ABUNDANCE AND DISTRIBUTION OF PLASTIC DEBRIS IN BEACH SEDIMENT AND SEAWATER OF THE NORTHERN STRAITS OF MALACCA

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ABUNDANCE AND DISTRIBUTION OF PLASTIC DEBRIS IN BEACH SEDIMENT AND SEAWATER OF THE NORTHERN STRAITS OF MALACCA

by

LIM ER VIN

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LIST OF SYMBOLS

%	percent/percentage
>	more than
<	less than
–	substract
=	equal to
±	plus minus
°C	degree Celsius
°	degree
®	trademark

LIST OF ABBREVIATIONS

kg	kilogram
µm	micrometer
m^2	squared metre
cm	centimeter
mm	millimetre
n	number
g	gram
UV	ultraviolet
mL	millilitre
L	litre
J	Joules
m^3	cubic metre
d	density
km	kilometre
cm^{-1}	per centimetre
St.	Station
MPMA	Malaysian Plastics Manufacturers Association
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
MSFD	Marine Strategy Framework Directive
FAO	Food and Agriculture Organization

LIST OF ABBREVIATIONS

PE	Polyethylene
PP	Polypropylene
EPS	Expanded Polystyrene
PA	Polyamide or Nylon
PS	Polystyrene
PVC	Polyvinyl chloride
PET	Poly(ethylene terephthalate)
PMA	Polymethylacrylate
PMMA (Acrylic)	Polymethylmethacrylate
PU	Polyurethane
PC	Polycarbonate
PVA	Polyvinyl alcoho
POM	Polyoximethylene
PTFE	Polytetrafluoroethylene
WWF	World Wide Fund
ICC	International Coastal Clean Up
NOAA	National Oceanic and Atmosphere Administration
UK	United Kingdom
ALDFG	abandoned, lost, or otherwise discarded fishing gears
MPW	mismanaged plastics waste
M_E	plastic emission

LIST OF ABBREVIATIONS

POP	persistent organic pollutants
BaP	Benzo[a]pyrene
MESTECC	Ministry of Energy, Science, Technology, Environment & Climate Change
MPA	marine protected area
CEMACS	Centre for Marine and Coastal Studies
NMEMC	National Marine Environmental Monitoring Centre
USM	Universiti Sains Malaysia
BCI	beach cleanliness index
BC	beach cleaning frequency
AB	availability of waste bin
AA	occurrence of anthropogenic activities
NF	occurrence of natural factor
NSWMD	National Solid Waste Management Department
IUCN	International Union for Conservation of Nature
St.	sampling station
Inc	incorporated
GPS	global positioning system
fdH_2O	filtered distilled water
M	molar
Fe (II)	Ferum (II)
NaCl	Sodium chloride

LIST OF ABBREVIATIONS

m^1	concentration of original solution of solution needed
v^1	volume of original solution needed
m^2	final concentration of the solution
v^2	final volume of the solution needed
UTV	upward terminal velocity
ANOVA	analysis of variance
HSD	honestly significant different

KELIMPAHAN DAN TABURAN SERPIHAN PLASTIK DALAM SEDIMEN PANTAI DAN AIR LAUT PERAIRAN UTARA SELAT MELAKA

ABSTRAK

Plastik menyumbang sebanyak 60% - 80% daripada sampah marin di seluruh dunia. Pada tahun 2021, Malaysia adalah antara negara pencemar plastic yang tertinggi (tempat ke-3 teratas) di dunia. Untuk mencapai pengurusan plastik yang lebih baik, data yang lebih terperinci mengenai status pencemaran plastik di Malaysia diperlukan bagi pelaksanaan Pelan Hala Tuju Malaysia Ke Arah Sifar Penggunaan Plastik Sekali Guna 2018-2030 dan Pelan Hala Tuju Malaysia Kelestarian Plastik 2021-2030. Kajian ini bertujuan untuk merekodkan kelimpahan dan taburan (1) sisa plastik makro- (> 2.5 cm) dan meso- (0.5 - 2.5 cm) di beberapa kawasan pantai, dan (2) sisa plastik mikro- (< 0.5 cm) di permukaan laut terpilih di bahagian utara perairan Selat Melaka. Semua tapak kajian adalah pantai awam, iaiu Pulau Songsong, Teluk Aling, dan Pulau Gazumbo, manakala Pulau Lembu adalah Kawasan Perlindungan Taman Laut (MPA). Sisa-sisa plastik yang dikumpul dari transek yang ditentukan di pantai telah dikategorikan mengikut bentuk dan juga segmen pasaran ekonomi di Malaysia. Kebanyakan sisa plastik makro (53 - 75% daripada jumlah berat kesulurahan; $p=0.0277$, $\alpha<0.05$) dan meso (53 - 80% daripada jumlah bilangan keseluruhan) terkumpul di kawasan pesisir belakang. Pantai awam seperti Pulau Gazumbo (7.32 ± 9.90 g/m^2) dan Pulau Songsong (9.77 ± 11.35 g/m^2) mencatatkan purata jisim makroplastik tertinggi bagi setiap meter persegi mengikut zon. Teluk Aling pula mencatatkan purata jisim makroplastik terendah bagi setiap meter persegi mengikut zon (3.58 ± 3.21 g/m^2) tetapi tertinggi dalam purata bilangan mesoplastik bagi setiap meter persegi (0.56 ± 0.60 item/m^2). Purata bilangan makroplastik tertinggi bagi setiap meter persegi mengikut zon ditemui

di Teluk Aling (1.10 ± 1.29 item/m^2) dan Pulau Lembu (1.19 ± 0.30 item/m^2), manakala yang terendah ditemui di Pulau Gazumbo (0.44 ± 0.61 item/m^2). Kebanyakan makroplastik yang ditemui adalah plastik pembungkus seperti botol plastik, bekas dan bekas polistiren. Walaupun Pulau Lembu merupakan Kawasan MPA, purata makroplastik yang ditemui agak tinggi iaitu 7.17 ± 3.45 g/m^2 dan 1.19 ± 0.30 item/m^2). Berdasarkan analisis Indeks Kebersihan Pantai (BCI), Pulau Gazumbo (−3.99) adalah tapak kajian yang paling kotor, diikuti oleh Pulau Lembu (−2.92) dan Pulau Songsong (−2.85), manakala Teluk Aling (−1.63) adalah tapak yang paling bersih, dan ini adalah selaras dengan jisim sisa-sisa plastik makro yang ditemui di Kawasan tersebut. Tahap kebersihan di kesemua tapak kajian tidak memuaskan kerana nilai indeks yang berada di bawah sifar (0). Kebersihan di Kawasan ini mungkin terjejas kerana bilangan ketersediaan tong sampah yang rendah dan juga activiti pembersihan pantai tidak dijalankan dengan kerap, selain daripada kesan aktiviti manusia dan faktor semula jadi yang tidak dapat dikawal. Selain itu, analisa mikroplastik di dalam air dari permukaan laut juga telah dilakukan di barat laut Pulau Pinang, berhampiran pantai Teluk Aling dengan menggunakan jaring neuston (330 µm saiz mata pukat). Purata 0.31 ± 0.30 item/m^3 mikroplastik ditemui di kawasan kajian tersebut. Tren peningkatan dalam bilangan mikroplastik diperhatikan dari kawasan berhampiran pantai menuju ke kawasan laut lepas. Kebanyakan mikroplastik yang ditemui adalah di dalam bentuk serpihan (81.32%), dari polimer jenis polipropilena (25.42%), alkyd (23.16%) dan polietilena (20.62%), dan berwarna separa legap (42.65%). Tren peningkatan dalam bilangan mikroplastik ke arah saiz yang lebih kecil (0.1 mm – 5.0 mm) juga telah diperhatikan. Mikroplastik ini mungkin terhasil daripada penguraian sisa makroplastik dan mesoplastik yang ditemui di pantai Teluk Aling, di mana penggunaan plastic di dalam aktiviti harian dijalankan. Penguatkuasaan dasar dan penyelidikan mengenai alternatif yang lestari serta pengurusan harus fokus pada plastik pembungkusan dan pertanian untuk mengurangkan serpihan plastiknya yang besar dan kecil.

ABUNDANCE AND DISTRIBUTION OF PLASTIC DEBRIS IN BEACH SEDIMENT AND SEAWATER OF THE NORTHERN STRAITS OF MALACCA

ABSTRACT

Plastics account for 60% - 80% of marine debris worldwide and Malaysia is the top three plastic polluter country in the world through river pathway to marine environment in 2021. A comprehensive database of the status of plastic pollution in Malaysia is needed to help in achieving better management of plastics, such as the plan in Malaysia's Roadmap toward Zero-Single-Use Plastics 2018-2030 and Plastics Sustainability Roadmap 2021-2030. This study aims to record the abundance of macro- (> 2.5 cm) and meso-plastic (0.5 – 2.5 cm) debris at selected beaches and microplastics (<0.5 cm) at selected sea surface in the northern Straits of Malacca. All study sites are publicly accessible beaches (Pulau Songsong, Teluk Aling, and Pulau Gazumbo) except Pulau Lembu which is in a Marine Protected Area (MPA). The debris was collected from predetermined transects on the beach and categorised according to its size, form and economic market segments in Malaysia. Most of the macro- (53 – 75% of total mass; $p=0.0277$, $\alpha<0.05$) and meso-plastics (53 – 80% of the total number) were accumulated at the backshore area. Public beaches such as Pulau Gazumbo (7.32 ± 9.90 g/m^2) and Pulau Songsong (9.77 ± 11.35 g/m^2) recorded the highest mass of macroplastics per area by zone. Teluk Aling recorded the lowest mass of macroplastics per area by zone (3.58 ± 3.21 g/m^2) but the highest in mesoplastic (0.56 ± 0.60 $item/m^2$). By number, the highest number of macroplastics per area by zone was found at Teluk Aling (1.10 ± 1.29 $item/m^2$) and Pulau Lembu (1.19 ± 0.30 $item/m^2$), while the lowest was found at Pulau Gazumbo (0.44 ± 0.61 $item/m^2$). Most of the macroplastics found were packaging plastics such as plastic bottles, containers and polystyrene foam debris. Although Pulau Lembu is an MPA, the amount of macroplastics found was relatively high (7.17 ± 3.45 g/m^2, 1.19 ± 0.30 item/m^2). Based on beach cleanliness index, Pulau Gazumbo (−3.99) was the dirtiest site, followed by Pulau Lembu (−2.92) and Pulau Songsong (−2.85), while Teluk Aling (−1.63) was the cleanest site, which can explain the mass of macroplastic debris found relatively. However, all the study sites' cleanliness may not be ideal, as the indexes were less than zero. The cleanliness could be compromised by the low availability of waste bin and insufficient frequency of beach cleaning, in addition to the effect of anthropogenic activities and uncontrollable natural factors. Microplastic (< 0.5 cm) at the sea surface of northwest Penang, near Teluk Aling beach was also investigated by towing with neuston net (330 µm mesh size). Average of 0.31 ± 0.30 item/m^3 of microplastics were found at the study site. An increasing trend of microplastics was observed towards an offshore point. Fragment form of microplastics (81.32%), polypropylene (25.42%), alkyd (23.16%), and polyethylene (20.62%) polymer microplastics, and semi-transparent (42.65%) microplastics were found the most. An increasing trend of microplastics towards the smaller size was observed. The microplastics maybe fragmented from the macroplastics and mesoplastics found at the beach of Teluk Aling, and fishing, recreational, and daily activities nearby using plastic. Policy enforcement and research on sustainable alternatives and management should focus on packaging and agricultural plastics to reduce its debris and its smaller counterparts.

CHAPTER 1

INTRODUCTION

1.1 Overview

When small plastic fragments at the sea surface of western Sargasso Sea were reported by Carpenter and Smith in 1972, the issue of plastics gained the world's attention. Earlier report by Buchanan (1971) who reported synthetic fibres and at the North Sea fragments among the plankton samples was came to light after that. The first record of the plastic items ingested by albatrosses in the late 1960, which indicated the impact of plastics that maybe the reason of chicks' death was also gained attention along with other earlier reports of association of plastics with marine animals such as birds (Harper and Fowler, 1987).

Beach litter also came under increased scrutiny. Scott (1972) examined a few inaccessible beaches that have only small number of visitors and hypothesized that most litter came from marine-based sources including fishing and shipping. Since then, due to the impacts of the plastic debris and the potential impact of small plastics, more and more studies have been carried out to determine the abundance and distribution and the sources of marine debris including plastics and microplastics especially at the beach and sea (GESAMP, 2015). Subsequently, freshwater environments such as river and lake and other habitat were also started to gain attention (Khan, 2020).

Plastics accounted for 60 to 80 percent (%) of the marine debris (Andrady et al., 2011). Many studies also found plastics are ubiquitous and invaded many parts of the planet, including remote polar regions, atmosphere, mountain, and deep sea (Chen et al., 2020; Mishar et al., 2021; Peng et al., 2018). In light of this, many studies were also done to understand the fate and transport of the pollution, such as vertical migration, biofouling, the degradation mechanisms from macroplastics to microplastics, and the sorption and desorption of pollutants such as persistant organic pollutant, as examples (Botterell et al., 2019; Kaiser et al., 2017; Song et al., 2017; Ziccardi et al., 2016). Through simulation and modelling, Studies on prediction about the transport of plastics based on probability and factors such as distance to sources, population data, and others were also done to understand the possible distribution pattern of plastics and microplastics, the possible pathway, such as rivers, as well as the estimated amount of plastic debris that could be mismanaged and reached the ocean around the world (Jambeck et al., 2015; Lebreton et al, 2017; Meijer et al., 2021; Van der Mheen et al.,2020).

All urgency to studying subjects around plastic pollution raised when there are understanding of the impacts of different sizes of plastics, such as macroplastics (>2.5 cm), mesoplastics (0.5 – 2.5 cm), and microplastics (<0.5 cm) on wide range of organisms at different habitat and trophic transfer, which could be affecting human in the future (Foley et al., 2018; Wright et al., 2013).

In light of this and given the vast distribution of plastics pollution, selected beaches and sea surface area were studied to collect the data of plastics pollution and contribute to the Malaysia's database of plastic pollution especially in the northern Straits of Malacca. Around 67% of global waste ended up on coastlines (Lebreton et al., 2019), where the waste can be originated from many sources, such as the wastes that entered the ocean. Beach is also one of the suggested final destinations of plastic waste besides the seafloor (Onink et al., 2021; Ryan, 2015). In a simulation of plastic particle, Van der Mheen et al. (2020) showed that 100% of the plastic particle beached at the north Indian Ocean coastline, including the northern Straits of Malacca within three years, while in long term 90% beached at either north or south of the Indian Ocean. Furthermore, other land-based sources such as intentional or unintentional littering by beachgoers could also contribute to the load of debris at the beach. Therefore, combining various sources and natural factors such as winds and currents, beach became a hotspot of plastic debris deposition.

Apart from rivers, the abundance and distribution of microplastics at the sea surface surrounding Malaysia especially at northern Straits of Malacca is poorly documented. This is important to determine the plastic debris that enter the ocean from land-based or marine-based sources. The plastic debris at the sea surface can sink to the bottom and affecting the habitat at the seafloor through biofouling, marine aggregates, vertical migration of planktons, and other mechanisms. This could eventually affect the benthic communities (Courtene-Jones, 2017; Kaiser et al., 2017; Lamb et al., 2018; Reichert et al., 2018). Furthermore, different coastal dynamics such as backwashing of the swash wave near the shore can also backwash the plastic debris including microplastics from the beach back to the ocean, changing the location of the debris (Zhang et al., 2017a). These show the dynamic of the ocean in mediating the transport of plastic debris.

1.2 Problem statement

More baseline data is still needed in contributing to the database of status of plastics pollution in different habitat of Malaysia, such as beaches and sea surface. Few studies have investigated the sea surface conditions in the Straits of Malacca, highlighting the growing concern of plastic pollution in this region. One study focused on the northern Straits, covering areas such as the coastal seas of Balik Pulau, Seberang Perai, Penaga in Penang, and Kuala Muda in Kedah (Tan & Mohd Zanuri, 2023). The other two studies were conducted in the southern Straits, specifically at Port Dickson and the coastal sea near the Langat River (Zainuddin et al., 2022; Anuar et al., 2023).

Other studies were mostly conducted at the South China Sea at the east coast of Malaysia. The data will help in providing a comprehensive status of the pollution in Malaysia, along with other knowledge on the effect of anthropogenic activities, possible sources, type, the possible mechanisms of transport, and distribution of the plastic pollution. Especially the beach of Pulau Songsong, Pulau Lembu, and Pulau Gazumbo, which the status of plastic pollution is still lacking, the knowledge gap needs to be filled to help in risk assessment and improving the policy and law as well as mitigation strategy, such as the management of plastic production and waste and the education towards the society (Fauziah et al., 2021). Beach Cleanliness Index (Aminuddin. 2019) was used to assess the cleanliness of selected study sites, serving as an indicator of how effectively each beach is maintained and managed. This index will then be analysed with the actual data on the abundance and distribution of plastic debris collected during this study for further analysis. This can align with the objectives of the Roadmap towards Single-use Plastics by 2030 in 2018 and Plastic Sustainability Roadmap in 2021, such as deciding the problematic single-use plastics to be phased out and more sustainable plastic products (Ministry of Energy, Science, Technology, Environment & Climate Change (MESTECC), 2018); "Malaysia Plastics Sustainability Roadmap 2021-2030 launched", 2021).

Overall, this study, along with similar research, not only establishes a baseline for future comparisons regarding pollution levels but also assesses the potential environmental and ecological risks associated with plastic debris. By identifying the types and sources of debris present at the study sites, the findings can provide valuable insights for authorities and policymakers to improve plastic waste management strategies and raise public awareness about the environmental impact of plastic pollution.

1.3 Objectives of the study

This study can provide baseline data of status of macroplastics, mesoplastics, and microplastics pollution for the selected study sites. In future study on the same study sites, the data obtained from this study can be a reference for future assessment, which can help in determining whether our remedy and prevention now are useful when comparing the data now and future.

The objectives of this study are:

1. To determine the beach cleanliness index of Pulau Lembu, Pulau Songsong, Teluk Aling, and Pulau Gazumbo in the northern Straits of Malacca.

2. To evaluate the presence, abundance, distribution, and type of macroplastics and mesoplastics at the selected beaches in the northern Straits of Malacca.

3. To evaluate the presence, abundance, distribution, and type of microplastics at the sea surface of northwest of Penang in the northern Straits of Malacca.

CHAPTER 2

LITERATURE REVIEW

2.1 Plastics and plastics pollution

Plastics are considered as marine debris. Marine debris is defined as any persistent solid material that is made or processed and intentionally or unintentionally, directly or indirectly disposed or abandoned in the marine environment (National Ocean Service, 2018). Single event of natural disaster could bring large amount of marine debris. For instance, a large amount of marine debris estimated 5 million tons was washed by the tsunami caused by the Tohoku earthquake in Japan to the Pacific ocean in 2011 (Ministry of Environment, Japan, 2012; Murray et al., 2018). Marine debris can also present in a large scale of body, such as the famous Great Pacific Garbage Patch, in the North Pacific Ocean between North America and Japan. It comprised of subtropical convergence zone, Western Garbage Patch and Eastern Garbage Patch (National Geographic, 2019). Most debris found at the garbage patch are plastics with abandoned fishing gears accounting for 46% of the 79,000 tons of plastics. More worrying is most of the debris are microplastics, accounting for 94% of 1.8 trillion pieces of plastics where the debris are trapped within a rotating body of water in a cyclone-like fashion and hence forming the garbage patch (Lebreton et al., 2018). In the recent International Coastal Cleanup, the top 10 marine debris are all plastics, with cigarette butts being the top one and other plastics such as food wrappers, straws, cutlery, plastic beverage bottles, caps, plastics bags and others. The intriguing data is that the small plastics, which are defined as less than 2.5 cm has higher number of item found than the sum of the number of top 10 items of plastics listed (Ocean Conservancy, 2019). This shows the seriousness of plastics pollution issues apart from marine debris as it can impact the environment and the biota living with it including human.

Plastics are made through the process of polymerization and polycondensation of smaller monomer, which are small hydrocarbon chain made from distillation of crude oil into a smaller fraction of hydrocarbon chain (PlasticsEurope, 2019). The term plastics derived from the word "Plastikos", which mean fit for moulding and due to this and other benefits such as lightweight, durable, cheap, and bioinertness for many industries such as packaging, construction, household, automotive, energy and others are using plastics as the material. The high demand leads to high global production of fossil fuel-based plastics resin from 2 million tons in 1950 to 402.4 million tons in 2021 as shown in Figure 2.1 since the first fully synthetic plastics, "bakelite" was invented in 1907 (Geyer et al., 2017; Plastic Europe, 2022).

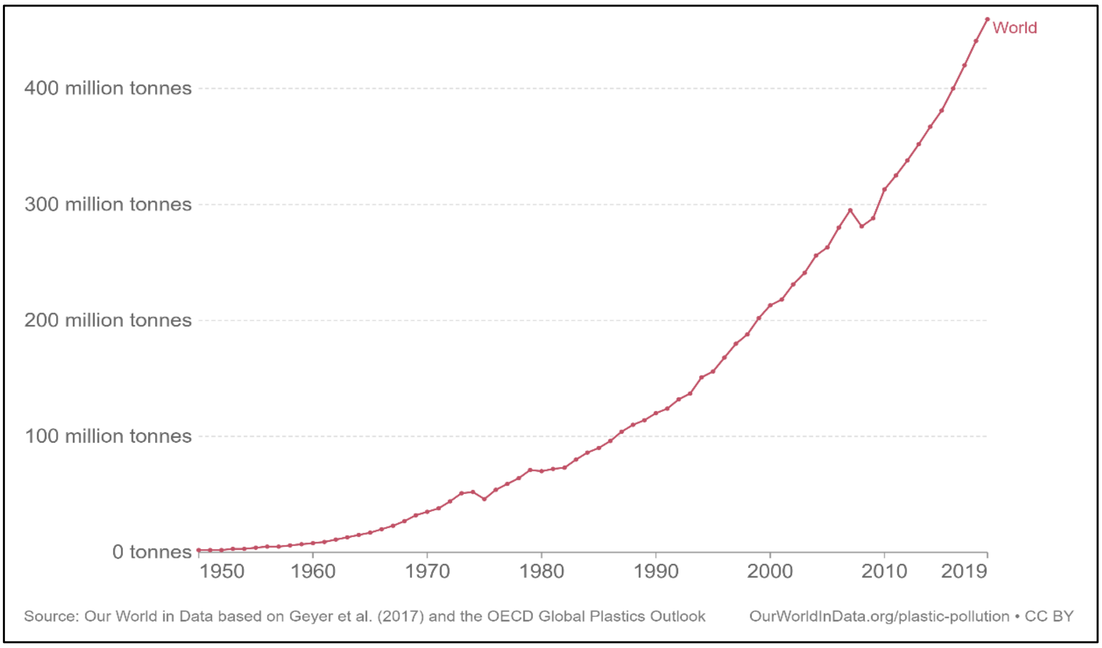

Figure 2.1 Global plastics production from 1950 to 2019 (tonnes) (Retrieved from Geyer et al. (2017); Plastic Europe, 2022; Ritchie & Roser (2022)).

By region, Asia and Africa contributed the most mismanaged plastic waste, with 64.56% and 22.16% of the global mismanaged plastic waste. For the waste entering the ocean, Asia contributed 80.99% while Africa contributed 7.99% (Ritchie & Roser, 2022).

To date, many types of plastics were invented with different properties and each has its unique strength compared to each other. The different types of plastic resin, its application and specific gravity are tabulated in Table 2.1. Different types of plastic and its advantages have made plastics ventured into various industries as shown in Figure 2.2, where packaging industries stand as the highest user of plastics. In Malaysia, packaging also occupied 48% of the share of the plastics market in 2018, the highest among electrical and electronic, household, automotive, agriculture and others (Malaysian Plastics Manufacturers Association (MPMA) (2019). The large plastic industry would contribute to plastic pollution if its product is mismanaged. Until 2015, a total of 8300 million tons of virgin plastics have been produced. Only 9%, which is 600 million tons of 6300 million tons of plastic waste generated had been recycled. The other 12% were incinerated while the remaining 79% were discarded in the landfill or other natural environment (Geyer et al., 2017).

Table 2.1 Different types of plastic resin, its potential products, and specific gravity (Azo Materials, 2001; Baker et al.,2012; AcmePlastics.com, American Chemistry Council, n.d.; 2018; GESAMP, 2015; Massarelli et al., 2021;MSFD, 2013; Kiedzierski et al., 2017; Pence, 2009; SpecialChem, n.d.; The Plastic People 2018; Thomasnet, n.d.; Turner, 2021).

Type of resin	**Application**	**Specific gravity**
Polyethylene (PE)	Plastic bags, storage containers	0.91–0.96
Polypropylene (PP)	Rope, bottle caps, gear, strapping	0.90–0.92
Expanded Polystyrene (EPS)	Cool boxes, floats, cups	0.01–1.05
Polyamide or Nylon (PA)	Fishing nets, rope	1.02–1.15
Polystyrene (PS)	Utensils, containers	1.04–1.10
Polyvinyl chloride (PVC)	Film, pipe, containers	1.16–1.58
Poly(ethylene terephthalate) (PET)	Bottles, strapping	1.34–1.45
Polyester resin + glass fibre	Textiles, boats	>1.35
Alkyd	Paint binder	1.24–2.10
Cellulose Acetate	Cigarette filters	1.22–1.24
Polymethylacrylate (PMA)	Sheet for laminated glass, lubricant addictive	1.17–1.20
Polymethylmethacrylate (PMMA) (Acrylic)	Medical manifold, windshield, screen display, solar devices	1.09–1.20
Polyurethane (PU)	PU foam, carpet underlay, cushion, apparel	1.20
Polycarbonate	Safety goggle, surgical instrument, skylight	1.20–1.22
Polyvinyl alcohol (PVA)	Food film, hydrogel for contact lens lubricants and wound dressing	1.19−1.31
Polyoximethylene (POM)	Plumbing fittings, medical devices, automotive part, gears, bearing.	1.41−1.61
Polytetrafluoroethylene (PTFE)	Non-stick utensil	1.70–2.28

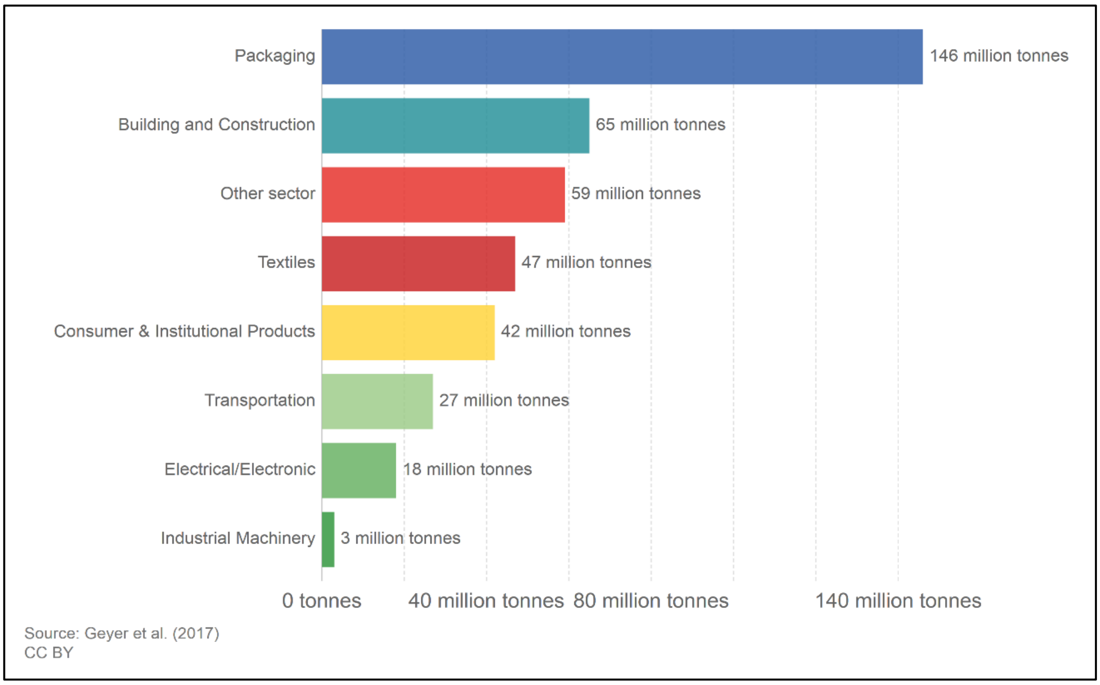

Figure 2.2 Primary plastic production categorized by industrial sector in 2015 (tonnes per year) (Retrieved from Geyer et al., 2017; Ritchie and Roser (2022)).

2.2 Status of plastics in Malaysia

Based on a study by Jambeck et al. (2015), Malaysia stands as the top 8 of the countries ranked by mass of mismanaged plastic waste (Jambeck et al., 2015). The waste generation rate in Malaysia is 1.52 kilogram (kg)/person/day, which is second to Sri Lanka and higher than China although China is the top country ranked by mass of mismanaged plastic waste by coastal population annually. Malaysia had coastal population of 22.9 million in 2010. With the waste generation rate and the fact that plastic waste occupied 13% of all wastes and 57% of it are mismanaged, this leads to an estimate of 0.94 million metric tons of mismanaged plastic waste/year, which weighted 2.9% of the total mismanaged plastic waste by all coastal populations of 192 countries studied in 2010. Through river discharge, Malaysia ranked top 3 in the world in 2021 in releasing mismanaged plastic waste to the ocean, with 105 rivers among the 1656 rivers contributing to 80% of the global emission of mismanaged plastic waste (Meijer et al., 2021). With an 9% emission rate river of the generated mismanaged plastic waste to the ocean, Malaysia releases 73,000 metric tons annually. In 2019, Malaysia had plastic waste occupied 20% of all the waste, second to food waste as the top waste of the country (Chu, 2019). China, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam contributed 60% of the 8 million tons of plastic enter the ocean every year (World Wide Fund (WWF), 2020) The number of mismanaged wastes may increase as it is predicted by 2025 the cumulative mismanaged plastic waste will be increased by an order of magnitude if the management of waste is not improving (Jambeck et al., 2015). The mismanaged plastic, either by littering or uncontained dumping, can be transported by natural factors such as wind, rain, and runoff, will become marine debris besides being deposited in other natural environment.

Table 2.2 shows the common plastic item used by Malaysian based on literature review. Figure 2.3 and Figure 2.4 show more data on other plastic items and plastic straws based on a specific survey by Ipsos (2019) and Hemananthani Sivanandam (2019), respectively. Variety of plastic packaging such as plastic bag and plastic straws are the most used items by Malaysians and 22% use plastic straws daily. Microplastics associated with personal care product as exfoliant were also used.

Table 2.2 Data of usage rate of common plastic items by Malaysian based on news reports, organization reports, and published journal articles.

Plastic Item	**Description**	**Reference**
Plastic resin	Based on the data of year 2014 to 2018, the resin consumption is 73 kg/person/year.	MPMA (2019)
Plastic packaging	The usage rate is 16.8 kg/person/year, which is the highest among six Asian countries analysed in the study.	Word Wide Fund Malaysia (WWF) (2020)
Plastic bag	On average, the usage rate is 8 bags per person per week	Jamain, M. K. I. (2019)
Plastic straw	The usage rate is 1 number/person/day based on conservative estimate that a person will receive a plastic straw along with the drink ordered.	Brown (2017)
Fabric	In 2018, 6.3% of 3.1 million tonnes of solid waste ended up in landfills were plastics, increased from 2.8% in 2012.	Chu (2019)
Microplastics in personal care products	199 million can be discharged annually based on the survey of Malaysian with 214 respondents, where six of 10 products used contain microplastics with size of 3 – 178 µm.	Praveena et al. (2018)

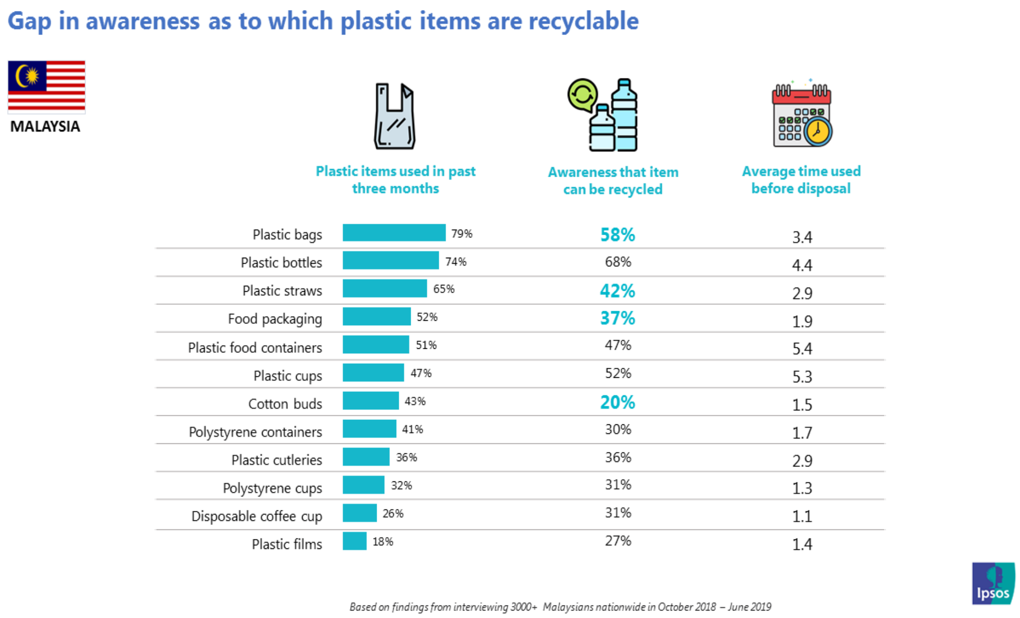

Figure 2.3 The data of plastic items used in the past three months before the survey, awareness of the recyclability of the item, and the average time used before disposal based on more 3000 respondents across Peninsular and east Malaysia (Ipsos, 2019).

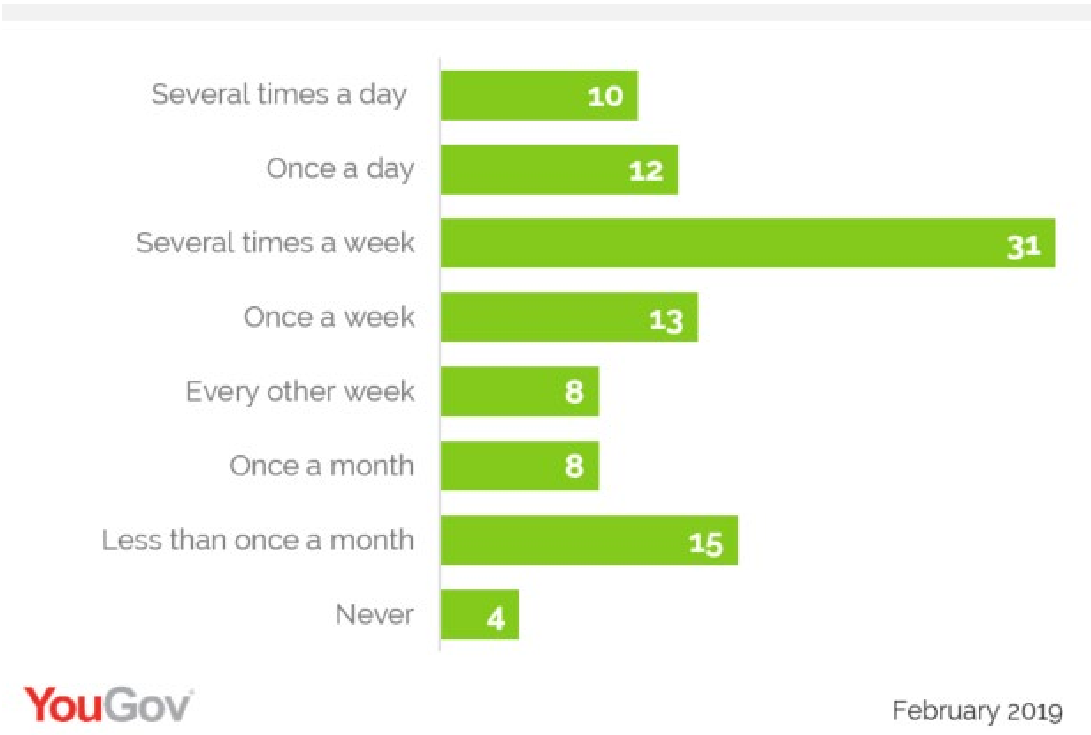

Figure 2.4 The frequency of using plastic straws among Malaysians (Sivanandam, 2019).

From the International Coastal Clean Up (ICC) in 2018, Malaysia has collected a total of 20,1097 items. All of the top 10 items were all compose of plastic items. Plastic beverage bottle was the most collected item with 50,699 in number, among the other items including cigarette butt, food wrappers, straws, plastic bags, and others. If the wastes mentioned in ICC report were not collected through this event, the wastes maybe transported back to the ocean or to other environment through storm and backwash. This is the same scenario to the consumed and end-of-life plastics items mentioned as a result of Table 2.2, Figure 2.3, and Figure 2.4, if the wastes are not managed well. This can affect not only the place where the wastes resided, but other places it travelled to as well due to the durability and persistence characteristic of plastic as mentioned in the section before (Corcoran et al., 2009).

Due to the plastic pollution issues, Malaysia's roadmap towards Zero Single-use plastics 2018-2030 (MESTECC, 2018) and Malaysia Plastics Sustainability

Roadmap ("Malaysia Plastics Sustainability Roadmap 2021-2030 launched", 2021) were introduced to address plastic pollution and create a circular economy by phasing out unsustainable products, developing sustainable alternatives to improve plastic recovery, recyclability, and reusability, as well as enhancing the pipeline of plastic usage and waste management. For the Roadmap towards Zero Single-use plastics, it suggested policy directions and responsibilities to each stakeholder, and phase by phase approach to eliminate single-use plastics, including the implementation and enforcement of "no plastic bag", "no straw by default", and pollution levy polices, research and development on sustainable alternative to plastics, expansion of the scope and increment in production of biodegradable plastics, and integration of plastics issues into education system, Malaysia Plastics Sustainability Roadmap emphasizes on developing sustainable products and better collection and sorting schemes, for example, by switching to mono-material to eliminate unnecessary plastics to ensure recyclability. It also provides possible frameworks on phasing out unsustainable products and reusing sustainable products to ensure material circularity. To support these roadmaps, baseline studies on plastics pollution surrounding Malaysia and other regions are needed to track our progress of alleviating plastic pollution issues.

Table 2.3. 2.4, and 2.5 grouped some examples of studies across Asia on abundance and distribution of marine debris, which included plastic debris. Different tables describe studies with a different unit of expression of plastic debris.

Table 2.3 Abundance and distribution of marine debris at beaches across Asia with focus on plastic debris (number(n)/metre squared (m^2) and gram (g)/m^2).

Country	Location	Proportion of plastics (% by n or weight)	Mean number or density (n/m^2)	Mean weight/density (g/m^2)	Common plastics debris found	Reference
China	Shantou	47.37 by number	0.0015	Overall-0.0001033	Plastic garbage, fishing gears	Zhou et al. (2011)
	Xiashan beach in Dapeng bay, Shenzhen	33.33 by number	0.02667			(Data retrieved from year 2010 of the study)
	South Lovers' Road, Zhuhai	77.78 by number	0.06222			
	Golden Sand Beach in Hailing Island, Yangjiang	83.33 by number	0.01			
	Anjing village, Maogang distract, Maoming	33.33 by number	0.02122			
	Qiaogong port, Beihai	36.36 by number	0.008			
	The moon bay, Sanniang Bay, Qinzhou	44.44 by number	0.04444			
	Dapingpo tour area, Fangchenggang	35.75 by number	0.03844			
	Sanya	90.91 by number	0.05			
	Rizhao (four beaches at the Southeast of Shandong province)	31.80 by number	0.08239	1.276	-	Zhou et al. (2015)

Table 2.3 (continued) Abundance and distribution of marine debris at beaches across Asia with focus on plastic debris (number(n)/metre squared (m^2) and gram (g)/m^2).

Country	Location	Proportion of plastics (% by n or weight)	Mean number or density (n/m^2)	Mean weight or density (g/m^2)	Common plastics debris found	Reference
Japan	8 Japanese beaches	Overall – 92.20 by number; 57.20% by weight	3.35	13.74	Fragments, resin pellets	Kusoi & Noda (2003)
Malaysia	Port Dickson – Teluk Kemang	73 by number; 57.55 by weight	0.153	0.644	Plastic bags, bottles, polystyrene and food wrappers	Agamuthu et al. (2012)
	Port Dickson – Pasir Panjang	94 by number; 63.08 by weight	0.827	20.408	Fishing gears, other plastics	
	Kuala Terengganu – Batu Burok	57 by number; 36.07 by weight	0.081	0.708	Plastic bags, bottles, polystyrene and food wrappers, household	
	Kuala Terengganu – Sebarang Takir	72 by number; 62.86 by weight	0.530	5.459	Household	
	Port Dickson – Teluk Kemang	80 by number; 49.40 by weight	0.210	1.021	Plastic bags, bottles, Polystyrene, household	Kamil et al. (2012)
	Port Dickson – Pasir Panjang	61 by number; 59.84 by weight	0.390	27.575		
	Port Dickson – Teluk Kemang	72.51 by number; 57.55 by weight	0.153	0.644	Plastic, paper, polystyrene	Kamil (2012)

Table 2.3 (continued) Abundance and distribution of marine debris at beaches across Asia with focus on plastic debris (number(n)/metre squared (m^2) and gram (g)/m^2).

Country	**Location**	**Proportion of plastics (% by n or weight)**	**Mean number or density (n/m^2)**	**Mean weight or density (g/m^2)**	**Common plastics debris found**	**Reference**
Malaysia	Port Dickson – Pasir Panjang	82.89 by number; 62.17 by weight	0.276	6.803	Bulky waste, plastic, polystyrene	Kamil (2012)
	Kuala Terengganu – Batu Burok	57.04 by number; 36.12 by weight	0.081	0.709	Plastic, food waste paper, polystyrene	
	Kuala Terengganu – Sebarang Takir	72.95 by number; 65.90 by weight	1.006	10.232	Plastic, polystyrene	
	Kota Kinabalu – Tanjung Aru	45.16 by number; 63.09 by weight	0.028	0.147	Plastic, polystyrene	
	Kota Kinabalu – Teluk Likas	98.80 by number; 80.61 by weight	1.073	4.017	Plastic, polystyrene	
	Johor – Minyak Beku	33 by number; 31 by weight	0.0192	0.1722	-	Kadir et al. (2015)
	Johor – Sungai Lurus	80 by number; 39 by weight	0.0380	0.0868	plastic bag, plastic bottle, polystyrene and sweet wrapper	

Table 2.3 (continued) Abundance and distribution of marine debris at beaches across Asia with focus on plastic debris (number(n)/metre squared (m^2) and gram (g)/m^2).

Country	**Location**	**Proportion of plastics (% by n or weight)**	**Mean number or density (n/m^2)**	**Mean weight or density (g/m^2)**	**Common plastics debris found**	**Reference**
Malaysia	Port Dickson – Saujana, Nelayan, Bagan Pinang, Cermin beaches	62 by weight (Hard and film plastic, foamed plastic)	-	Overall - 26.2570	Overall – Cigarette butts, foam fragments, Food wrappers, plastic cutleries, plastic fragments, bottle caps, food containers, beverage bottles, grocery bags	Chong & Kannan (2016)
	Tawau – Sebatik Island	55 by number	719	-	Plastic packages, plastic bottles, bottle caps, Styrofoam	Estim & Sudirman (2017)
	Malacca - Pulau Besar mainland	68.96 by number; 40.79 by weight	0.020	0.299	Hard plastic bottle, plastic bag, food wrappers	Aminuddin (2019)
	Malacca - Pulau Besar facing sea	56.00 by number; 44.73 by weight	0.028	0.314	Toiletries, detergent bottles, shampoo confectionary, plastic bags, convenience plastic food wrappings	

Table 2.3 (continued) Abundance and distribution of marine debris at beaches across Asia with focus on plastic debris (number(n)/metre squared (m^2) and gram (g)/m^2).

Country	Location	Proportion of plastics (% by n or weight)	Mean number or density (n/m^2)	Mean weight or density (g/m^2)	Common plastics debris found	Reference
Malaysia	Langkawi - Penarak Beach	90.24 by number; 73.60 by weight	0.037	0.092	Sweet wrappers, plastic bag, drinking bottles	Aminuddin (2019)
	Langkawi - Tengah Beach	20 by number; 56.88 by weight	0.031	0.335	Cigarette butt	
	Johor - Sibu Island mainland	97.44 by number; 84.66 by weight	0.076	0.817	Plastic bags, food wrappers, plastic bottles, straws, household detergent	
	Johor - Sibu Island facing sea	68.75 by number; 46.15 by weight	0.022	0.078	Polystyrene from disposable food containers, drink containers	
	Pulau Perhentian - Pinang Seribu	81.10 by number; 84.92 by weight	0.103	1.892	Plastic bottle, detergent bottles, polystyrene	
	Pulau Perhentian - Tanjung Butong	90.90 by number; 95.45 by weight	0.060	1.006	Hard plastic	
	Perlis - Kuala Perlis coastal area	81.67 by weight		53150	-	Odli et al. (2020)

Table 2.3 (continued) Abundance and distribution of marine debris at beaches across Asia with focus on plastic debris (number(n)/metre squared (m^2) and gram (g)/m^2).

Country	**Location**	**Proportion of plastics (% by n or weight)**	**Mean number or density (n/m^2)**	**Mean weight or density (g/m^2)**	**Common plastics debris found**	**Reference**
Taiwan	Jianzilu beach	79.87 by number	0.4904	-	Overall – Plastic fragments, bottle caps, fishery polystyrene, cigarette butts, rope, plastic bags	Kuo & Huang (2014)
	Longdong beach	83.79 by number	0.1525	-		
	Baishawan beach	96.63 by number	0.1285	-		
	Jiashawan beach	91.62 by number	0.1512	-		
	Tamsui fishing port	83.15 by number	0.1912	-		
	Aodi fishing port	92.06 by number	0.4327	-		

Table 2.4 Abundance and distribution of marine debris at beaches across Asia with focus on plastic debris (n/km and kg/km).

Country	**Location**	**Proportion of plastics (% by n)**	**Mean number or density (n/km)**	**Mean weight or density (kg/km)**	**Common plastics debris found**	**Reference**
Malaysia	Sabah – Tajung Aru	90.0 by number	796 (Top ten most numerous item)	15.2 (Top ten most numerous item)	Overall – Clear plastic bottles, food wrappers, plastic fragments, coloured plastic bottles, cups and other	Mobilik et al. (2013)
	Sabah – Kosuhoi	83.4 by number	800 (Top ten most numerous item)	18.7 (Top ten most numerous item)		

Table 2.4 (continued) Abundance and distribution of marine debris at beaches across Asia with focus on plastic debris (n/km and kg/km).

Country	Location	Proportion of plastics (% by n)	Mean number or density (n/km)	Mean weight or density (kg/km)	Common plastics debris found	Reference
Malaysia	Pandan Beach, Lundu	37.81 By number	537	-	Clear plastic bottle, cups, packaging, plastic fragment, plastic bottle caps, colour plastic bottle, food wrappers, cigarette lighters	Mobilik et al. (2014)
	Pasir Pandak Beach, Kuching	34.71 by number	1047	-		
	Temasyah Beach, Bintulu	33.97 by number	478	-		
	Tg. Lobang Beach, Miri	38.68 by number	588	-		
	Port Dickson – Saujana Beach	86.73 by number; 51.26 by weight	647 ± 360	18.8 ± 4.0	Packaging, plastic fragments, cups, plastic	Mobilik et al. (2015)
	Kuala Terengganu – Batu Rakit	88.60 by number; 55.69 by weight	723 ± 676	22.5 ± 6.9	Shopping bags, plastic food wrappers, clear plastic bottles	

Table 2.4 (continued) Abundance and distribution of marine debris at beaches across Asia with focus on plastic debris (n/km and kg/km).

Country	**Location**	**Proportion of plastics (% by n)**	**Mean number or density (n/km)**	**Mean weight or density (kg/km)**	**Common plastics debris found**	**Reference**
Malaysia	Kuching – Pasir Pandak	Overall – 69.58 by number	786	-	Overall – Clear plastic bottles, plastic fragments, plastic food wrappers, coloured plastic bottles and other	Mobilik et al. (2016)
	Bintulu – Temasya		555	-		
	Kota Kinabalu – Tangjung Aru		816	-		
	Sandakan – Kosuhoi		887	-		
	Klang – Saujana		487	-		

Table 2.5 Abundance and distribution of plastic debris at beaches across Asia according to sizes and specific intertidal zone (n/m^2 and g/m^2).

Country	Location	Zone	Size (cm)	Mean or density		Common plastics	Reference
				n/m^2	g/m^2		
China	Lovers Beach, Zhuhai	High tide line	0.5 – 2.0	156	-	Resin pellet, film, and granule for plastic production	Zhao et al. (2015)
			2.0 – 10.0	54	-		
	Black Sand Beach, Macau		0.5 – 2.0	2	-	-	
			2.0 – 10.0	11	-		
	Cheung Sha Beach, Hong Kong		0.5 – 2.0	0	-	-	
			2.0 – 10.0	2	-		
			> 10.0	1	-		
	Sanniang Bay, Qinzhou		0.5 – 2.0	5	-	-	Zhao et al. (2015)
			2.0 – 10.0	7	-		
	Silver Beach, Beihai		0.5 – 2.0	6	-	-	
			2.0- 10.0	13	-		
	Shiluokou, Weizhou island		0.5 – 2.0	57	-	Rope for Fishing industry	
			2.0- 10.0	124	-		
			> 10.0	3	-		
	Eight beaches along Guangdong coast, South China	High strandline	0.5 - 1 cm	163 ± 154	1.8672 ± 2.266	Styrofoam disposable food boxes, heat-insulated boxes, buoys	Fok et al. (2017)

Table 2.5 (continued) Abundance and distribution of plastic debris at beaches across Asia according to sizes and specific intertidal zone (n/m^2 and g/m^2).

Country	Location	Zone	Size (cm)	Mean or density		Common plastics	Reference
				n/m^2	g/m^2		
Iran	Nine Beaches along Persian Gulf, Bushehr	High tide line	> 0.5	949.17	-	Plastic discarded from fishing activity, visitors, sewage effluents	Dobaradaran et al. (2018)
Korea	Tae-An Shin-An Go-Heung Yeo-Su U1-Jin Gang-Reung	High tide line	> 2.5	0.516 1.264 0.544 0.288 0.224 0.172	6.588 30.788 7.604 3.52 0.216 0.304	Rope	Jang et al. (2014)
	12 beaches along west, south, and east coast	High strandline	> 2.5	1.0	0.58	Styrofoam buoy for aquaculture	Lee et al. (2015)
			0.5 - 2.5	37.7	0.65		
		Backshore and high strandline	> 2.5 0.5 - 2.5	3.9 897.3	- -		
	20 beaches along west, south, and east coast	Overall of backshore, middle line, and water edge	0.5 -2.5	13.2 ± 28.7 (0 – 44)	1.50 ± 4.0 (0-63.8)	Styrofoam packaging, styrofoam buoy for aquaculture, hard plastic for daily life	Lee et al. (2017)