopecten magellanicus*)	16–18
Amphipod (*Orchestia gammarellus*), Lugworm (*Arenicola marina*) & Barnacle (*Semibalanus balanoides*)	20–2000
Mussel (*Mytilus edulis*)	2–16
Sea cucumbers	Various

2.4. Mitigation

The mitigation of microplastic pollution has not yet begun (Hannam, 2014). Existing legislation preventing microplastic pollution has been limited only to preventing micro beads from being used in health and beauty products. Micro beads are only one of the many sources of microplastic pollution. Eliminating just micro beads still leaves the presence of other kinds of plastic particles that find their way into bodies of water. Not enough is known about these other sources of plastic pollution.

2.4.1. Government Policies World Wide

Microbeads in health and beauty products have been under the microscope recently as legislation and scientific journals articles have condemned their use. In the United States, the state of Illinois became the first state to ban the use of microbeads in health and beauty products due to the recorded levels of microbead pollution in the bordering Great Lakes (Heger, 2014). The extent of the microbead pollution was measured and was found to be a major problem. There were 1.1 million particles per square kilometer in Lake Ontario alone. This led to several peer reviewed studies of the implications of plastic pollution in the Great Lakes, which exposed the reality of the situation. The spike in awareness of the negative effects of microbeads coupled with the pollution data caused the elimination of them from products by the use of successful state legislation. Legislation in other states has also been proposed as a result of Illinois' investigations. Additionally, there have been instances in the US where some manufacturers have even voluntarily pledged to eliminate microbeads from their products because of the increasingly negative public opinion about microbeads.

Outside the U.S., a legislator in the state of New South Wales, Australia, has proposed a national ban on the use of microbeads in all products and plans to have them eliminated by 2016 (Hannam, 2014). To go even further, he has also started working with a nonprofit organization in Australia to provide lists of approved products to customers. Thousands of people in Australia, (Catterick, 2014) have already used the "Good Scrub Guide" of all the approved products for that Country.

2.4.2. Mitigation Efforts

Despite the efforts to eliminate plastic microbeads from health and beauty products, microplastic pollutants are still finding their way into the world's waters by other means. Many efforts to lessen the extent of the pollution have attempted targeted advertising to consumers to discourage them from buying products with plastics. However, attempts to do so have been ignored (Vegter, 2014). Most attempts have failed because of their inability to persuade consumers to buy more expensive alternatives to plastic. Most people do not know that plastics are worth preventing from the product stream. The lack of information on the problem is a major factor in the failure of such efforts. To add on to this, governments have not legislated against the problem because of the lack of information. This, coupled with plastic manufacturing lobbyists' influences, makes government intervention almost impossible at this point in time.

2.4.3. Practicality of Prevention

Contributing to the resistance to ban or control plastics is the fact that plastics have proven to be the inexpensive way to package and manufacture goods, making these goods very affordable. The reality behind the increase in microplastic pollution is that it is directly proportional to the increase of plastics in consumer goods (Vegter, 2014). This means that efforts to move manufacturing away from the use of plastics face an uphill battle. However, companies are willing to cooperate when faced with a decision they cannot ignore. When American companies were presented with the evidence from the Great Lakes (mentioned in section 2.3.1), they were willing to cooperate and pledged to phase out the use of plastic microbeads in their products. This shows that change can be achieved in the prevention of microplastics from getting into the pollution stream.

2.5. Situation in Hong Kong

It is extremely difficult to quantify the amount of macroplastics and microplastics in the ocean, therefore some researchers have chosen to study the amount of mismanaged waste generated from coastal populations (Andrady et al., 2015). Inadequately disposed materials and litter are examples of mismanaged waste that likely ends up in the world's oceans.

Table 2.6 shows waste estimates for the twenty countries in 2010 with the most mismanaged plastic waste by mass. These twenty countries make up 83% of the worlds mismanaged waste. Sixteen of these twenty countries with more mismanaged waste are classified as middle-income locations, where we can infer that fast economic growth is occurring; however waste management procedures are having a slower development. China is ranked number one on this list with 1.32-3.53 million metric tons of plastic marine debris per year. China's mismanaged plastic waste will more than double by 2025 if better waste and recycling management framework is not introduced. These plastic debris will continue to pollute the marine environment of Hong Kong until change occurs.

Currently Hong Kong is surrounded by an unknown amount of potentially toxic microplastics. The Hong Kong government is taking small steps to learn more about the impact of plastic pollution. Representatives from Hong Kong attended the Second Global Conference on Land-Ocean Connections sponsored by the United Nations Environment Program (GPA, 2014). The Global Partnership on Marine Litter (GPML) has a specific objective that recognizes microplastic pollution. The objective states, "To assess emerging issues related to the fate and potential influence of marine litter, including (micro) plastics uptake in the food web and associated transfer of pollutants and impacts on the conservation and welfare of marine fauna"(para. 4). One of the reasons Hong Kong should be concerned with microplastic pollution is because of the aforementioned uptake in the food chain by marine organisms.

Table 2.6: Ranking of the top 20 Countries with the Most Estimated Mass of Mismanaged Waste (in Units of Millions of Metric Tons per Year) for 2010 (Andrady et. al, 2015)

Rank	Country	Econ. classif.	Coastal pop. [millions]	Waste gen. rate [kg/ppd]	% plastic waste	% mismanaged waste	Mismanaged plastic waste [MMT/year]	% of total mismanaged plastic waste	Plastic marine debris [MMT/year]
1	China	UMI	262.9	1.10	11	76	8.82	27.7	1.32–3.53
2	Indonesia	LMI	187.2	0.52	11	83	3.22	10.1	0.48–1.29
3	Philippines	LMI	83.4	0.5	15	83	1.88	5.9	0.28–0.75
4	Vietnam	LMI	55.9	0.79	13	88	1.83	5.8	0.28–0.73
5	Sri Lanka	LMI	14.6	5.1	7	84	1.59	5.0	0.24–0.64
6	Thailand	UMI	26.0	1.2	12	75	1.03	3.2	0.15–0.41
7	Egypt	LMI	21.8	1.37	13	69	0.97	3.0	0.15–0.39
8	Malaysia	UMI	22.9	1.52	13	57	0.94	2.9	0.14–0.37
9	Nigeria	LMI	27.5	0.79	13	83	0.85	2.7	0.13–0.34
10	Bangladesh	LI	70.9	0.43	8	89	0.79	2.5	0.12–0.31
11	South Africa	UMI	12.9	2.0	12	56	0.63	2.0	0.09–0.25
12	India	LMI	187.5	0.34	3	87	0.60	1.9	0.09–0.24
13	Algeria	UMI	16.6	1.2	12	60	0.52	1.6	0.08–0.21
14	Turkey	UMI	34.0	1.77	12	18	0.49	1.5	0.07–0.19
15	Pakistan	LMI	14.6	0.79	13	88	0.48	1.5	0.07–0.19
16	Brazil	UMI	74.7	1.03	16	11	0.47	1.5	0.07–0.19
17	Burma	LI	19.0	0.44	17	89	0.46	1.4	0.07–0.18
18*	Morocco	LMI	17.3	1.46	5	68	0.31	1.0	0.05–0.12
19	North Korea	LI	17.3	0.6	9	90	0.30	1.0	0.05–0.12
20	United States	HIC	112.9	2.58	13	2	0.28	0.9	0.04–0.11

2.5.1. Education Efforts

Hong Kong's Green Council organizes the International Coastal Cleanup event for Hong Kong each year (South China Morning Post, 2014). Events like that one where communities gather together to rid beaches of plastic waste promote awareness of the plastic pollution in Hong Kong. It is good that the Hong Kong government is using these cleanup efforts to educate the public, however cleaning up only the plastic you can see is not reducing microplastic pollution or educating the public about microplastics.

3. Methods

The goal of this project was to determine the types of microplastics present on Hong Kong beaches, the amount of these microplastics, and the types and amounts in different locations at different times of year. Additionally this project aimed to determine the public's awareness and willingness to pay for plastic pollution mitigation. We completed this project under the guidance of Dr. Lincoln Fok at the Hong Kong Institute of Education. The team gathered and analyzed data using the methods outlined in this chapter to discover how prevalent and how well known microplastics on Hong Kong beaches were. We combined the data we collected with Dr. Lincoln Fok's ongoing research to arrive at conclusions and recommendations for the public.

Our goal was completed by achieving the following objectives:

* Determine the abundance of microplastics present in beach sand.

* Determine differences of microplastic pollution levels among beaches.

* Determine differences of microplastic pollution levels of beaches during summer and winter.

* Determine the knowledge, awareness, and behavior towards microplastics of people in Hong Kong.

3.1. Determining Types of Microplastics

We sampled sand on beaches of Hong Kong, then filtered out the pieces of plastic while we were on the beach. We took those samples to the lab to visually sort out the different types of plastics. For the purpose of this study, we defined microplastics as plastics smaller than 5mm. Finally, we scanned them using FTIR to determine which types of plastics are present as microplastics on Hong Kong beaches.

3.1.1. Determining Sample Locations

We determined our sample locations by choosing strategically located beaches on both the west and east side of Hong Kong SAR. The beaches selected were evenly spaced around Hong Kong and were the same beaches that Dr. Lincoln Fok had sampled in the summer. The reason for the repetition was to compare winter results (January and February) with those from the summer to show the differences and similarities between the two sets of data. We used Google Maps to pin point the locations of the beaches that we could sample. It was key to find beaches that were light in color on the map. Darker colored beaches are a sign that the beach is extremely rocky thus not ideal for sampling because of how the rocks prevent microplastics from being washed onto shore. With the guidance of Dr. Fok and Paul Cheung (Dr. Fok's Research Assistant), we selected ten beaches along the Hong Kong SAR coastline from which to collect samples.

3.1.2. Sampling Procedure

The sand samples from each beach were collected by following the protocol that Dr. Lincoln Fok has developed. This method has been used previously and is scientifically sound. We sampled sand at four randomly selected points along the 30 meters of the trash line found on the most recent high tide line. Particles larger than .333 mm were retrieved from the sediment and brought to the chemistry labs at HKIEd for further laboratory analysis. The size selection is purely practical since the smaller particles are almost impossible to sort visually.

The detailed sampling procedure is described in Appendix C. At each beach we filled out a beach survey form, which can be found in Appendix D. This beach survey form was also developed by Dr. Lincoln Fok. In this form we recorded basic information about the beach including some general qualitative conditions of the beach, a description of the debris on the beach and the human activity on the beach. This form also included information about where the samples were taken and a sketch of the beach.

3.1.3. Laboratory Analysis

We analyzed the samples of sand that we collected by performing a series of laboratory tests. The pieces of plastic were originally collected through density separation in sea water at the beaches. Then we took each sample and visually separated and counted the plastics into five main categories: pellets, fragments larger than 5mm, fragments smaller than 5mm, expanded polystyrene (EPS) larger than 5mm, and EPS smaller than 5mm. After this, we determined the material of the pellet category by performing attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR) on each individual pellet. Only pellets were scanned since they are the raw material used in the industry and therefore have less additives to cloud the scan result. Then we grouped each FTIR result as polyethylene (PE), polypropylene (PP), or as other plastics.

For every beach visited, we also took a sample of sand to test the moisture content. In the lab we transferred the sample for the humidity test to a petri dish, and we weighed it on a digital scale. Then we put the samples of sand and the samples of plastics in a laboratory oven at 105 °C for 48 hours to evaporate the moisture in the sand. After evaporation, we weighed the moisture samples again to evaluate how much water had been evaporated in order to have the ability to calculate the microplastics per liter of sediment at a normalized weight.

3.2. Determining Perceptions of Microplastics in Hong Kong

In addition to determining the types of microplastics present on the beaches in Hong Kong, we also determined the people of Hong Kong's perceptions of microplastics by using a questionnaire. With the guidance of Dr. Fok, we created a question bank consisting of one starting question, socio-demographic questions, and three main categories. The starting question was necessary because we aimed to find out if people had any knowledge of microplastics before taking the survey. If the participant had not heard of microplastics, we provided a brief explanation before they continued to fill out the rest of the questionnaire. The three categories included, knowledge, behavior and awareness. All of these statements were based on a scale of one through five, where one equals strongly disagree and five equals strongly agree, to create a simple way to compare data. Half of the questions from the knowledge, behavior and awareness categories were written in the positive form and half in the negative form. For each survey administered, the respondent received an equal amount of positive and negative questions to avoid the trend of choosing all the same answer. See Appendix E for the survey questionnaire in English. This survey gauged the public's knowledge and awareness of microplastics in general and specific to the Hong Kong region in particular. We found out the percentage of people who knew that microplastics exist and that they contain toxins harmful to humans. The survey involved neutral questions so as not to be biased when trying to discover the public's opinions. We administered surveys to 100 participants at the Hong Kong Institute of Education's campus. We aimed to survey an equal number of male and female participants to best represent the Hong Kong public.

3.3. Prevention

We used our collected data to target specific prevention methods based on the types of plastics that we found on the beaches of Hong Kong. Once we found that some types of microplastics were more prevalent than others, we then decided to focus on the causes of the most prevalent types of microplastic. From their causes, we were able to propose methods of preventing further microplastic pollution from these sources.

3.4. Summary

We aimed to determine the types and levels of microplastic pollution at Hong Kong beaches and the local people's perception about the problem. We visited ten beaches and collected sample material. We visually separated the micro and macroplastics from organic material and other litter. Once separated, we counted each plastic category, and normalized it into plastics per liter sediment to obtain a standardized quantitative understanding of the amount of pollution. We used ATR-FTIR to determine the type of plastic each pellet was. We used a survey to determine the Hong Kong public's knowledge and awareness of microplastics and the pollution they cause. The findings of these efforts were helpful for us to create an action plan focused on prevention and mitigation of microplastic pollution. Details of this plan will be discussed in the next chapters.

4. Results and Analysis

The results from our sampling and surveying are summarized in the following chapter. We decided to focus on the microplastics that we found at the beaches we sampled. The data is analyzed focusing on the location and geographical differences of the beaches we sampled. We additionally analyzed the data by comparing the microplastic pollution levels from our winter sampling results to other researchers' summer results. To have a global perspective, we analyzed how our results compared to similar studies conducted elsewhere in the world. We analyzed the data collected from our surveys to understand some common perceptions of microplastics in Hong Kong.

4.1. Plastics Found on Beaches

For this project we wanted to determine the microplastic contents on the beaches surrounding Hong Kong. To do this we counted the number of plastic pieces in each of five categories: small (<5mm) expanded polystyrene (EPS), large (>5mm) expanded polystyrene (EPS), small (<5mm) fragments, large (>5mm) fragments, and pellets (<5mm). For the purposes of our research, large EPS and large fragments were not considered to fall in the microplastic category.

Figure 4.1 shows the percentage of each category of plastic found on all the beaches. Over 80 percent of the plastics retrieved from all the beaches were microplastics. This is significant because the majority of plastics on beaches are not commonly seen and people are not aware of their presence. Small EPS made up 65.6 percent of all the plastics found while large EPS made up 11.7 percent. This means that over three fourths of the plastics found on the beaches is EPS, which is commonly known as styrofoam. This is a significant finding, because this could be an area to focus on for prevention and mitigation of microplastic pollution. The large amount of EPS can be explained by its wide use around Hong Kong, specifically as take-out containers and storage for fish.

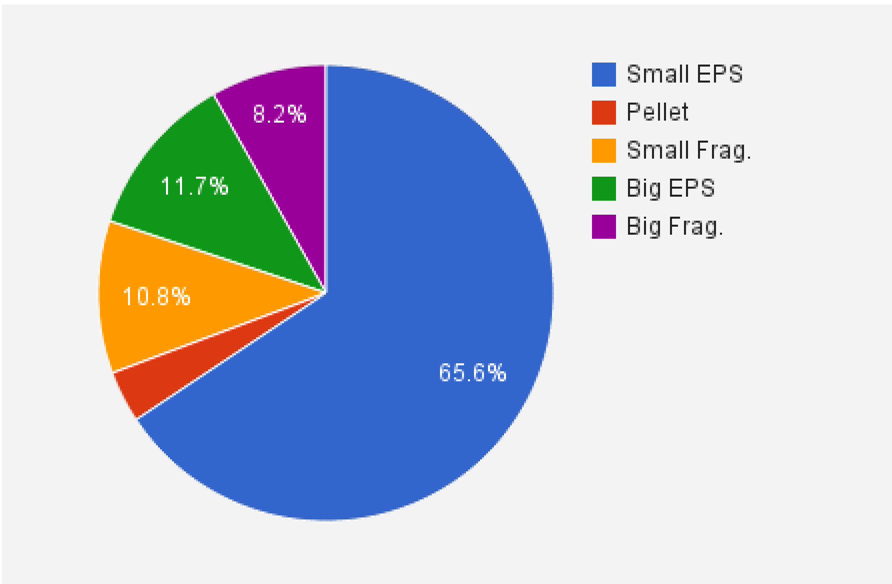

Figure 4.1: Plastics Found on Beaches

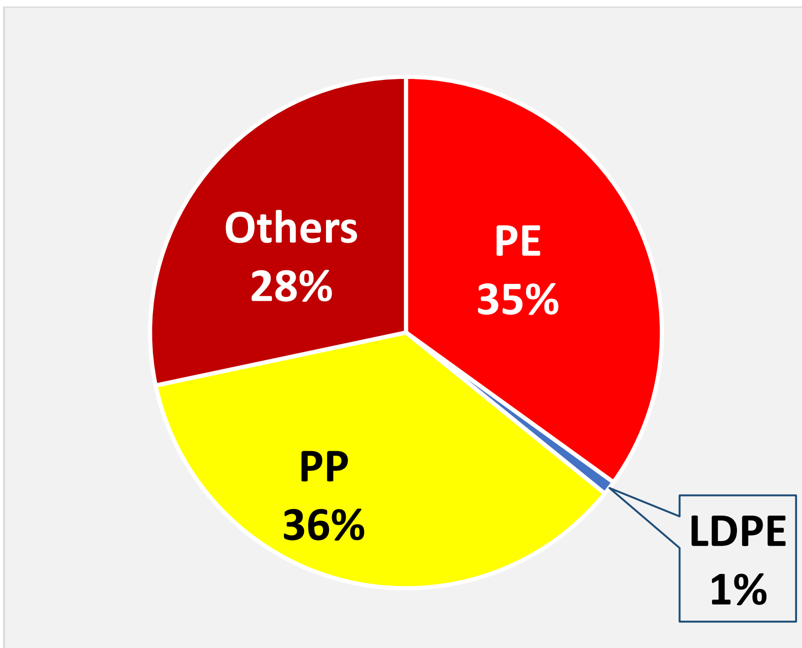

Figure 4.2: Types of Plastic Pellets

From all the plastics recovered, 3.7 percent were pellets. These pellets are raw material used in factories to make plastic objects. Figure 4.2 shows the results of the FTIR analysis of these pellets, in categories of Polyethylene (PE), Low Density Polyethylene (LDPE), Polypropylene (PP), and Others. See Appendix G for detailed results of the pellets recovered during sampling. The fact that these plastics were confirmed to be mostly pure plastics shows that they are raw material used in factories. PP and PE are less dense than water meaning they can float. We interpret that these pellets most likely came from the ocean. This information together means that the sources of the microplastic pellets are the factories using plastics, most likely upstream of the Pearl River.

We also examined the relationship between the five categories of plastics. There is a correlation between large and small fragments ($R^2=0.871$). As seen in Figure 4.3, the trend line has a slope of around 1, meaning that the number of small and large fragments increase or decrease at about the same rate. However, as seen in Figure 4.4, the correlation between large and small EPS debris is much lower ($R^2=0.581$) but the relationship is more extreme. The trend line for large and small EPS has a slope of around 3.5. This is significant because as the number of large EPS increased, the number of small EPS increased three and a half fold. Although correlation does not necessarily mean causation, we believe this is because EPS breaks down the easiest of all the plastics sampled. This means that if we assume large EPS causes small EPS, reducing the amount of large EPS debris will reduce the amount of small EPS at a much faster rate.

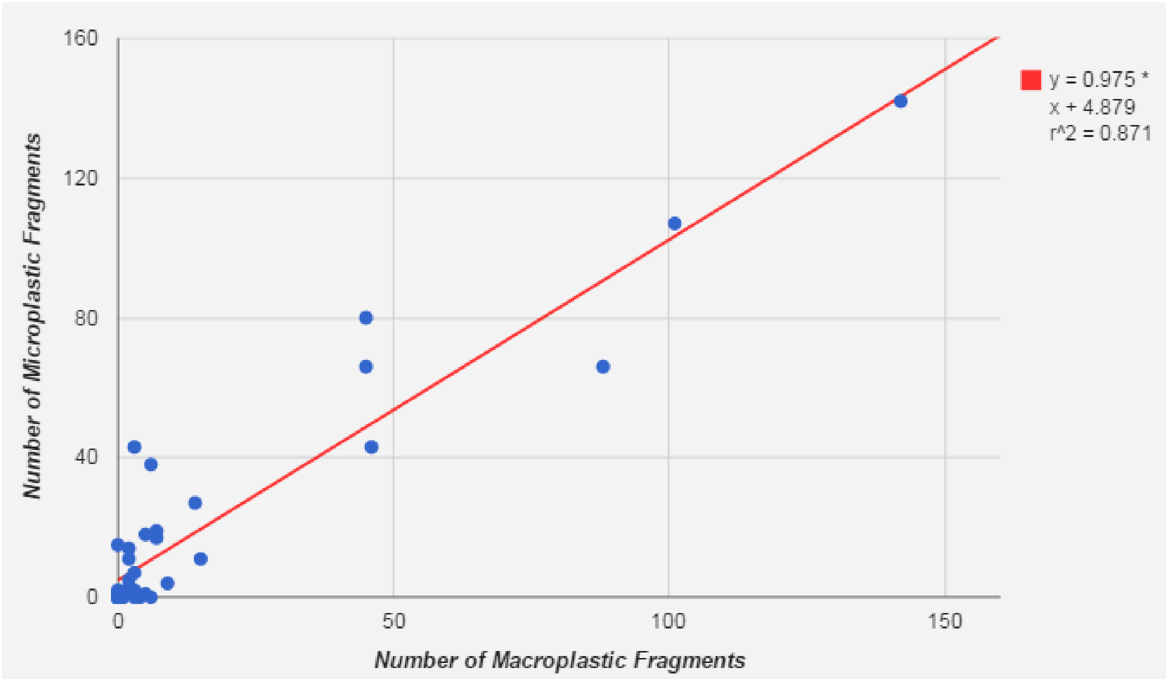

Figure 4.3 Relationship between Macrofragments and Microfragments

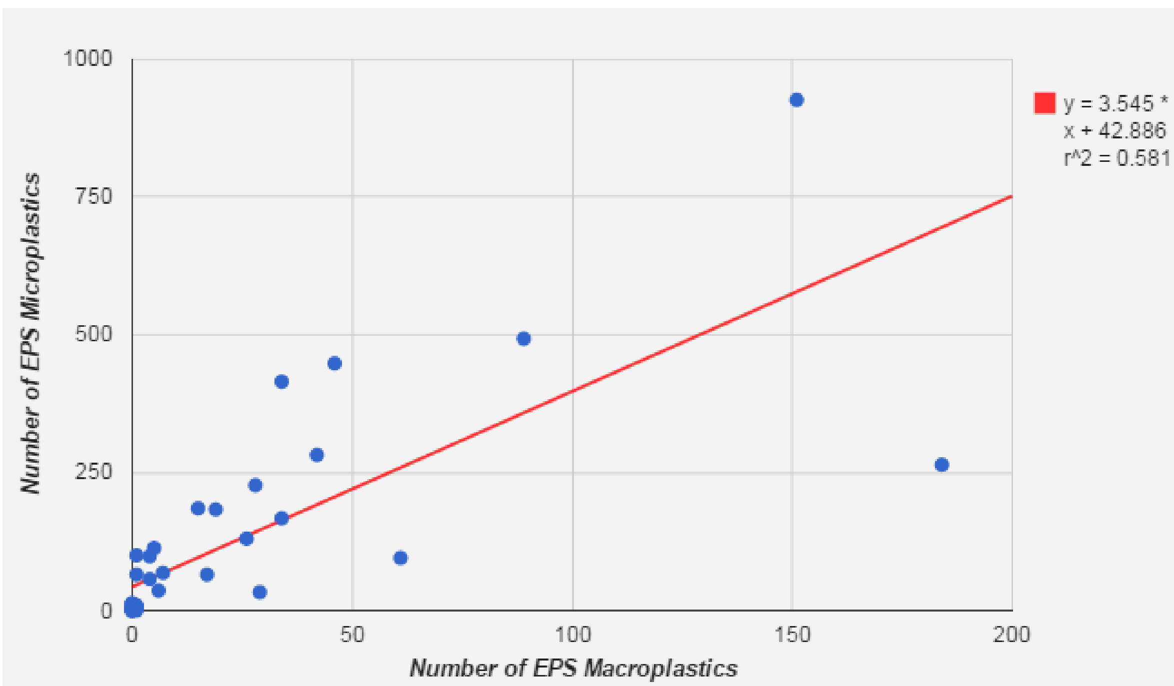

Figure 4.4 Relationship between Macro-EPS and Micro-EPS

4.2. Microplastic Pollution Level Differences Among Beaches

In this section we examine the results of the counts of each of the categories of plastics for four beaches that we have chosen as being representative of our data as a whole. To view the complete results from all ten beaches sampled, please see Appendix E. We chose to discuss these four beaches based on their locations. The four beaches are San Shek Wan, Fan Lau Tung Wan, Tung Lung Island, and Long Ke Wan. On the map in Figure 4.5, the four beaches analyzed in this chapter are highlighted in red. Notice the distribution of beaches we sampled surrounding Hong Kong in all directions.

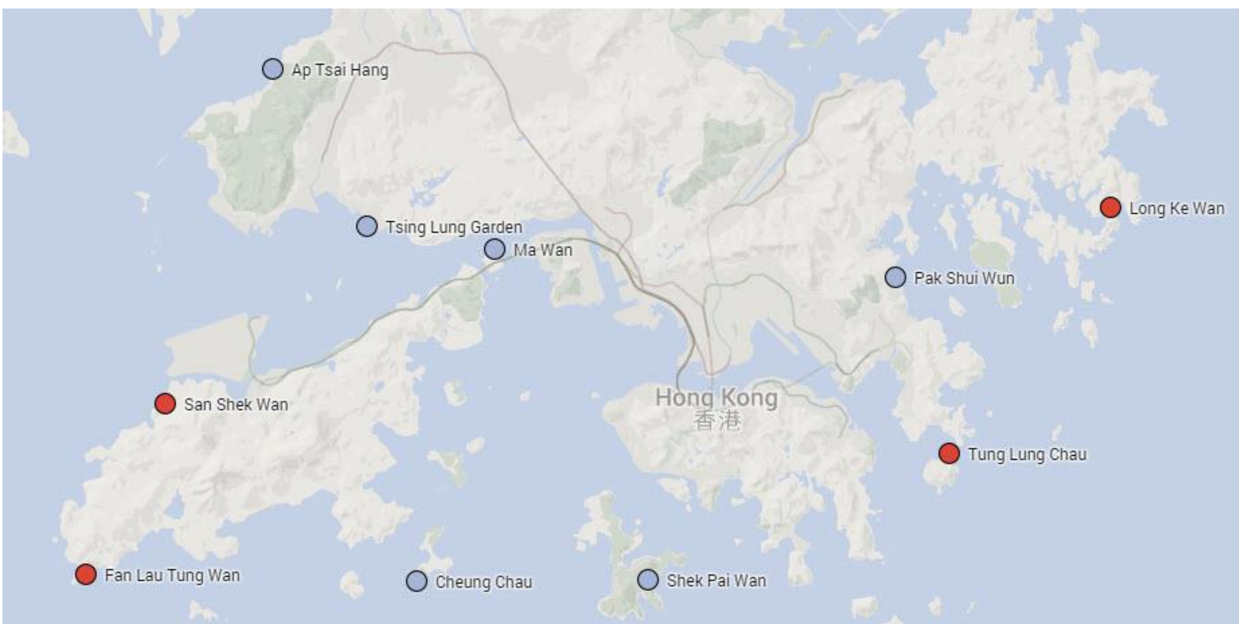

Figure 4.5: Map Showing the Locations of All Beaches Sampled in Hong Kong Indicated by Blue Pins with the Beaches Discussed in this Chapter Indicated by Red Pins

Through this project, we wanted to explore the varying amounts of microplastics present per liter sediment among the ten sampled beaches. In this section, we explain some of the factors that may have led to the differences in numbers. The number of plastic pieces varied greatly from beach to beach. Figure 4.6 shows the number of microplastics per liter of sediment found on each beach sampled in the winter (January-February) of 2015.

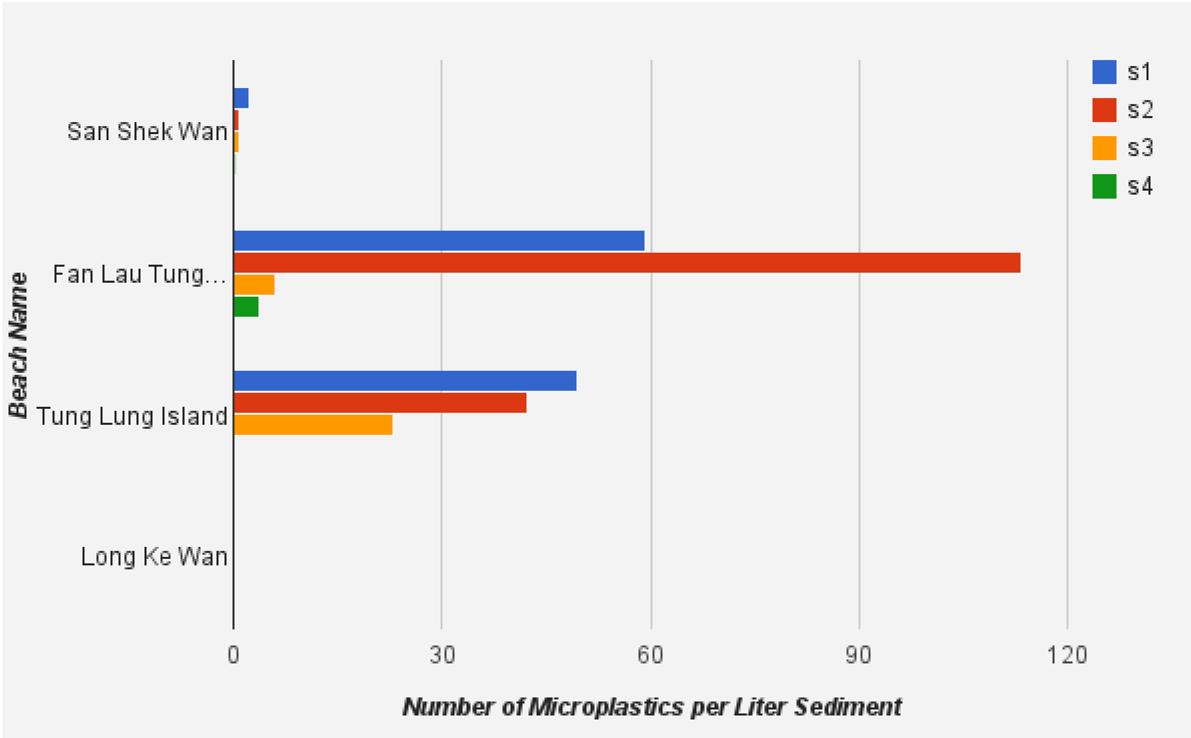

Figure 4.6 Number of Microplastics per Liter of Sediment in Samples 1 through 4 for Each Beach

4.2.1. San Shek Wan

The top of Figure 4.6 shows the number of microplastics per liter of sediment collected at the beach San Shek Wan. The number of microplastics per liter of sediment was not uniform over all four samples taken at that beach. Sample 1 had a ratio of 2.3 microplastics per liter, which is significantly more than sample 4, which only had 0.2 microplastics per liter. San Shek Wan is located on the west side of Hong Kong, on Lantau Island. This location is very close to the mouth of the Pearl River, so the plastic waste flowing from there could potentially be deposited on San Shek Wan. However, a new barrier that is between San Shek Wan and the open ocean is the bridge construction for the bridge to Macau. A bridge is being built from Hong Kong to Macau, and we observed the bridge construction taking place while we were sampling. The new bridge runs parallel to San Shek Wan, and this may be disrupting the normal tides bringing in plastics. The bridge construction may prevent the area's usual flow of microplastics from getting to the beach. Additionally, it may contribute to the beach's microplastic pollution from construction debris.

4.2.2. Fan Lau Tung Wan

Fan Lau Tung Wan is located in south-west Hong Kong on the southern tip of Lantau Island. This beach visually had the most plastic waste and general trash compared to any other beach we sampled. This can be explained by the fact that it is so close to the Pearl River flow of water coming out into the ocean. The beach is exposed, leading us to realize that summer typhoons bring a lot of plastic debris ashore. Figure 4.7 shows an example of the vastness of debris that typhoons can wash up.

Figure 4.7: Debris on the Coast of Fan Lau Tung Wan

After observing the immense amount of debris, it is not surprising that Fan Lau Tung Wan had 45.7 microplastics per liter sediment, the most compared to all ten beaches we sampled. Figure 4.6 shows the variation of microplastics per liter sediment for each sample taken at Fan Lau Tung Wan. There is an uneven distribution of microplastics on this beach. Sample two had a significantly larger number of microplastics per liter sediment compared to the rest of the samples with 113.5. The next highest was sample one with 59.4, but samples three and four's amount were miniscule in comparison. There were no clear differences in the landscape of the beach or any other obvious factors that might have contributed to such a large difference among samples. We believe that the differences are due to natural variation along the beach because microplastics are not distributed evenly.

4.2.3. Tung Lung Island

Tung Lung Island is located in south-eastern Hong Kong and has no protection or barriers to shield it from Victoria Harbor. Figure 4.6 shows the variation of microplastics per liter of sediment at Tung Lung Island. We were not surprised by the large amount of microplastics we found there because of its exposure to Victoria Harbor. Additionally, we observed that there is a pier at this beach. We hypothesize that the pier could be trapping microplastics in the area resulting in higher sample numbers. Sample 4 had significantly more microplastics than all of the other samples from Tung Lung with 238.6 microplastics per liter sediment. We believe that this has to do with the micro-environment of the beach. Sample 4's quadrat was located just behind a large boulder. The rock may have prevented microplastics from washing away with the tide once they had settled at that location. Because of these observations, we have excluded sample four from our results. For more information on why we made this decision, refer to Appendix H.

Figure 4.8: Microplastics in the Density Separation Process at Tung Lung Island

Beach. After performing density separation four times this picture was taken, showing the large number of plastic pieces all throughout the sediment on Tung Lung. Sample 4 at Tung Lung required up to seven repetitions of density separation in order to retrieve all the plastics compared to only an average of three repetitions at beaches with fewer plastics.

4.2.4. Long Ke Wan

At Long Ke Wan only one piece of plastic was found, an EPS, and it wasn't a microplastic therefore there were zero microplastics per litre sediment. We hypothesize that this is because of Long Ke Wan's location and geographical environment. This beach is located on the far eastern side of Hong Kong territory near the reservoir in Sai Kung peninsula. Long Ke Wan is located at the end of a very long narrow bay, which we believe is greatly reducing the chances of plastics reaching the beach.

The number of pieces of microplastics per liter sediment varied from none at Long Ke Wan to 45.7 at Fan Lau Tung. One major difference between the relatively clean beaches and the dirty beaches is the degree to which there had been cleanup efforts at each type of beach. Long Ke Wan is a very popular beach that receives many visitors. Because of that, the beach is cleaned up on a daily basis. Additionally, in the summer months beaches may have more visitors that contribute to the total amount of macroplastics, which would then turn into microplastics in the future.

The geography of the surrounding area also has an effect on the microplastic pollution levels of beaches. Some beaches are in a bay and protected by land. Long Ke Wan is an example of this, being located at the innermost end of a bay protected on both sides by rocky land. Figure 4.9 shows the landscape around Long Ke Wan. The surrounding land breaks the flow patterns of the water from the ocean and slows the influx of microplastics reaching all the way to the beach. We hypothesize that this protection from the open ocean makes it much more difficult for plastics to come from the ocean onto this beach. This protective landscape helps keep Long Ke Wan clean to the point where zero microplastics were found on the beach when sampled in the winter.

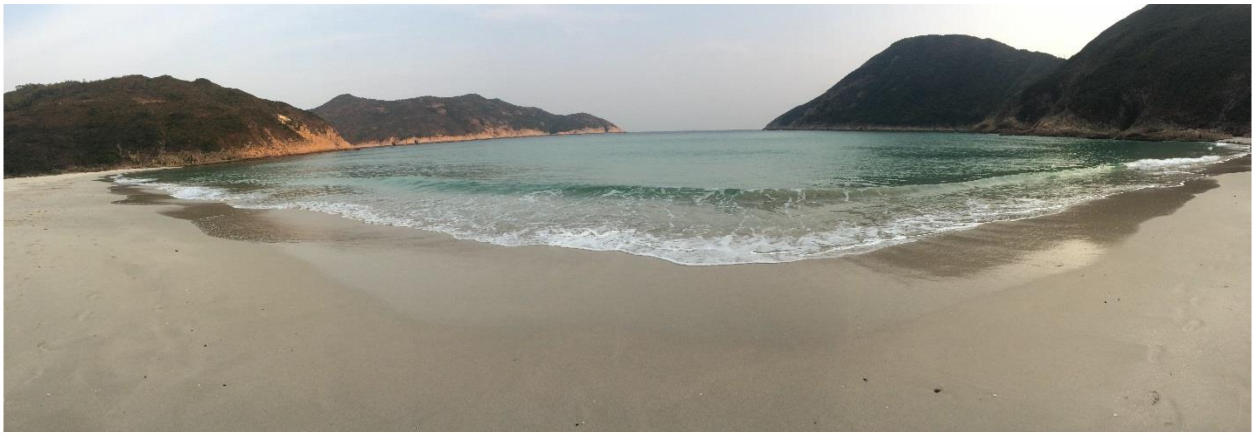

Figure 4.9: Picture of Long Ke Wan

4.3. Microplastic Pollution Differences Between Summer and Winter

Figure 4.10 is a graph of the number of microplastics per liter sediment for all ten beaches in both summer and winter. Please note the logarithmic scale on the horizontal axis. There is a large drop in number of microplastics from summer to winter on average. This shows that the number of plastics on the beach is not consistent throughout the year due to a variety of potential factors, such as wind and storms. The summer is considered the "rainy" season in Hong Kong, which plays a leading role in our findings (Hong Kong Tourism Board, 2015). The immense amount of rain can wash many loose plastic debris pieces and particles from their resting spots and into the ocean where they would then wash back onto shore. This would pollute the waters around Hong Kong more in the summer, which would lead to more microplastic findings. The storms that bring in the rain in the summer also have powerful winds that can move the microplastics very easily causing more microplastics to be blown into the marine environments. Once the microplastics are in the ocean, they can then be washed back onto the many shores along the Hong Kong coastline.

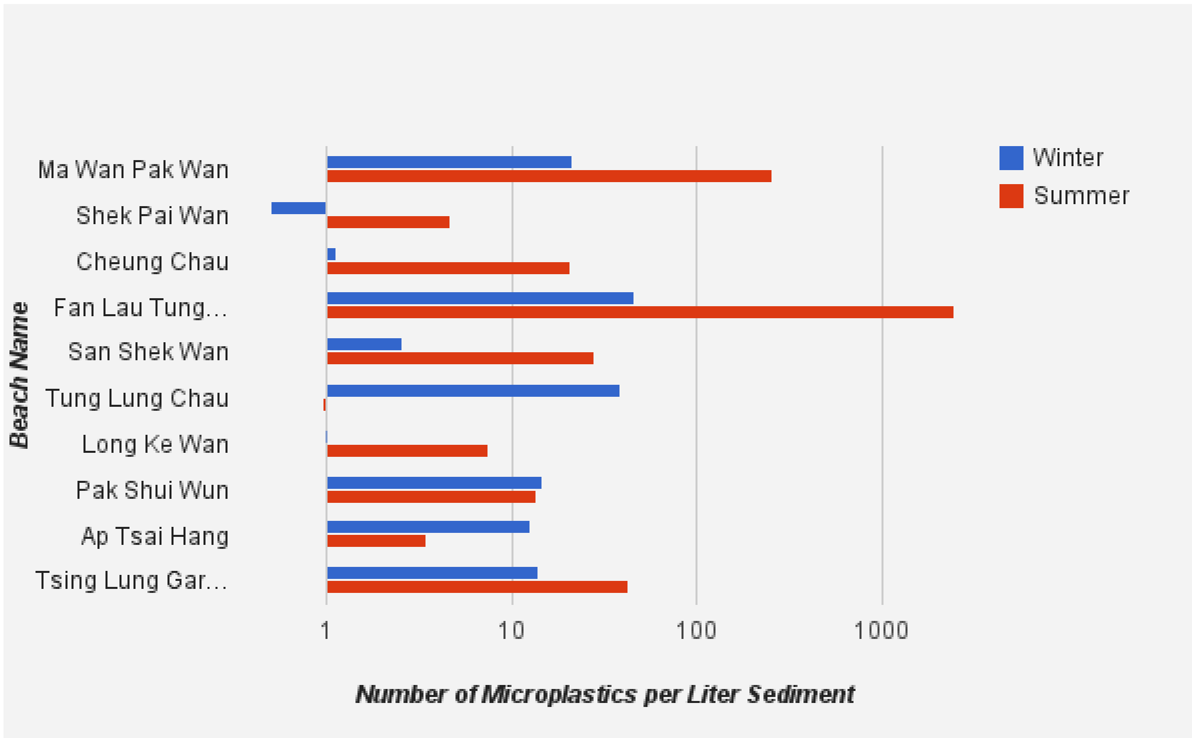

Figure 4.10: Number of Microplastics Found on Each Beach per Liter Sediment: Summer versus Winter

The microplastic counts consisted mostly of EPS. Expanded polystyrene made up over 75% percent of the microplastics collected. From going to all these beaches we noticed that EPS can be moved very easily by the wind due to its extremely low density. Because it can be moved so easily, we believed that the amount of EPS can vary greatly and rapidly. However, similar trends were seen when analyzing the data without EPS compared to the data including EPS. Figure 4.11 shows the microplastic counts at each beach sampled for both summer and winter, excluding EPS. The number of microplastics was still greater in the summer than the winter for every beach. The reason for Tung Lung Chau having more microplastics in the winter than in the summer is unknown.

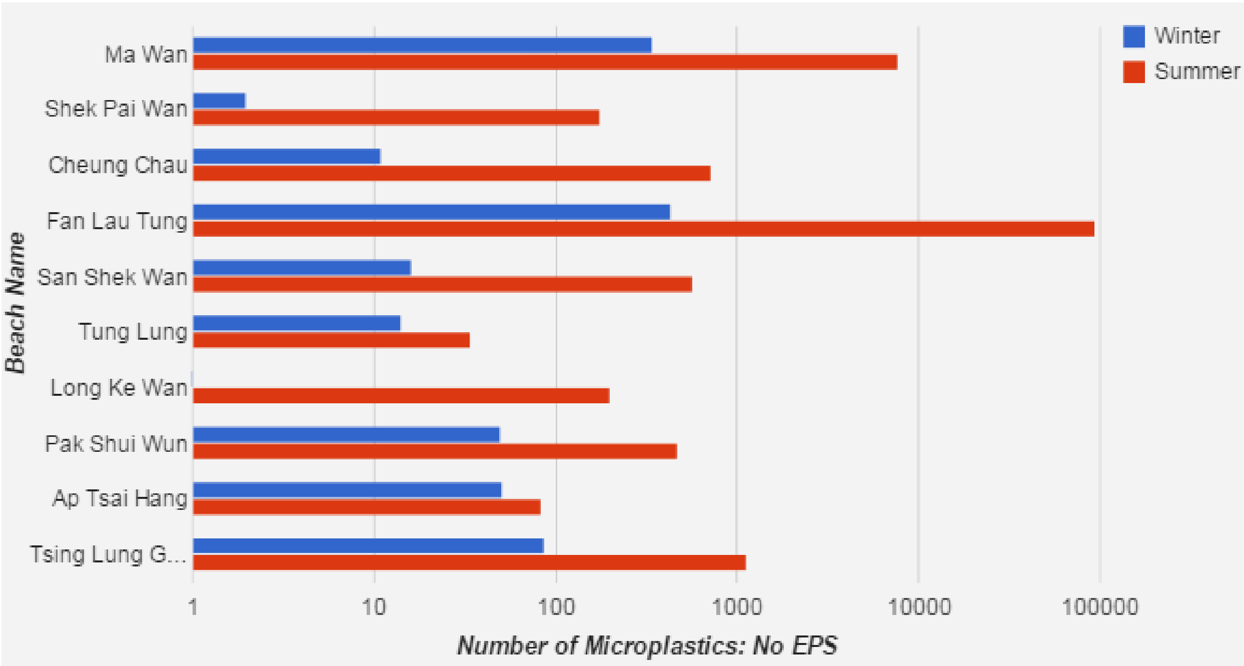

Figure 4.11: Total Number of Microplastics on Each Beach in Summer versus Winter, not Including EPS

4.4. Hong Kong Comparison to World

There are a number of previous studies of number of microplastics found in beaches around the world. Figure 4.12 shows some of this previous research completed by Browne et al. (2011). Our data from all the beaches sampled in the winter comes out to be 3.75 microplastics 250mL^{-1} (15/L) sediment, which is in the lower range of the data shown around the world. This is a lot lower than expected. If all of the beaches sampled in Hong Kong in the summer are averaged, the number of microplastics is 71.8 250mL^{-1} (287/L) sediment. This is above the scale of all previous data shown in Browne et al. If all the sampled beaches in Hong Kong are averaged for the whole year (combining summer and winter data), the number of microplastics comes out to be 37.8 250mL^{-1} (151/L) sediment, which is on the uppermost end of the previous research's results around the world. This means that the waters around Hong Kong have some of the highest amounts of microplastic pollution in the world. This should be because as seen in Table 2.6, China has the highest estimated amount of mismanaged plastic waste per year.

One important difference to note is in the sampling procedures. In Browne et al., when sampling the beaches they only collected samples to a depth of 1cm. This is substantially different than our sampling procedure of collecting sediment to a depth of 4cm. We believe that by collecting samples to a greater depth, we actually reduced the number of microplastics retrieved $250mL^{-1}$ sediment. This is because we found that most microplastics are on the sediment's surface or right near the surface. The deeper into the sediment we dug, the fewer microplastics there were.

Another very important difference to note is the difference in how microplastics were defined. In Browne et al., microplastics were defined as plastics smaller than 1mm, while for our research we used smaller than 5mm. This is an underlying issue with microplastics; research on this topic is at its beginning stages and there is no universal definition of microplastics. Because of this difference in definition, it is harder to compare results. Our results should have an inflated number of microplastics $250mL^{-1}$ sediment relative to the results of Browne et al.

Figure 4.12 Previous Microplastic Research (Browne 2011)

4.5. Knowledge, Awareness, and Behavior

We carried out a survey to get an overall understanding of the Hong Kong publics' views on the microplastic pollution problem. Specifically, we aimed to determine three key attributes of microplastic pollution including knowledge, awareness and behavior. We believed that these three categories could accurately portray the public's perception of the microplastic pollution problem. We collected 104 survey questionnaires from people at HKIEd, mostly students and staff, based on a convenience sampling strategy. People at HKIEd come from all over Hong Kong, and we attempted to get an equal number of male and female respondents; however, our results cannot necessarily be considered representative of the whole population of Hong Kong. The detailed breakout of the responses we got can be found in Appendix F.

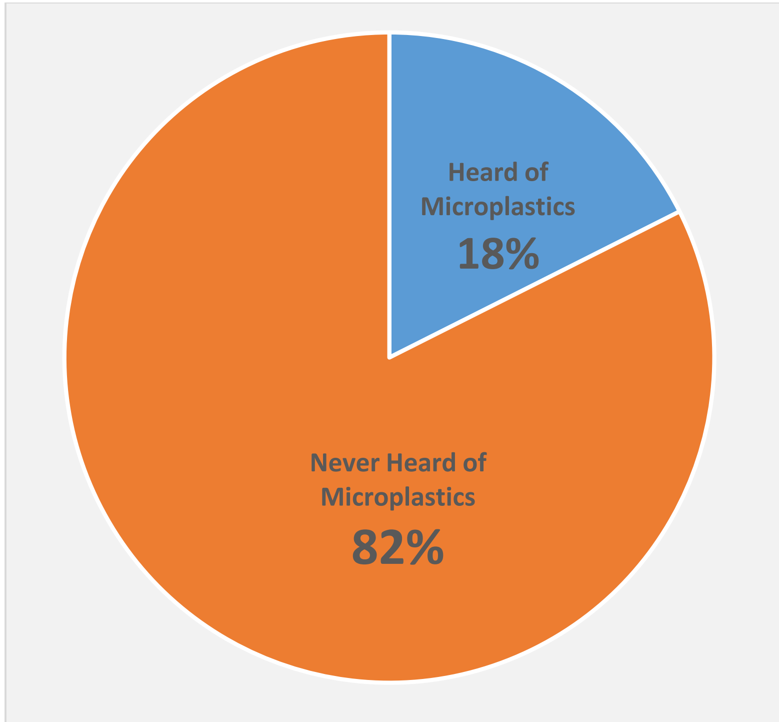

Figure 4.13: Percentage of Survey Respondents who had "Heard of microplastics" and who had "Never heard of microplastics"

The most important finding from our survey data was determining that very few people had heard of microplastics. As Figure 4.13 visualizes, when asked about their knowledge of microplastics, 82% of respondents said they had never heard of microplastics. Interestingly, even though many participants had never heard of microplastics, most of the respondents thought the microplastics are toxic and therefore directly affect human health. The average response for these questions did not vary significantly between people who said they had heard of microplastics and those who had not.

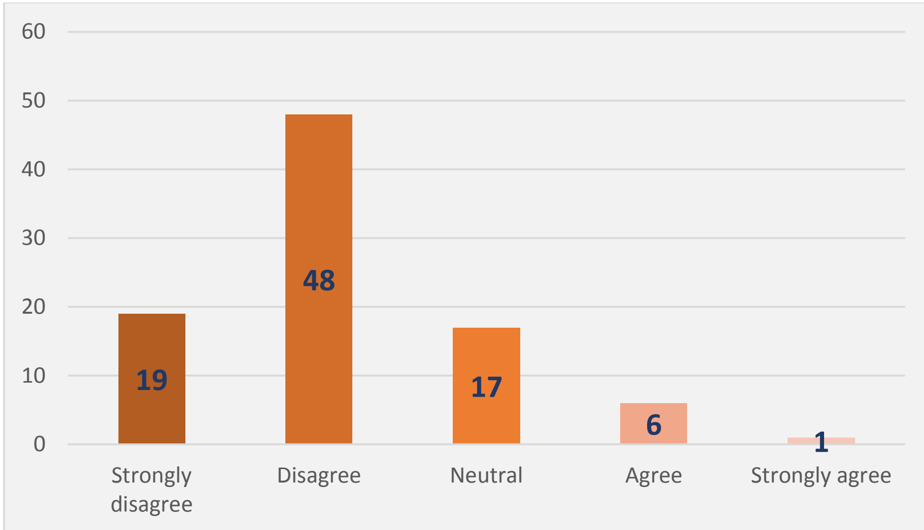

Figure 4.14: Survey Responses to "Microplastics are not toxic"

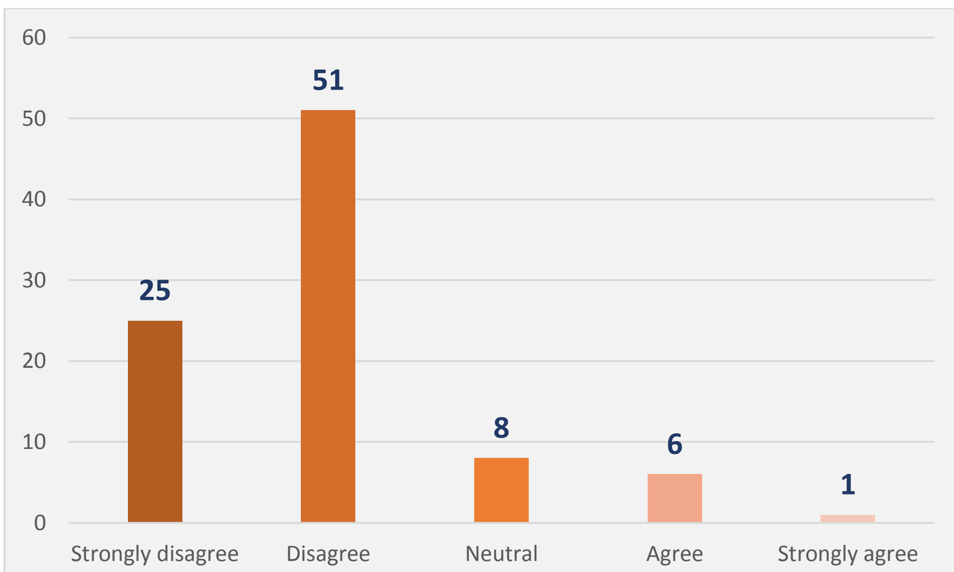

Figure 4.15: Survey Responses to "Microplastics do not affect human health"

Overall, the responses we received show that more participants agreed with positively phrased statements about their behavior compared to knowledge and awareness statements (see Appendix F:). We attribute this behavior to the fact that Hong Kong is an environmentally challenged area and people think they recycle their waste enough and try to be helpful when it comes to protecting their environment. However, we thought it was most notable that 18 participants disagreed with Statement 19, “I have personally contributed to microplastic pollution.” With an inadequate recycling program in Hong Kong, it is hard to believe that people do not contribute to the problem at all. This shows how unaware the people we surveyed were about microplastic.

Also, 62% of people we surveyed claimed they throw plastic waste into common waste bins (Figure 4.16). This means there might be a considerable amount of plastic waste that does not get recycled.

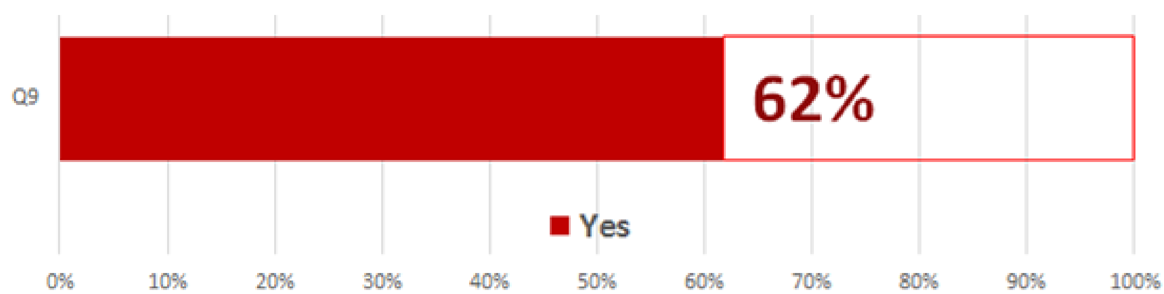

Figure 4.16: "I throw plastic waste into common waste bins."

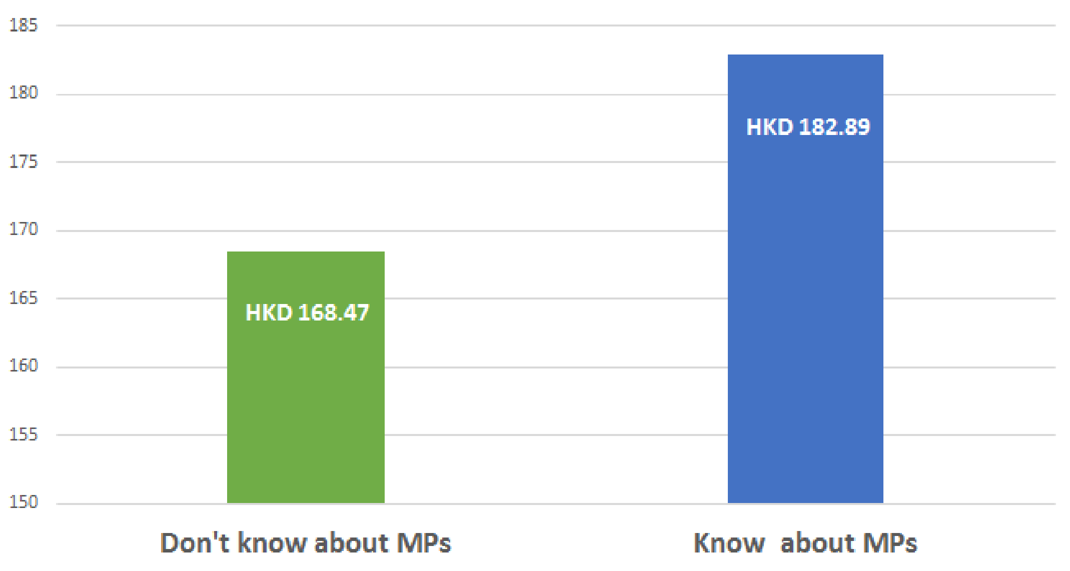

Figure 4.17: Average Willingness to Pay for Reducing Microplastic Pollution

Most of the survey takers agree that they would help encourage the government to work on the microplastic problem in Hong Kong. Furthermore, the respondents were willing to contribute a median of HK$100 in the effort to mitigate the levels of microplastic pollution in the waters surrounding Hong Kong. Some respondents were even willing to pay upwards of HK$ 1,200 to address this problem. The fact that the respondents were mostly students must also be taken into account. The majority of students do not have a substantial income. Therefore, we infer that the general population may be willing to contribute more, on average, to this cause. It should also be noticed that people who had heard about microplastics were willing to pay more for mitigation efforts (Figure 4.17).

Financially the respondents were willing to contribute somewhat to the cause, though not as willingly as they are willing to contribute their time. About forty percent of people would be willing to contribute financially versus, about fifty percent of respondents were willing to "personally participate in the cleanup efforts of microplastics in Hong Kong."

Our data shows that most people have never heard about microplastics. Despite this fact, they believe microplastics are harmful, and would be willing to contribute financially and through volunteering in order to reduce the harmful effects of microplastics. With the analysis of the beach sampling data, and the findings from our surveys, we have developed conclusions and recommendations to aid in the mitigation of this problem in Hong Kong.

5. Conclusions and Recommendations

In this chapter we present our conclusions based on the analysis of our research results. We also provide our recommendations based on the conclusions that we made while maintaining a practical perspective. While we realize that widespread change to the way microplastics are handled cannot happen overnight, we do believe our recommendations can start the process of changing some of the bad habits that have contributed to the microplastic problem.

5.1. Conclusions

Our research results can explain many of the underlying reasons for the levels of microplastic pollution that we detected. To start, our results indicate that the levels of microplastic pollution are generally higher in the summer than in the winter. We believe this is because of the "rainy season" weather patterns that occur in the summer months.

Another key result we noticed was the variation in the number of microplastics that were found based on the location of the beaches we sampled relative to the Pearl River Delta. In general, the beaches we sampled that were closer to the mouth of the Pearl River or closer to the biggest population centers had more microplastics on them than the beaches that were further away or more remote. This finding did not surprise us as it is known that the Pearl River is very heavily polluted (Hao, 2007). Factories and cities in Mainland China that are situated along the Pearl River contribute tremendously to the problem.

Our survey revealed some interesting findings about the Hong Kong people's perceptions of microplastics. Most people we surveyed had never heard of microplastics. The survey also revealed that many people would personally participate in the effort to clean up the beaches and eliminate microplastics. Our results indicate that many people would be willing to pay a small amount every year in an effort to prevent microplastic pollutants. Overall, the most important conclusion we obtained from the survey was that many people are completely unaware of the problem. This would be the first thing we would need to correct to begin to mitigate the problem.

5.2. Recommendations for Hong Kong

To ramp up the effort to mitigate microplastic pollution, we believe that it would be most important to spread awareness of the issue first. Without awareness of the problem, not many people are going to try to prevent it. To do this, we recommend that more studies are done to show the implications of the harmful effects of widespread microplastic pollution. When studies show the harmful effects of microplastics and how they can affect people and the environment, then we can begin to spread awareness.

We think that the most effective way to spread awareness would be through newspaper articles, television shows and documentaries, and social media. We have found these forms of communication to receive the most attention in the everyday lives of Hong Kong people. Therefore, we believe these methods of communicating our message will be the most effective. Once there is a suitable amount of awareness to the problem, then our data alongside with the studies explaining what makes microplastics harmful will show a clear need for action to mitigate microplastic pollution. Once the public is aware of the microplastic problem, then enough support for Government and non-Government organizations will grow so that action from these groups can be taken to start to mitigate the problem.

Our survey data show that although most people have never heard of microplastics, most people believe microplastics are present, toxic, and affect human health. The people we surveyed are willing to contribute financially and through volunteering in order to fight against microplastic pollution. Once an organized movement to prevent microplastic pollution gains enough support, we expect a strong backing for prevention and mitigation efforts.

5.3. Recommendations for the Hong Kong Local Residents

The first step in reducing microplastic pollution would be to effectively communicate better practices to the people in Hong Kong. The pollutant that showed up the most by far was EPS, which is widely used in everything from coolers to take away food containers. The issue with EPS is that is has an extremely low cost. It would be hard to tell people to stop using it when it is one of the most economical materials to use. One way to convince people to use less styrofoam is to mandate that restaurants charge money for take away food containers. A similar program is currently in place in Hong Kong for plastic bags. However, implementing a similar program would not stop fishermen from frequently using large EPS coolers; therefore, our message would be to push the government towards an EPS recycling program. EPS can easily be recycled into new foam packaging or durable consumer goods like cameras, coat hangers, and much more (EPS-IA, 2015). EPS recycling needs to be implemented here in Hong Kong and elsewhere, and it could be done very easily with the support of the public.

5.4. Recommendations for Future Research

Through our research we found that there are many more factors determining amounts of microplastics present on the beach than just geographical location. In order to better examine these other factors, we advise future research to consist of a selection of beaches close together geographically. Therefore, the geographical factors can be eliminated and the other factors such as beach direction and surrounding landscape can be examined with more accuracy and detail. This could help determine more specific causes of the microplastic pollution present on the beaches in those areas.

In addition, we believe it would be beneficial to further research the public's knowledge, awareness, and behavior. This could be done by surveying the public with a more representative survey sampling strategy instead of only people at HKIEd. This would provide a more accurate understanding of the awareness, knowledge and behavior of Hong Kong's population as a whole.

5.5. Summary

In summary, microplastic pollution is a significant problem that needs to be addressed. The levels of microplastic pollution are only going to go up as they do not ever cease to exist. Our data show that microplastic pollution is a problem here in Hong Kong and mitigation efforts are limited. We believe that change can happen when enough awareness is achieved and enough support is garnered. Then more action can be taken with real outcomes to successfully mitigate the microplastic pollution problem.

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Appendix A: Sponsor

Sponsoring Institution: Hong Kong Institute of Education

The Hong Kong Institute of Education (2014), or HKIEd, established on April 25, 1994, is a publicly-funded institution focused on advancement of teaching and learning. It provides academic and research programs on teacher education and related social sciences and humanities disciplines. The institute can be traced back to 1853 when the first formalized program of in-service teacher training was introduced at St Paul's College. Their official website states "The Institute aims to be a leading university on education, creating an impact and defining the education landscape not only for Hong Kong but also the Asia Pacific region" (Paragraph 3).

The HKIEd (2014) had a total of 9,680 students enrolled, as of September 30, 2014. There are three main undergraduate programs in addition to the graduate program. The three undergraduate programs are the Faculty of Liberal Arts and Social Sciences (FLASS), the Faculty of Education and Human Development (FEHD), and the Faculty of Humanities (FHM). As of June 30, 2014, there were 442 teaching staff at the HKIEd who were supported by 211 administrative staff. Also as of June 30, 2014, there were an impressive 217 ongoing research and development projects. The Hong Kong Institute of Education has a lot to be proud of with 94.4% of 2013 teacher education program graduates employed.

Sponsoring Liaison: Dr. Lincoln Fok (霍年亨)

Dr. Fok is currently an assistant professor in the HKIEd's Department of Science and Environmental Studies (ResearchGate, 2014). He studied Geography and graduated from Hong Kong University (HKU) with honors in 1998. After that he got his Master's Degree in 2001 and

PhD in 2011 from HKU (L. Fok, personal communication, December 11, 2014). Fok's original research interest focused on hydrology with a particular concern on the impacts of water and sediment quantity and quality along with their implications on the environment. Recently, his research has been extended to other fields including plastic pollution, ecotourism, protected area management, environmental consciousness and education.

Appendix B: Sampling Protocol

The Hong Kong Institute of Education

Department of Science and Environmental Studies

Microplastic Project – Beach Sampling Protocol

Dr. Lincoln Fok

Apparatus:

1. 50 x 50 cm quadrat	6. plastic tape measure (30 m)
2. 15 L water metal buckets X2[a]	7. shovels X2
3. 5 L water container[b]	8. random number generator[d]
4. sieve (333 µm) X4 or wire cloth (333 µm) X4[c]	9. sealable plastic bags (20 x 15 cm) X20
5. balance (max. 1,000 to 5,000 g, accuracy to 0.1g)	10. marker pens
	11. a meter ruler

[a]Make a 10 L mark on one of them; [b]Any handy water container that allows you to carry sea water; [c]Smaller mesh size is acceptable; [d]'Random' is a free random number generation app on mobile phones

Beach selection:

1. Select beaches that do not have a shark prevention net of any man-made structure which may hinder the natural flow of the waves and tides to the beach face
2. Select beaches with different geographic settings, such as varying proximity to rivers, beaches in inner bays and beaches facing different directions, etc.
3. Avoid sampling beaches with regular clean-ups
4. Focus on sandy shore, rocky beaches are not suitable for microplastic sampling

Preparation before sampling:

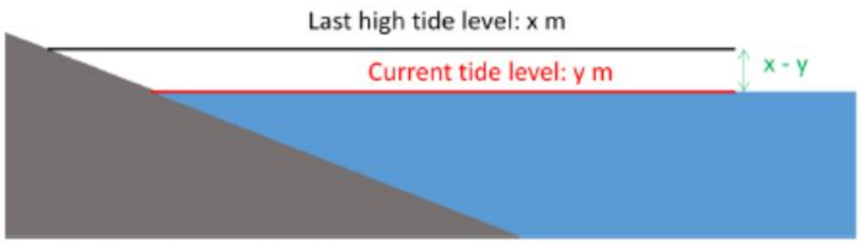
1. Record the level of the high tide from the last two calendar months (including the current month) from your local tidal gauge
2. Check the level of tide at the time of your sampling
3. Avoid sampling during daily high tide because the tide water may be too close to the swash line on which you collect samples

Filling in beach survey form:

1. Observe the environment carefully when you arrive at the beach
2. Fill in as many entries, such as wind direction and types of debris, as possible before you leave the beach

Sampling procedures:

1. Once the difference between the last high tide level and the current tide level is acknowledged using a meter ruler, the trash line, where all marine debris is deposited, can be identified



2. Randomly put a 30-m transect along the trash line
3. Generate 4 random numbers between 0 and 300
4. Put a quadrat at the location where the number indicates (e.g. a random number 4 indicates 0.4 m from the origin)
5. Collect plastic items that are larger than 5 mm on the surface of the sediment and preserve them in a sealable plastic bags
6. Use a shovel to excavate the top 4 cm sediment and fill the water bucket up the 10 L mark
7. Record the weight of all sediment collected (you may need to weigh it in portions)
8. Weigh approximately 100 g of sediment, record the exact weight and preserve it in a sealable plastic bag for the determination of sediment moisture content
9. Transfer about 1/4 of the sediment to the other empty water bucket and fill that bucket with sea water until the water well covers the sediment
10. Stir the sediment thoroughly with a shovel to allow microplastics in the sediment to float and be careful not to peel off the interior of the bucket if you are using a plastic bucket (metal bucket is preferred)
11. Filter the supernatant with the sieve or the wire cloth and retain the microplastics collected on the sieve or the wire cloth (and it is fine to

have some sand on the sieve or the wire cloth)

12. Repeat step 10 and 11 until there is no microplastic appearing from the sediment
13. Repeat step 8 to 11 for the rest of the 10 L sediment you have collected from ONE sample location and transfer the entire content into a sealable plastic bag
14. Label the sample no. clearly on all the plastic bags
15. Wash the buckets and shovels with sea water to ensure no microplastics will contaminate the next sample
16. Repeat step 4 to 12 for the remaining 3 locations

Remark:

1. Generate extra random numbers if undesirable objects or vegetation appear on the sampling locations, e.g. boulder, dunes and erosion feature
2. If there are very few microplastics found in a sample, the wrong trash line might have been located. Check vertically up or down the beach to see if other areas are more abundant of microplastics. Perform step 9 to 10 to check if necessary
3. Avoid sampling during bad weather or when the waves are high. Safety is our first priority
4. If there are not enough sieves or wire cloths, transfer all the microplastics collected from each sample carefully to a sealable plastic bag and label it with a marker pen. Wash the sieves or wire cloths thoroughly to ensure no microplastics are left on them before reusing them

Appendix C: Beach Survey Form

Beach survey form for microplastic sampling

1. Basic information

Name of beach		Location [DD]	LAT	_____._______________°N
			LON	_____._______________°E
Beach ID		Date & Time of survey		___/___/20___ ___:___
Water Control Zone		Name(s) of surveyor(s)		

2. General conditions

Air Temp (°C)		Wind direction	☐N/ ☐E/ ☐S/ ☐W
Beaufort no.		Wind	☐Onshore / ☐Offshore

Rainfall	☐<24h ☐<48h ☐<72h ☐>72h since last rain event and _________ mm rainfall measured on that day at the nearest weather station
Rain intensity (if raining)	☐Misting ☐Light rain ☐Steady rain ☐Heavy rain ☐Other:
Sky condition	☐Sunny ☐Mostly sunny ☐Partly Sunny ☐Mostly Cloudy ☐Cloudy
Amount of cloud cover	☐No clouds ☐1/8 – 1/4 ☐3/8 – 1/2 ☐5/8 – 7/8 ☐Total
Wave	☐Calm ☐Normal ☐Rough Wave height ____m
Tidal phase	☐High ☐Low ☐Ebbing ☐Flooding ☐Other:

3. Description of beach

Type	Residential	Industrial	Commercial	Agricultural	Undeveloped
%					

Beach uses	☐Swimming ☐Boating ☐Fishing ☐Surfing ☐Windsurfing ☐Diving ☐Kayaking ☐Jet skiing ☐Beachcombing ☐Vehicular traffic ☐Kiteboarding ☐Other (specify):
Beach materials / sediments	☐Sugar sand ☐Fine sand ☐Coarse sand ☐Sand/shell mix ☐Mucky ☐Pebbles ☐Rocky ☐Shell ☐Other (specify):
Habitat around the beach	☐Dunes ☐Wetlands ☐River/steam ☐Forest ☐Park ☐Protect areas / reserve ☐Urban/boardwalk ☐Parking ☐Other:
Does beach erosion exist?	☐Yes (Take photos of evidence) ☐No

4. Beach debris

How often are floatable debris found on the beach?	☐Never ☐Sometimes ☐Frequently ☐Very frequently
Known sources of debris	
Types of debris	☐Street litter ☐Food-related litter ☐Medical items ☐Sewage-related ☐Building materials ☐Fishing-related ☐Household waste ☐Tar/oil ☐Other:
Additional observations	

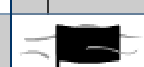
5. Sample collection

Trash line height [mCD]		Length [m]		Width [m]	

Four random locations	[A]	[B]	[C]	[D]
	Sample 1	Sample 2	Sample 3	Sample 4
Total wt. of sediment [g]				
Quadrat on vegetation?	☐Yes ☐No	☐Yes ☐No	☐Yes ☐No	☐Yes ☐No

6. Sketch of beach (Label features)

Beaufort Scale

Beaufort number	Wind Speed (mph)	Seaman's term		Effects on Land
0	Under 1	Calm		Calm; smoke rises vertically.
1	1-3	Light Air		Smoke drift indicates wind direction; vanes do not move.
2	4-7	Light Breeze		Wind felt on face; leaves rustle; vanes begin to move.
3	8-12	Gentle Breeze		Leaves, small twigs in constant motion; light flags extended.
4	13-18	Moderate Breeze		Dust, leaves and loose paper raised up; small branches move.
5	19-24	Fresh Breeze		Small trees begin to sway.
6	25-31	Strong Breeze		Large branches of trees in motion; whistling heard in wires.
7	32-38	Moderate Gale		Whole trees in motion; resistance felt in walking against the wind.
8	39-46	Fresh Gale		Twigs and small branches broken off trees.
9	47-54	Strong Gale		Slight structural damage occurs; slate blown from roofs.
10	55-63	Whole Gale		Seldom experienced on land; trees broken; structural damage occurs.
11	64-72	Storm		Very rarely experienced on land; usually with widespread damage.
12	73 or higher	Hurricane Force		Violence and destruction.

Appendix D: Survey

Microplastic Research Survey

The objective of this survey is to discover how people perceive microplastic pollution and its effects in Hong Kong. We aim to quantify people's opinions to inform our research conclusions. All of your responses will remain anonymous and no identifying information will be collected. We truly appreciate your assistance in our endeavor. If you have any questions or concerns please feel free to contact us via email at hkied@wpi.edu. Thank you for taking the time to complete this survey.

Have you ever heard about microplastics? [ ] Yes [ ] No

Please rank your opinion of the following statements.

Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1.Microplastics can be found on every single beach in Hong Kong.					
2. Microplastics found in Hong Kong originate from urban runoff from Hong Kong.					
3. Microplastic pollution is a serious global problem.					
4. I am unaware of microplastic pollution.					
5. The marine environment surrounding Hong Kong has plastic pollution.					
6. I am not willing to tell my family and friends about the issue of microplastics in Hong Kong.					
7. I never recycle plastic food containers.					
8. Microplastic pollution is worst on the southern beaches of Hong Kong.					
9. I never throw plastic waste into common waste bins.					
10. I am willing to personally participate in the cleanup efforts of microplastics in Hong Kong.					
11. Microplastics found in Hong Kong do not originate from the Pearl River.					
12. Microplastic pollution is worst on the western beaches of Hong Kong.					
13. Microplastics pollution is not a serious problem in Hong Kong waters.					

14. I am not willing to pay an annual fee to fund the cleanup efforts of microplastics in Hong Kong.					
15. Microplastics do not affect human’s health.					
16. I always recycle plastic bottles.					
17. I am willing to encourage the government to work on the issue of microplastics in Hong Kong.					
18. Microplastics contribute to the coastal pollution in Hong Kong.					
19. I have personally contributed to microplastic pollution.					
20. Microplastics found in Hong Kong do not originate from the open ocean.					
21. It is not important to raise awareness of microplastic pollution.					
22. I do not know a lot about microplastics.					
23. I want to learn more about microplastics.					
24. Marine animals will not consume microplastics as food.					
25. Microplastics are not toxic.					
26. Microplastic pollution is worst on the eastern beaches of Hong Kong.					
27. All plastic marine debris will eventually become microplastics.					
28. The beaches surrounding Hong Kong do not have plastic pollution.					
29. Microplastics do not have a profound impact to sustainable development in Hong Kong.					
30. Microplastics have affected my leisure activities on the beaches of Hong Kong.					

How many HKD per year would you pay to help reduce the number of microplastics in Hong Kong? HK$__________

Socio-Demography Information

1. Gender [M] [F]

2. Age [18-24] [25-34] [35-44] [45-55] [55-64] [65+]

3. Education Background (circle the highest level completed)

[Primary school] [secondary school] [post-secondary education(associate degree, diploma or higher diploma)] [undergraduate] [postgraduate or above] [N/A]

4. What do you classify yourself as?

[ ] Student [ ] Staff [ ] Other__________

5. If you selected "student" what is your program of study? _______________________

6. Occupation

[Student] [Agriculture and Fishing] [Mining and Quarrying] [Manufacturing] [Electricity, Gas and

Water] [Construction] [Wholesale, Retail and Import/Export Trades, Restaurants, and Hotels] [Transport, Storage, and Communications] [Financing, Insurance, Real Estate, and Business Services] [Community, Social, and Personal Services] [Retired] [Housewife] [Other (specify)] _____________________________

7. Number of children

[0] [1] [2] [3] [4] [>5]

8. Monthly salary before tax

[under $9,000] [$9,001-12,800] [$12,801-20,000] [$20,001-40,000] [over $40,001]

9. What is your nationality?

[ ] Hong Kong [ ] Other__________

10. If you selected “other” what is your reason for visiting?

[ ] Business [ ] Leisure [ ] Visiting family [ ] Other__________

Appendix E: Beach Sampling Data

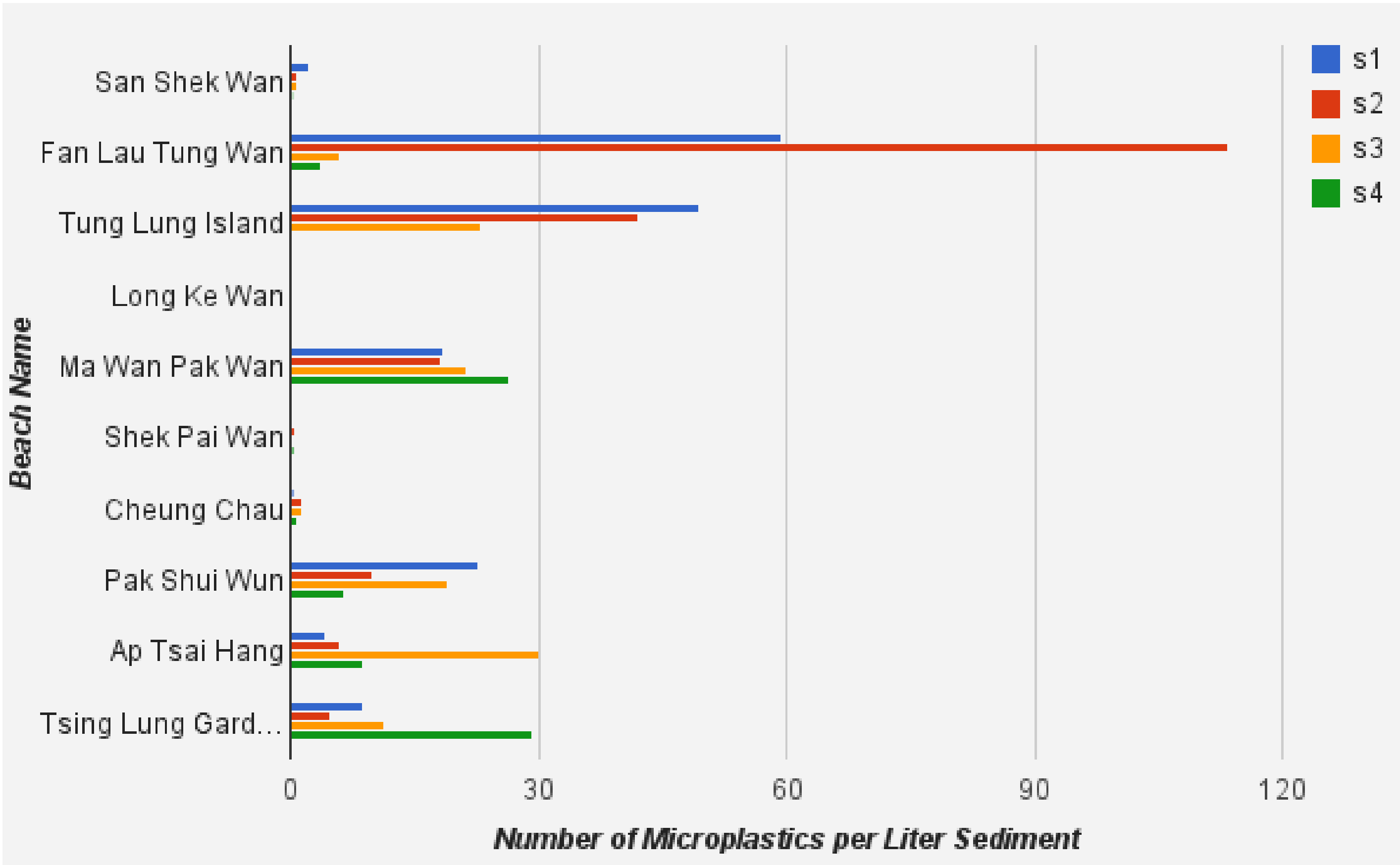


Figure E.1: Number of Microplastics for each Sample of each Beach

Table E.1 Number of Microplastics per Beach for both Summer and Winter

Beach	Winter(Microplastics/L)	Summer(Microplastics/L)
Ma Wan Pak Wan	21.15	258.925
Shek Pai Wan	0.5	4.7
Cheung Chau	1.125	20.5
Fan Lau Tung Wan	45.675	2491.325
San Shek Wan	2.575	27.625
Tung Lung Chau	38.3	0.95
Long Ke Wan	0	7.475
Pak Shui Wun	14.575	13.7
Ap Tsai Hang	12.5	3.425
Tsing Lung Garden	13.85	42.15

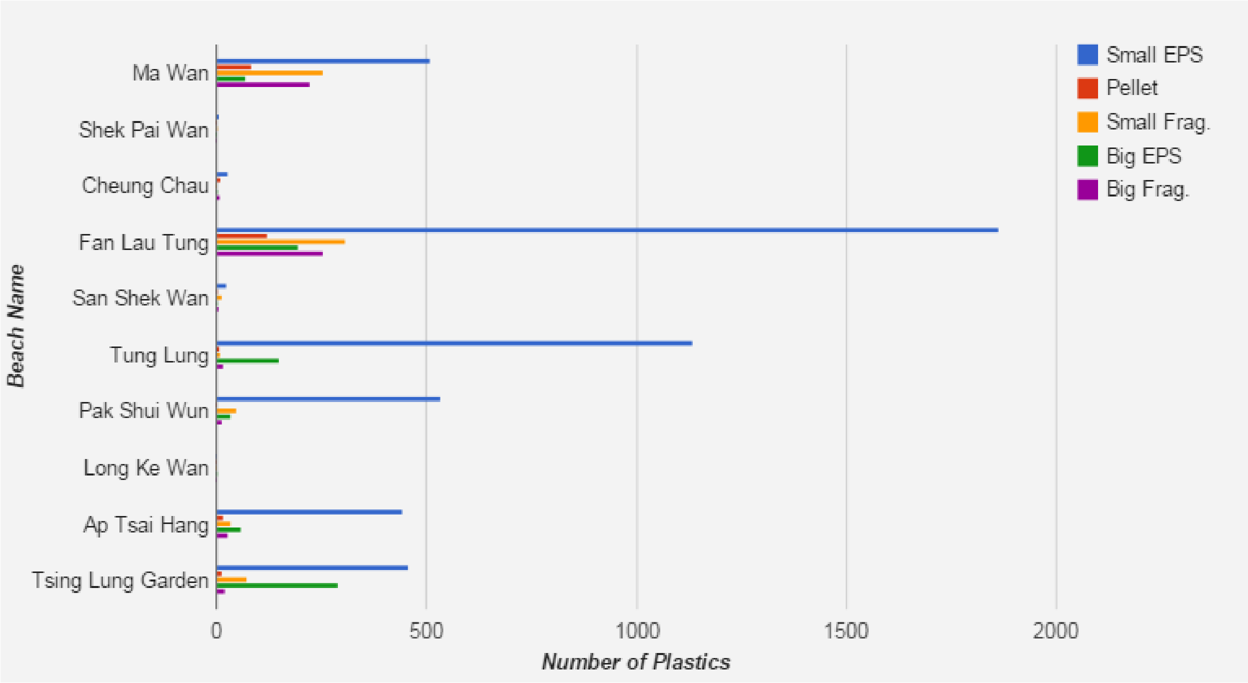


Figure E.2 Number of Plastics for each Category of every Beach

Table E.2: Total Count of each Plastic Category for Every Beach

	Small EPS	Pellet	Small Frag.	Big EPS	Big Frag.
Ma Wan	508	83	255	69	224
Shek Pai Wan	5	0	2	0	0
Cheung Chau	29	11	0	2	7
Fan Lau Tung	1866	122	306	197	256
San Shek Wan	24	2	14	1	4
Tung Lung	1135	6	8	151	16
Pak Shui Wun	533	0	50	36	13
Long Ke Wan	0	0	0	1	0
Ap Tsai Hang	443	16	35	59	27
Tsing Lung Garden	457	13	74	291	21

Appendix F: Survey Results Data

Here is the breakdown of responses we got from the survey for each question. We grouped them according to their categories (Knowledge, Behavior and Awareness) and whether they were negatively or positively worded statements. The average response for positively worded questions, which was on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree) can be seen as green lines. This scale is inverted for the negatively worded questions. For the questions themselves, please refer to Appendix D:

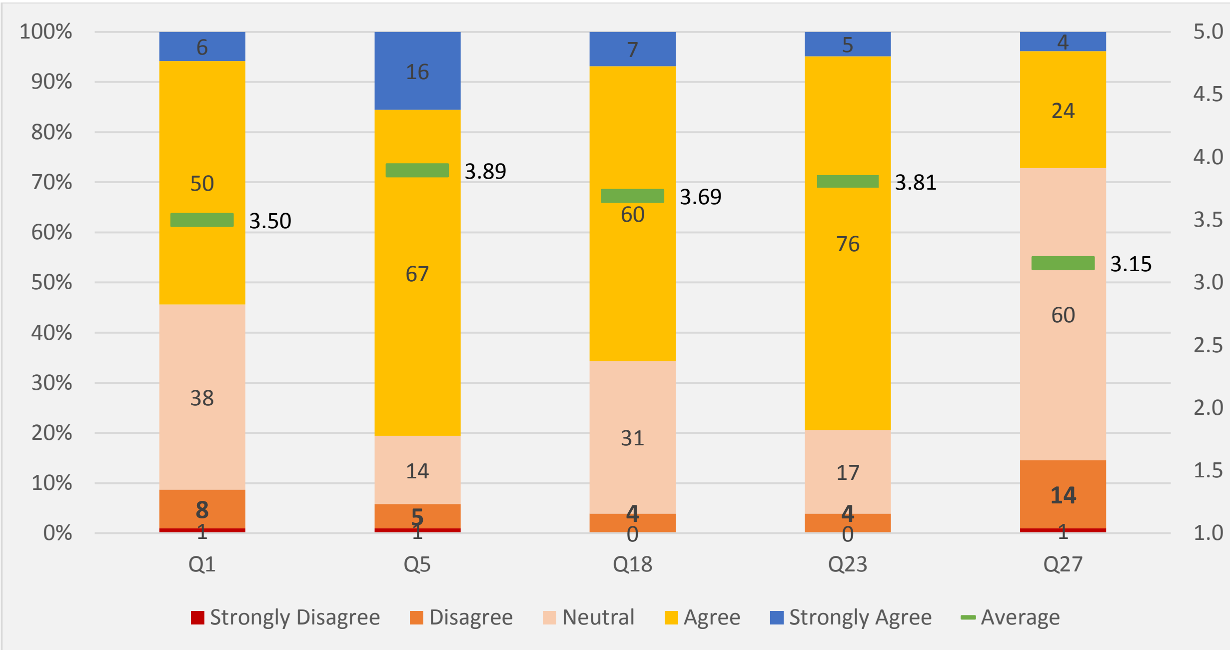


Figure F.1: Response for positively worded knowledge questions

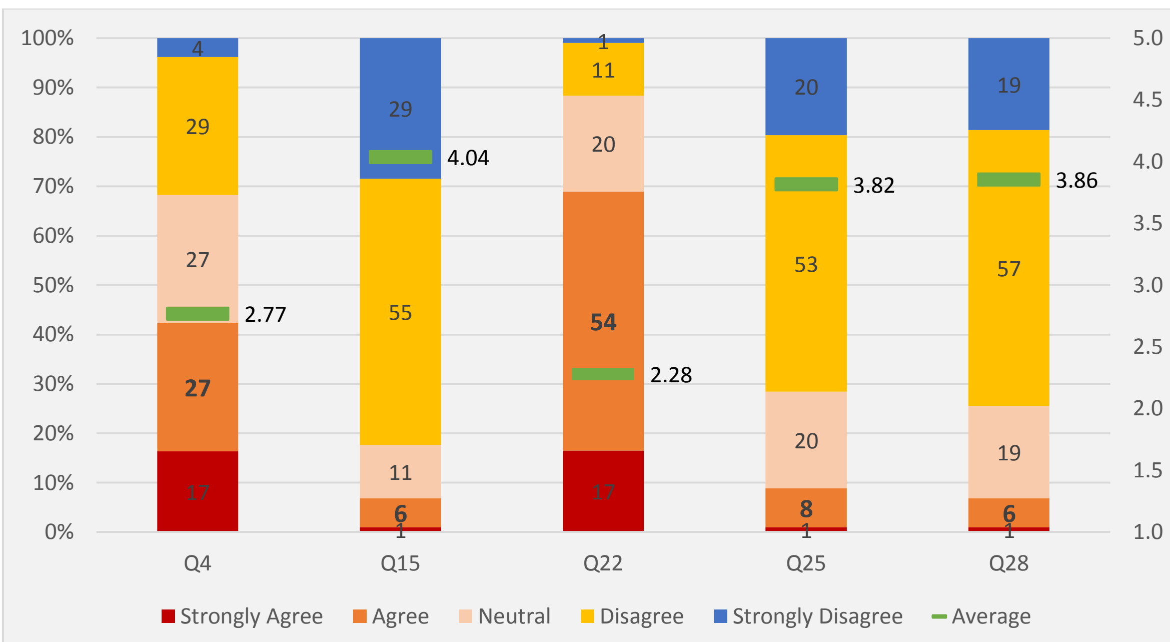


Figure F.2: Response for negatively worded knowledge questions

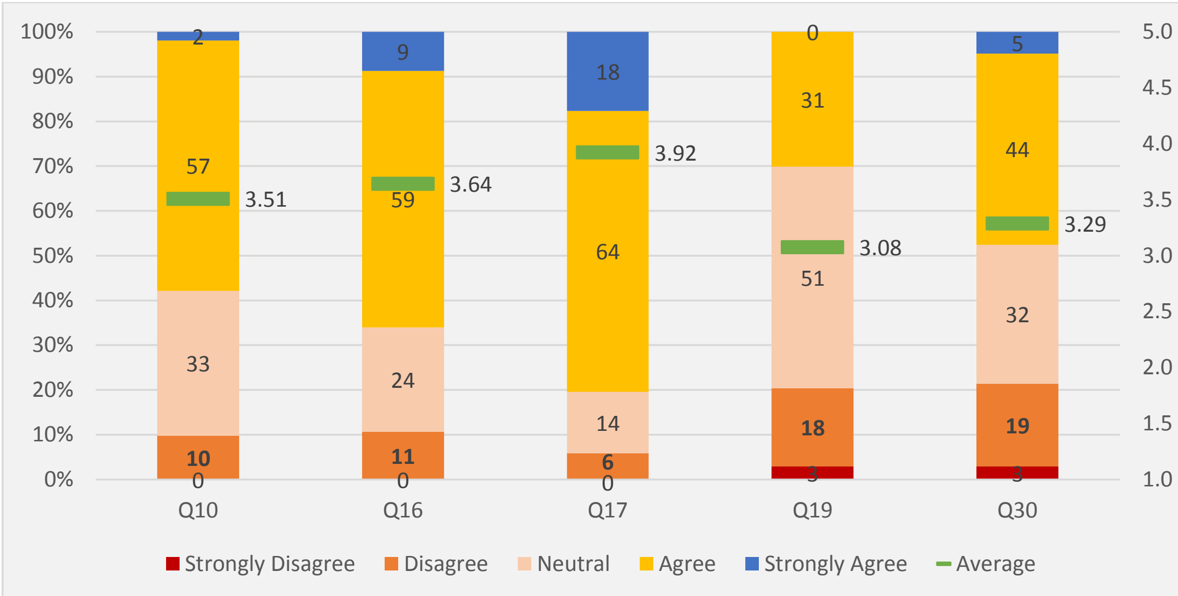


Figure F.3: Response for positively worded behavior questions

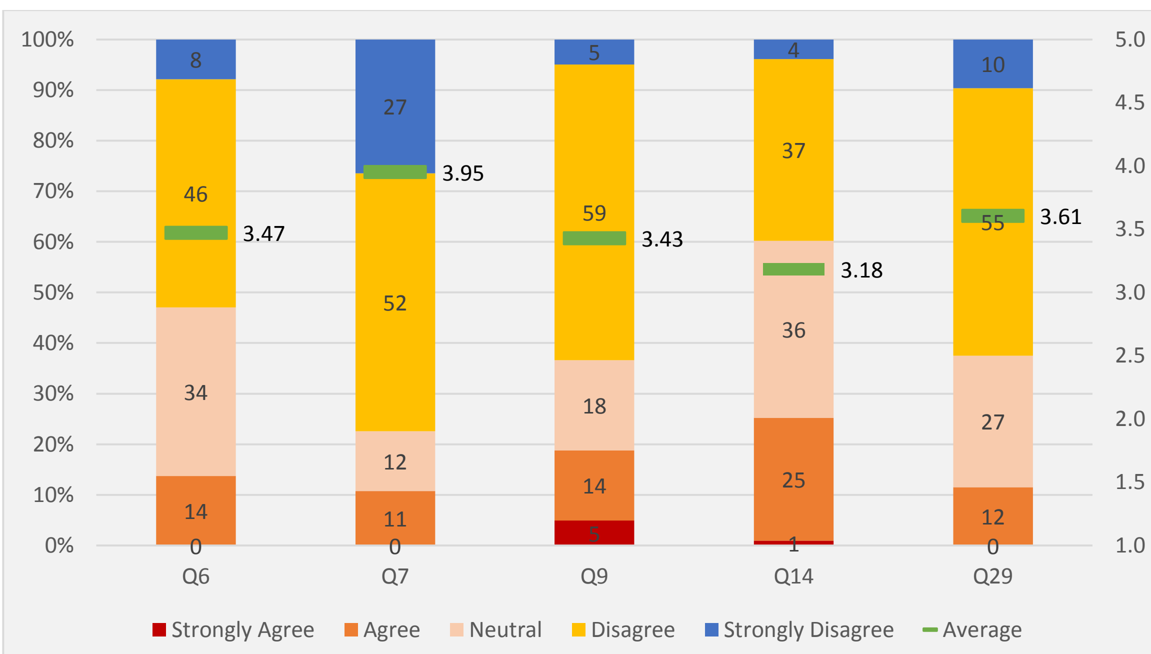


Figure F.4: Response for negatively worded behavior questions

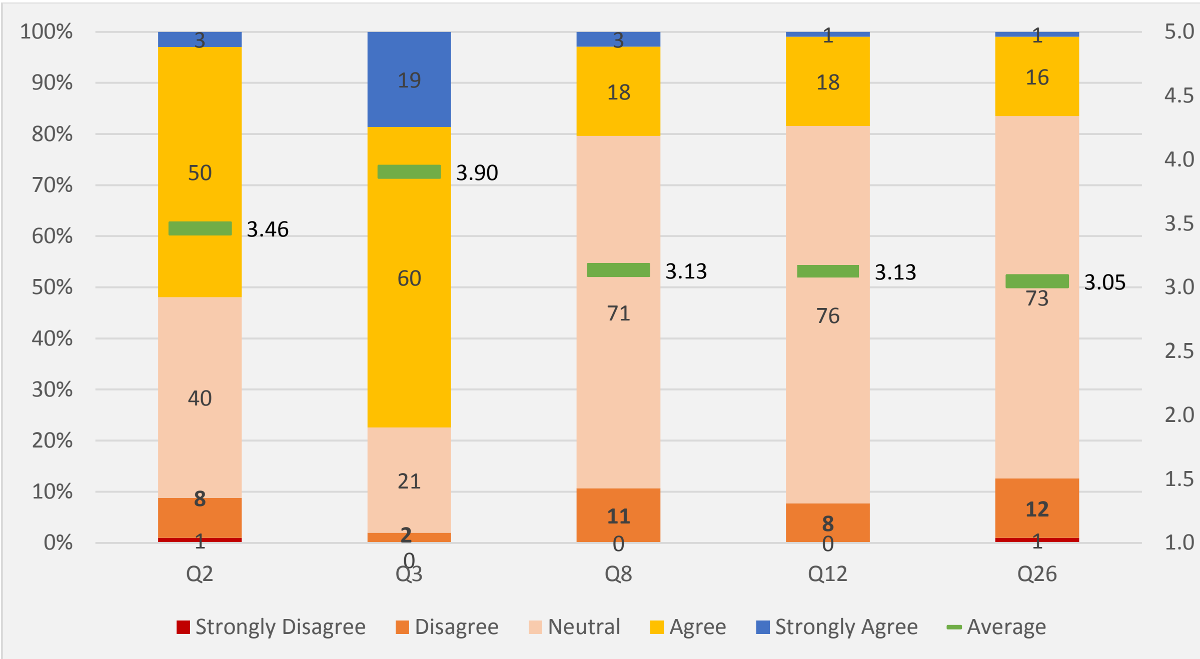


Figure F.5: Response for positively worded awareness questions

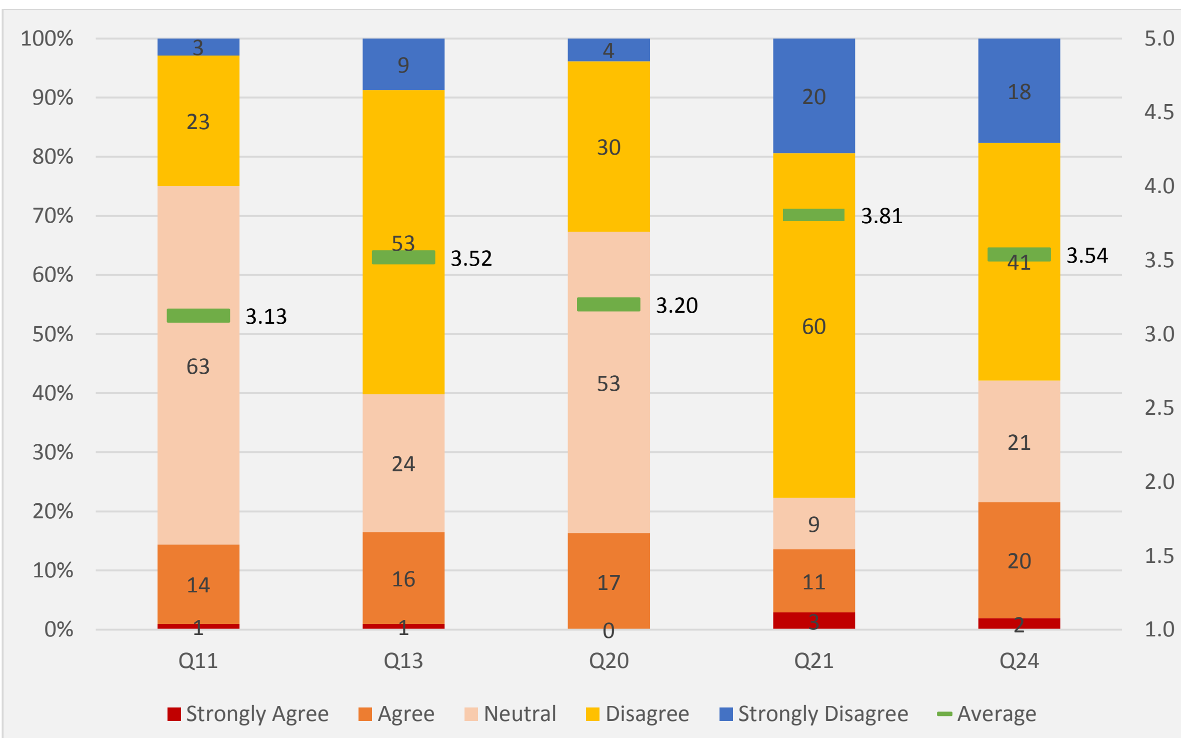


Figure F.6: Response for negatively worded awareness questions

Appendix G: FTIR Data

Table G.1: FTIR Data

Pellet				
Beach	**Sample**	**Pellet number**	**Shown on FTIR:**	**Classified as:**
Ma Wan	2	1	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	2	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	3	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	4	NIC12818.DX DIOCTADECYL SULFIDE	PP
	2	5	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	6	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	2	7	MP0149.DX POLYETHYLENE, ERACLENE 80	PE
	2	8	MP0144.DX POLYETHYLENE PLASTICIZED #1	PE
	2	9	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	10	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	2	11	MP0144.DX POLYETHYLENE PLASTICIZED #1	PE
	2	12	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	13	MP0574.DX PARAFFIN	others
	2	14	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	15	MP1614.DX WINDOW SEAL BLACK	others
	2	16	MP1603.DX SILICHROM	others
	3	1	MP0365.DX POLY(ETHYLENE:PROPYLENE:DIENE) (50% ETHYLENE, 4% DIENE)	PE
	3	2	MP0281.DX POLY(STYRENE-ETHYLENE-BUTYLENE)	others
	3	3	MP1603.DX SILICHROM	others
	3	4	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	3	5	MP0365.DX POLY(ETHYLENE:PROPYLENE:DIENE) (50% ETHYLENE, 4% DIENE)	others
	3	6	MP0365.DX POLY(ETHYLENE:PROPYLENE:DIENE) (50% ETHYLENE, 4% DIENE)	others
	3	7	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	3	8	MP1614.DX WINDOW SEAL BLACK	others

	3	9	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	3	10	MP0279.DX POLY(STYRENE:ETHYLACRYLATE)	others
	3	11	MP1586.DX BEACH SHOE CHINA #2	others
	3	12	MP1603.DX SILICHROM	others
	3	13	MP1587.DX BEACH SHOE CHINA #3	others
	3	14	MP1587.DX BEACH SHOE CHINA #3	others
	3	15	MP1614.DX WINDOW SEAL BLACK	others
	3	16	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	3	17	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	3	18	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	4	1	MP0148.DX POLYETHYLENE, ENGAGE 8180	PE
	4	2	MP0279.DX POLY(STYRENE:ETHYLACRYLATE)	others
	4	3	MP1614.DX WINDOW SEAL BLACK	others
	4	4	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	4	5	MP0365.DX POLY(ETHYLENE:PROPYLENE:DIENE) (50% ETHYLENE, 4% DIENE)	others
	4	6	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	4	7	MP0365.DX POLY(ETHYLENE:PROPYLENE:DIENE) (50% ETHYLENE, 4% DIENE)	others
	4	8	MP1614.DX WINDOW SEAL BLACK	others
	4	9	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	4	10	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	4	11	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	4	12	MP0386.DX POLY(ETHYLENE:PROPYLENE), DAPLEN KSR 4525	others
	4	13	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	4	14	MP0378.DX ESCORENE ULTRA 02020, COPOLYMER EVA TYPE	others
	4	15	MP0201.DX POLYPROPYLENE+VISTALON	PP
	4	16	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	4	17	MP1587.DX BEACH SHOE CHINA #3	others
	4	18	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	4	19	NIC14283.DX STEARATE CALCIUM	others
	4	20	NIC14283.DX STEARATE CALCIUM	others
	4	21	NIC14283.DX STEARATE CALCIUM	others
	4	22	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP

	4	23	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	4	24	MP1586.DX BEACH SHOE CHINA #2	others
	4	25	MP0365.DX POLY(ETHYLENE:PROPYLENE:DIENE) (50% ETHYLENE, 4% DIENE)	others
	4	26	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	4	27	MP0203.DX POLYPROPYLENE+VISTALON 719, 1:1	PP
	4	28	NIC12818.DX DIOCTADECYL SULFIDE	others
	4	29	MP1587.DX BEACH SHOE CHINA #3	others
	4	30	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	4	31	NIC12818.DX DIOCTADECYL SULFIDE	others
	4	32	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	1	MP1587.DX BEACH SHOE CHINA #3	others
	1	2	NIC14323.DX NOPCO 8034	others
	1	3	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	1	4	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	1	5	MP1614.DX WINDOW SEAL BLACK	others
	1	6	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	1	7	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	1	8	MP1587.DX BEACH SHOE CHINA #3	others
	1	9	MP0245.DX RUBBER CAR TYRE WINTER	others
	1	10	MP1587.DX BEACH SHOE CHINA #3	others
	1	11	MP0365.DX POLY(ETHYLENE:PROPYLENE:DIENE) (50% ETHYLENE, 4% DIENE)	others
	1	12	NIC12818.DX DIOCTADECYL SULFIDE	others
	1	13	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
Fan Lau Tung	1	1	MP1587.DX BEACH SHOE CHINA #3	others
	1	2	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	3	MP0200.DX POLYPROPYLENE, STAMYLAN P 512MN10	PP
	1	4	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	1	5	NIC12106.DX BYK 031	others
	1	6	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	1	7	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	1	8	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE

	1	9	MP1586.DX BEACH SHOE CHINA #2	others
	1	10	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	11	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	1	12	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	1	13	MP0148.DX POLYETHYLENE, ENGAGE 8180	PE
	1	14	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	15	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	16	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	17	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	18	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	19	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	20	MP1586.DX BEACH SHOE CHINA #2	others
	1	21	MP0199.DX POLYPROPYLENE, MOPLEN EPQ 30 RF	PP
	1	22	MP0200.DX POLYPROPYLENE, STAMYLAN P 512MN10	PP
	1	23	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	24	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	1	25	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	1	26	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	1	27	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	28	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	29	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	30	MP0200.DX POLYPROPYLENE, STAMYLAN P 512MN10	PP
	1	31	MP1587.DX BEACH SHOE CHINA #3	others
	1	32	MP0377.DX ELVAX 460, COPOLYMER EVA TYPE	others
	1	33	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	1	34	MP0769.DX COLOR MASTERBATCH POLYPROPYLENE + WHITE PIGMENT	PP
	1	35	MP0199.DX POLYPROPYLENE, MOPLEN EPQ 30 RF	PP
	2	1	MP0199.DX POLYPROPYLENE, MOPLEN EPQ 30 RF	PP
	2	2	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	3	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	2	4	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	2	5	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	2	6	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP

	2	7	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	2	8	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	2	9	MP1586.DX BEACH SHOE CHINA #2	others
	2	10	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	2	11	MP1614.DX WINDOW SEAL BLACK	others
	2	12	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	2	13	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	14	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	15	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	2	16	MP1587.DX BEACH SHOE CHINA #3	others
	2	17	MP0195.DX POLYPROPYLENE, ATACTIC #1	PP
	2	18	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	19	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	20	NIC08618.DX LEVAFLEX EP-390, POLYPROPYLENE BASED	PP
	2	21	MP0279.DX POLY(STYRENE:ETHYLACRYLATE)	others
	2	22	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	23	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	24	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	25	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	26	MP0365.DX POLY(ETHYLENE:PROPYLENE:DIENE) (50% ETHYLENE, 4% DIENE)	others
	2	27	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	28	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	29	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	30	MP1586.DX BEACH SHOE CHINA #2	others
	2	31	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	32	MP0574.DX PARAFFIN	others
	2	33	MP0200.DX POLYPROPYLENE, STAMYLAN P 512MN10	PP
	2	34	MP0365.DX POLY(ETHYLENE:PROPYLENE:DIENE) (50% ETHYLENE, 4% DIENE)	others
	2	35	MP0206.DX POLYSTYRENE HIGH IMPACT #3	others
	2	36	MP1614.DX WINDOW SEAL BLACK	others
	2	37	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	38	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	39	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	40	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE

	2	41	MP1586.DX BEACH SHOE CHINA #2	others
	2	42	MP0195.DX POLYPROPYLENE, ATACTIC #1	PP
	2	43	MP0195.DX POLYPROPYLENE, ATACTIC #1	PP
	2	44	MP0141.DX POLYETHYLENE LOW DENSITY	PE
	2	45	MP0144.DX POLYETHYLENE PLASTICIZED #1	PE
	2	46	MP0195.DX POLYPROPYLENE, ATACTIC #1	PP
	2	47	MP0196.DX POLYPROPYLENE, ATACTIC #2	PP
	2	48	MP0142.DX POLYETHYLENE MEDIUM DENSITY	PE
	2	49	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	2	50	MP0379.DX ESCORENE ULTRA FL00728, COPOLYMER EVA TYPE	others
	2	51	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	52	MP0143.DX POLYETHYLENE OXIDIZED	PE
	2	53	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	54	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	55	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	56	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	57	MP0144.DX POLYETHYLENE PLASTICIZED #1	PE
	2	58	MP0144.DX POLYETHYLENE PLASTICIZED #1	PE
	2	59	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	2	60	NIC14805.DX LINEAR ALPHA OLEFIN C 24-28	PE
	2	61	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	62	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	63	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	64	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	65	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	66	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	67	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	68	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	69	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	3	1	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	3	2	NIC12106.DX BYK 031	others
	3	3	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP

	3	4	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	3	5	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	3	6	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	3	7	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	3	8	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	3	9	MP0365.DX POLY(ETHYLENE:PROPYLENE:DIENE) (50% ETHYLENE, 4% DIENE)	others
	3	10	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	4	1	NIC12154.DX BYK 035	others
	4	2	MP0148.DX POLYETHYLENE, ENGAGE 8180	PE
	4	3	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	4	4	MP0388.DX POLY(PROPYLENE:ETHYLENE), NOVOLEN 2900NC	others
	4	5	MP0200.DX POLYPROPYLENE, STAMYLAN P 512MN10	PP
	4	6	MP0144.DX POLYETHYLENE PLASTICIZED #1	PE
Tung Lung	2	1	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	2	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	3	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	3	1	MP0203.DX POLYPROPYLENE+VISTALON 719, 1:1	PP
Cheung Chau	2	1	MP0148.DX POLYETHYLENE, ENGAGE 8180	PE
	2	2	MP0148.DX POLYETHYLENE, ENGAGE 8180	PE
	2	3	MP0141.DX POLYETHYLENE LOW DENSITY	LDPE
	2	4	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	2	5	MP0144.DX POLYETHYLENE PLASTICIZED #1	PE
	2	6	MP0148.DX POLYETHYLENE, ENGAGE 8180	PE
	3	1	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP

	3	2	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	4	1	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	4	2	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	4	3	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
Tsing Lung Garden	1	1	MP0141.DX POLYETHYLENE LOW DENSITY	LDPE
	1	2	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	1	3	MP0385.DX MIRAVITHEN D23EA, COPOLYMER EVA TYPE	others
	1	4	MP0389.DX POLYPROPYLENE+POLY(ETHYLENE:PROPYLENE)	PP
	2	1	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	3	1	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	3	2	MP0145.DX POLYETHYLENE PLASTICIZED #2	PE
	3	3	NIC08677.DX POLYPHENYLENE OXIDE, NORYL	others
	3	4	MP0365.DX POLY(ETHYLENE:PROPYLENE:DIENE) (50% ETHYLENE, 4% DIENE)	others
	4	1	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	4	2	MP0193.DX POLYPROPYLENE WITH 20% TALC	PP
	4	3	MP0377.DX ELVAX 460, COPOLYMER EVA TYPE	others

Appendix H: Tung Lung Island Explanation

For the purpose of analysis of the data in this paper, sample four from Tung Lung was excluded from the calculations. This appendix is an explanation as to why sample four was excluded.

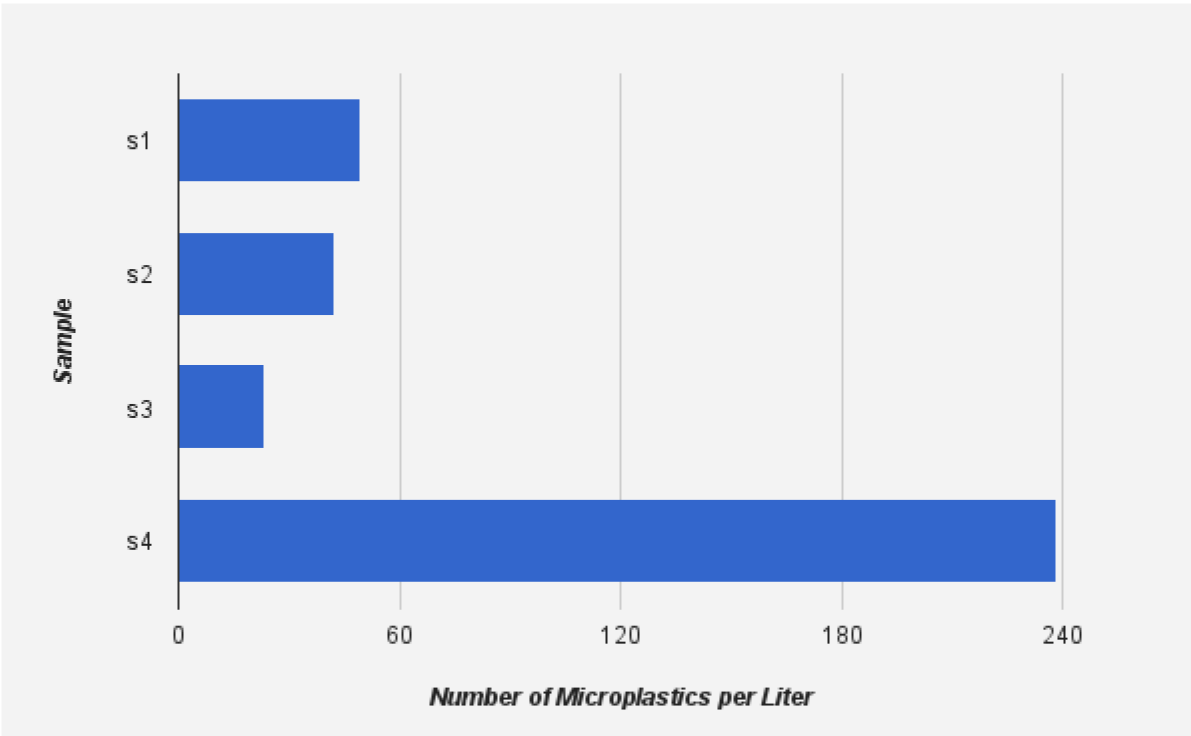
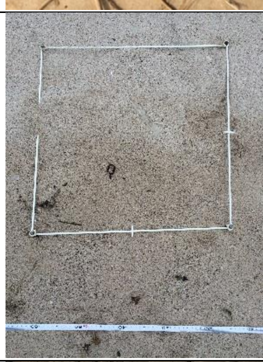


Figure H.1:Difference in Microplastic Quantity Between Samples

Sample four from Tung Lung was an outlier. As seen in Figure I.1, the number of microplastics per liter in sample 4 are drastically different than that of the other three samples. One possible explanation for this is the location that sample 4 was located. Sample 4 was located behind a large rock on the beach, as seen in Figure H.2. It is possible that the rock trapped more microplastics, keeping them in the sediment located above the rock. This could be the reason why sample four had 238.6 microplastics per liter while samples one through three had 49.6, 42.2, and 23.1 microplastics per liter respectively.

Figure H.2: Sample Four Located Behind Rock

Appendix I: Beach Quadrat Pictures

Beach	Sample 1	Sample 2	Sample 3	Sample 4
San Shek Wan	No Photo Available			
Fan Lau Tung Wan				
Tung Lung Island				
Long Ke Wan				

Appendix J: Beach Pictures

Figure J.1: Ap Tsai Hang

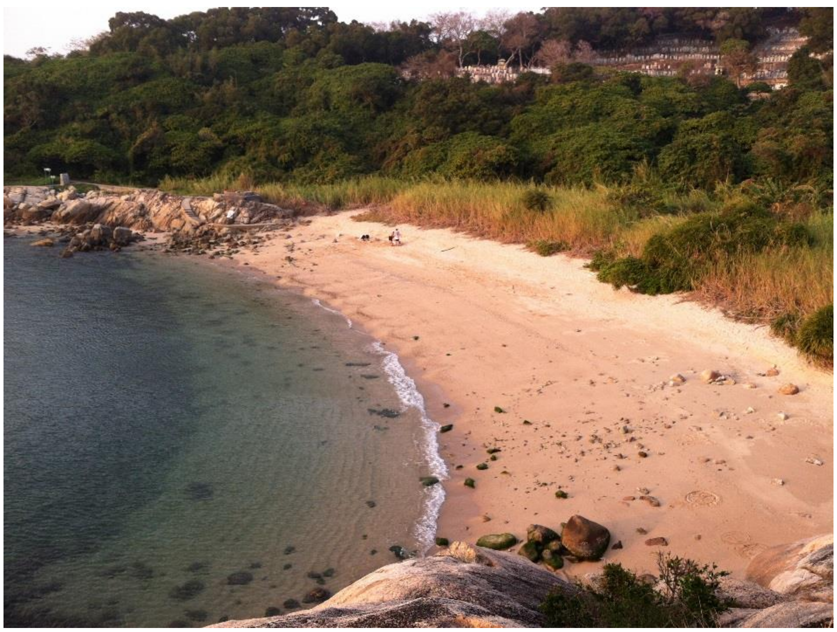


Figure J.2: Cheung Chau

Figure J.3: Fan Lau Tung Wan

Figure J.4: Long Ke Wan

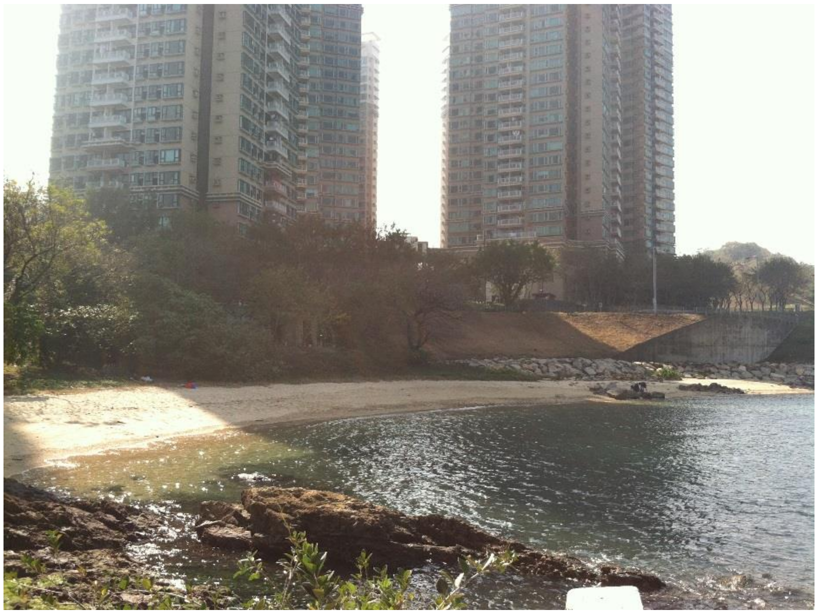


Figure J.5: Ma Wan

Figure J.6: Pak Shui Wun

Figure J.7: San Shek Wan

Figure J.8: Shek Pai Wan

Figure J.9: Tsing Lung Garden

Figure J.10: Tung Lung Chau