ABUNDANCE OF MESOPLASTIC ON BEACHES, MICROBIAL PROFILES AND COASTAL WATER QUALITY ANALYSIS AT SELECTED ISLANDS IN PENINSULAR MALAYSIA

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FACULTY OF SCIENCE
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ABUNDANCE OF MESOPLASTIC ON BEACHES, MICROBIAL PROFILES AND COASTAL WATER QUALITY ANALYSIS AT SELECTED ISLANDS IN PENINSULAR MALAYSIA

ABSTRACT

The marine environments including beaches around the world are littered with numerous types of waste particularly plastics. In Malaysia, there is increasing evidence of an extensive abundance of small plastic debris in coastal areas. The appearance of these plastics in coastal water might affect the quality of water and microbial organisms in it. Thus, this study aims to determine the mesoplastics (1 – 30 mm) abundance at the shorelines, coastal water quality, and microbial profiling at eight selected beaches. Triplicate sediment samples were collected from the top layer until 5 cm depth using a 50 × 50 cm quadrat. The separation of sediments and plastics was done using the nest sieving method. The mesoplastics were sorted and categorized by type and quantity based on the beach attributes. The water quality and microbiological parameters were determined by collecting triplicate coastal water samples at 3 m and 6 m distance from the shoreline and analyzed using standard methods. A series of physicochemical parameters namely temperature, dissolved oxygen (DO), pH, conductivity, salinity, turbidity, biochemical oxygen demand (BOD), total suspended solids, total dissolved solids, nitrate, ammonium, phosphate, and silicate were determined in this research. The microbial formation in coastal waters was analyzed using total heterotopic bacterial count and total coliform as indicators. A total average of 2631 ± 367 items/m^2 of mesoplastics was collected from all the sampling sites. The highest mesoplastics were found at Pinang Seribu beach, Pulau Perhentian with 1112 ± 30 items/$m^{2,}$ and the lowest mesoplastics at Jeti beach, Pulau Besar with 20 ± 4 items/m^2. The study indicates that the occurrence of marine debris at these beaches was not mainly caused by anthropogenic activities in that area but also was brought in from the sea. This may due to the physical condition and the beach position which tends to trap the marine debris from offshore. In addition, the ranges for the physicochemical parameters were 24.7 – 35.6°C for temperature, 2.20 – 7.87 mg/L for DO, 5.50 - 8.53 for pH, 36878 - 5226 µS/cm for conductivity, 32.42 – 33.81 ppt for salinity, 18.5 – 19.89 NTU for turbidity, 52.0 mg/L – 89.5 mg/L for BOD, 25.0 – 160.0 mg/L for TSS, 12.4 - 31.65 mg/L for TDS, 42.4 – 943.6 µg/L for nitrate, 47.3 – 353.6 µg/L for ammonium, 56.6 – 673.2 µg/L for phosphate, and 32.2 - 99.1 µg/L for silicate. Based on the water quality analysis, as per MMWQS, all the beaches fall within the limit suitable for recreational use. The most polluted beach was Pinang Seribu with low DO and high BOD, and TDS levels. The least polluted beach was Jeti beach with high DO and low levels of BOD, phosphate, and silicate. Moreover, the heterotopic bacterial count at all the sampling sites varied from 0.75 – 3.08 × 10^8 CFU/mL. The total quantity of coliforms at overall beaches were in the span of 22.64 to 50.84 × 10^8 MPN/100 mL. The highest amount of bacteria was observed at Pasir Belakang Beach and the lowest number was at Tengah Beach. The presence of mesoplastics in sediments on the selected beaches does not influence microorganisms in the seawater at that coastal line.

Keywords: abundance, beaches, islands, mesoplastics, marine debris

PENINGKATAN MESOPLASTIK DI PANTAI, PROFIL BAKTERIA DAN KUALITI AIR LAUT DI PULAU – PULAU TERPILIH DI SEMENANJUNG MALAYSIA

ABSTRAK

Persekitaran marin termasuk pantai di seluruh dunia telah dicemari dengan pelbagai jenis sisa terutamanya plastik. Di Malaysia, terdapat banyak bukti yang menunjukkan peningkatan serpihan plastik kecil di kawasan pesisiran pantai. Kewujudan serpihan plastik ini memberi impak kepada kualiti air laut and mikroorganisma di dalamnya. Oleh itu, kajian ini dijalankan untuk mengenalpasti kuantiti serpihan mesoplastik (1- 30 mm) di persisiran pantai, kualiti air laut dan profil mikroorganisma di lapan pantai terpilih. Di setiap pantai, tiga sampel pasir diambil daripada lapisan atas hingga kedalaman 5 cm menggunakan kuadrat yang berukuran 50 × 50 cm. Sampel-sampel ini diayak untuk mengasingkan sisa plastik dari butiran pasir dan sedimen. Mesoplastik ini diasingkan dan dikategorikan mengikut jenis dan kuantiti berdasarkan kedudukannya di persisiran pantai. Kualiti air dan parameter mikrobiologi telah dianalsis dari tiga sample air laut dari jarak 3m dan 6m dari gigi air menggunakkan kaedah standard.Parameter fizikal dan kimia yang diukur ialah suhu, oksigen terlarut (DO), pH, konduktiviti, kemasinan, kekeruhan, permintaan oksigen biokimia (BOD), jumlah pepejal terlarut, jumlah pepejal terampai, nitrat, ammonia, fosfat dan silikat. Komposisi mikroba di dalam air laut telah dianalysis menggunakan jumlah bakteria heterotopik dan jumlah koliform sebagai petunjuk. Sebanyak 2631 sisa/m^2 mesoplastik telah diperolehi daripada kesemua pantai yang dipilih. Jumlah tertinggi adalah di Pantai Pinang Seribu, Pulau Perhentian dengan 1113 sisa/m^2 dan jumlah yang paling sedikit pula diperoleh di Pantai Jeti, Pulau Besar dengan 21 sisa/m^2. Kajian menunjukkan bahawa kehadiran serpihan sisa marin di pantai – pantai ini bukan sahaja daripada aktiviti antropogenik di kawasan tersebut malah dibawa masuk melalui laut. Ini mungkin disebabkan oleh keadaan fizikal dan kedudukan pantai yang mempunyai kecenderungan untuk memerangkap serpihan marin dari laut. Tambahan pula, julat bagi parameter kajian adalah 24.7 – 35.6ºC untuk suhu, 2.20 – 7.87 mg/L untuk DO, 5.50 - 8.53 untuk pH, 36878 - 5226 µS/cm untuk konduktiviti,, 32.42 – 33.81 ppt untuk kemasinan, 18.5 – 19.89 NTU untuk kekeruhan, 52.0 mg/L – 89.5 mg/L untuk BOD, 25.0 – 160.0 mg/L untuk jumlah pepejal terampai, 12.4 - 31.65 mg/L untuk jumlah pepejal terlarut, 42.4 – 943.6 µg/L untuk nitrat, 47.3 – 353.6 µg/L untuk ammonia, 56.6 – 673.2 µg/L untuk fosfat dan 32.2 - 99.1 µg/L untuk silikat. Berdasarkan analisis kualiti air mengikut MMWQS, semua pantai dalam kajian ini tergolong dalam kategori yang dibenarkan untuk aktiviti rekreasi. Air laut yang paling tercemar adalah di Pantai Pinang Seribu dengan bacaan DO yang rendah and tahap BOD, dan TDS yang tinggi. Pantai yang kurang tercemar adalah Pantai Jeti dengan bacaan DO yang tinggi dan tahap rendah untuk BOD, fosfat and silikat. Selain itu, kiraan bakteria heterotopik di kesemua pantai berbeza dari 0.67 – 1.52 × 10^8 CFU/mL. Jumlah koliform di semua pantai berada dalam lingkungan 1.51 to 2.23 × 10^8 MNP/100 mL. Jumlah bakteria paling tinggi diperhatikan di Pantai Pasir Belakang dan bilangan terendah di Pantai Tengah. Kehadiran mikroplastik dalam pasir di pantai tidak mempengaruhi mikroorganisma di air laut sekitar persisiran pantai.

Kata kunci: peningkatan, pantai, pulau, mesoplastik, sisa marin

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LIST OF SYMBOLS AND ABBREVIATIONS

>	:	less than
<	:	more than
±	:	plus minus
%	:	percentage
ºC	:	degree Celsius
cm	:	centimeter
cm^2	:	centimeter square
g	:	gram
h	:	hour
kg	:	kilogram
km	:	kilometer
L	:	liter
m	:	meter
mm	:	millimeter
m^2	:	meter square
ml	:	milliliter
µm	:	micrometer
ANOVA	:	Analysis of variance
BOD	:	Biochemical oxygen demand
DO	:	Dissolved oxygen
DOE	:	Department of Environment
GPS	:	Global Positioning System
NOAA	:	National Oceanic and Atmospheric Administration

MMWQS	:	Malaysian Marine Water Quality Standard
TDS	:	Total Dissolve Solid
TSS	:	Total Suspended Solid
UNEP	:	United Nation Environmental Programme

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Background of Study

Water covers an approximated total volume of 1,386,000,000 km^3 of the Earth's surface, and 97% of this water is marine water (Aryal *et al.*, 2015). The marine ecosystem is the most extensive system on Earth, rich in biodiversity, and represents a significant portion (70%) of the biosphere (Aryal *et al.*, 2015; Maizatun & Mariani, 2011; Naik & Dubey, 2017; Thevarajoo *et al.*, 2015). This biodiversity is fundamental in providing a life-supporting and comprehensive range of ecosystems (Maizatun & Mariani, 2011). Moreover, the marine environment offers many types of habitats that support aquatic life. Marine habitats can be divided into the open ocean and coastal habitats. In Malaysia, the marine environment consists of sea, coastal areas, and islands (Gasim *et al.*, 2013).

Despite its valuable importance, the marine environment has been continuously polluted. This scenario occurs worldwide, particularly in coastal countries. Due to the escalation in the concentration of contaminants, marine pollution has turned out to be one of the foremost and irreconcilable subjects in recent years, which frequently cause pressures to marine biological systems (Anderson *et al.*, 2016; Carson *et al.*, 2011; Kumar *et al.*, 2016; Pettipas *et al.*, 2016; Sakthipriya *et al.*, 2015). There are many types of marine pollution. Primarily, marine pollution is triggered by the presence of plastic debris. Improper plastic waste disposal has given rise to many forms of plastic trash and harms the marine environment (Alshawafi *et al.*, 2017; Carson *et al.*, 2011; Jayanthi *et al.*, 2014; Pettipas *et al.*, 2016).

The marine environment in Malaysia also continues to deteriorate throughout the year (Gasim *et al.*, 2013; Maizatun & Mariani, 2011; Santos *et al.*, 2009). The major contributors to marine pollution are industries and urban areas along with the beachfront territories of Malaysia (Gasim *et al.*, 2013; Maizatun & Mariani, 2011). The most predominant category of marine trash found on shorelines in Malaysian beaches is plastic (Chan, 2006). Plastic is one of the significant syntheses of waste. As a result, plastic waste generation is an emerging concern in many countries, including Malaysia (Kershaw *et al.*, 2011; Webb *et al.*, 2013). Plastic contributes to the third highest waste volume in Malaysia next to putrescible and paper wastes (Veerasingam *et al.*, 2016a). Plastics and solid manufactured items found in the ocean environment are referred to as marine debris. Massive amounts of plastic waste are consistently dumped into the sea from both land and sea-based activities (Kershaw *et al.*, 2011).

The geography of Malaysia also contributes to this situation. Malaysia is situated at the conjunction of the South China Sea and the Straits of Melaka. This route is the main commercial shipping course between the Pacific and Indian Oceans. The Straits of Melaka are most vulnerable to vessel-based marine contamination such as oil and grease because of the heavy shipping volume compared to the South China Sea (Maizatun & Mariani, 2011). This is due to moderate development in the East coastal states and drastic growth densities in the West coastal states. Some reports of oil slicks drifting towards the East coast shoreline, apparently originating from transportation lanes or blow-out of an oil well in the seabed (Morton & Blackmore, 2001).

Plastic debris in the marine habitat can be categorized into nanoplastics, microplastics, mesoplastics, macroplastics, and megaplastics. Mesoplastics are generally referred to as small plastic debris or small pieces of plastic (Heo *et al.*, 2013). There is still no standard to define mesoplastics, and the term is not used consistently. Different authors have used various diverse size classes. According to several previous researches on the presence of small plastic debris from the year 2004 to 2020, mesoplastics can be defined as plastic debris found on sandy beaches with the size of 1 – 30 mm (Chen *et al.*, 2019; Hidalgo-Ruz & Thiel, 2013; Karuppasamy *et al.*, 2020).

Small plastic debris or mesoplastics are formed when large objects are gradually fragmented by intense sunlight. Besides that, there are also mesoplastics from essential sources, for example, small plastic particles used in cosmetics and industrial pellets.

Moreover, mesoplastics can enter the food web through ingestion by invertebrates such as barnacles, mussels, worms, and large vertebrates such as birds, mammals, and fishes. Additionally, plastic debris is a known source of persistent organic pollutants (POPs), capable of being transported and bioaccumulating in marine life. In addition, plastic on sandy shorelines can cause alterations in the penetrability and heat transfer between sediment grains, consequently impacting the marine ecosystem (Carson *et al.*, 2011; Hidalgo-Ruz & Thiel, 2013; Salim & Driss, 2013).

Marine plastics debris affects the beachfront zones and the seafloor at all depths (Van Dyck *et al.*, 2016). Furthermore, anthropogenic activities have a significant impact on the quality of coastal waters. Water pollution has numerous economic, ecological, and social consequences. These include the loss of marine life and recreational restrictions (Rahman *et al.*, 2016). A large portion of the plastic garbage on the shoreline does not decompose quickly. Instead, it stays in the seawater for a considerable length of time while utilizing oxygen as it degrades. When oxygen decreases, the survival of marine organisms is also affected (Mobilik *et al.*, 2014; Webb *et al.*, 2013).

The existences of microorganisms are very diverse in terms of their species and population. The diversity of bacteria leads to various roles in the marine ecosystem, such as the agent for nutrient cycling and degradation while driving critical biological system processes, including primary production and bioremediation (Muhammad Aizuddin *et al.*, 2014). The ecological interactions between small plastic debris and marine microorganisms have been minimal (Harrison *et al.*, 2014).

1.2 Problem Statement

The marine environments, including beaches around the world, are littered with numerous types of solid waste. The existence of plastic waste in the atmosphere is interrelated with anthropogenic activities and is progressively being perceived as a global pollution issue. Marine plastic debris contaminates seashores not only in developed countries but even in remote islands (Allsopp *et al.*, 2006). Environmental pollution by plastics is an emerging problem and is expected to persist for hundreds of years. There is increasing evidence of extensive abundance and contamination of small plastic debris in the country (Jayanthi *et al.*, 2014).

Conferring to the review conducted by Derraik (2002) on contamination of the marine environment by plastic debris, there is undeniable evidence that plastic pollution is dangerous to marine biodiversity. Consequently, it is critical to monitor plastic debris in the coastal environment so that proper and precise actions can be taken to mitigate the effects of plastic waste when it is introduced into the marine environment. (Derraik, 2002).

Even though numerous studies have been conducted on marine debris on the beaches, accurate information for complete comparative quantification has yet to be assembled. Moreover, in Malaysia, the survey of the coastal areas in the islands of Peninsular Malaysia is very lacking. Thus, this study provides information that can serve as an input for further research, conservation management and offers marine scientists better evidence.

Many reviews have been done in various nations evaluating the amount of plastic on shorelines, sea surface, seafloor, and water column. However, most of these reviews have focused on large (macro) debris and inadequate literature about small to microscopic particles (Allsopp *et al.*, 2006). Therefore, research and studies on marine litter on selected islands in Peninsular Malaysia are essential to determine the factors contributing to its existence.

Unfortunately, the mesoplastic abundance focused in this research was frequently overlooked because of its small size and invisibility.

In addition, there is less attention on the abundance of plastic debris based on different attributes such as foreshore (low tides and high tide zones or known as tidal zones) and backshore (berm) locations within a shoreline. Therefore, this study provides the quantities of marine debris found according to the profile of the beaches. Besides, the quantification of marine debris fraction in the sediment can indicate the state of health of the Malaysian shores and serve as a parameter for beach quality assessment, which can also be reflected with the existing microbial profile.

As in the case of Peninsular Malaysia, huge parts of its coastal region have been developed and commercialized to fulfill the needs of the tourism industry. This has resulted in high anthropogenic activity, including littering of plastic litters, affecting the seawater quality (Muhammad Aizuddin *et al.*, 2014). Thus, this study was conducted to investigate the effects of plastic debris abundance on marine bacteria by comparing the bacterial counts between selected beaches while considering several factors such as physico-chemical parameters and anthropogenic activity, and plastic distribution.

1.3 Research Objectives

This research was conducted to examine how coastal water quality and marine microbes are affected by the presence of small plastic debris (mesoplastics) at beaches of selected islands in Peninsular Malaysia. This study aims:

- To investigate the abundance and composition of mesoplastics at beaches of selected islands in Peninsular Malaysia.
- To determine the quality of the coastal water at selected islands in Peninsular Malaysia.
- To investigate the abundance of microbes in the coastal water at the selected islands in Peninsular Malaysia.
- To determine the correlation between mesoplastics, coastal water quality, and the abundance of microbes at the selected sites.

This study is crucial in determining Malaysian beaches' pollution level with small plastic debris, particularly islands, due to significantly less research on these shorelines. Small plastic debris such as mesoplastics has many adverse effects on the ecosystem, flora and fauna, and human health. Thus, it is vital to determine the pollution level in the Malaysian islands. In addition, this data will serve as a baseline for further research and guidelines on beach pollution health for policymakers. Furthermore, there are no studies conducted to determine the effect of mesoplastics on microorganisms. Therefore, this research will serve as a novel finding for any possible impact on microorganisms.

CHAPTER 2: LITERATURE REVIEW

2.1 Plastic Pollution

Plastics are the most common type of marine debris found worldwide (Angelini *et al.*, 2019). The presence of plastic in the environment creates numerous impacts on the ecosystem. From the tiny microbes to the entirely natural process of the globe are being affected by plastic waste (Cole *et al.*, 2011). Since the manufacturing of plastic products began in the 1950s, there has been evidence of plastic debris accumulation in the marine environment, including open oceans, shorelines, islands, and the seafloor (Barnes *et al.*, 2009; Monteiro *et al.*, 2018).

This situation has worsened over the last 60 years, when plastic usage has increased dramatically (Sathish *et al.*, 2019). Even though the recycling rate of plastic products is increasing, most of those discarded end up in the environment (Liu *et al.*, 2018). Plastic is a low-cost and convenient material that has been used for a wide range of societal applications. The properties of plastics, such as high stability, flexibility, lightweight, and durability, are the main reasons for the demand (Bhuyan *et al.*, 2020; Ho & Not, 2019; Lee *et al.*, 2017; Mu *et al.*, 2019; Nor & Obbard, 2014).

The bibliometric analysis conducted by Kasavan *et al*., 2021, shows that the studies on plastic pollution from the year 2000 to 2020 have covered a broad area of marine and freshwater ecosystems. There were 2182 research papers identified in this field in 107 countries (Kasavan *et al.*, 2021). Plastic pollutants are found in various sizes, including megaplastic, macroplastic, mesoplastic, microplastic, and nanoplastic (Andrady, 2011; Cole *et al.*, 2011; Thushari & Senevirathna, 2020).

In the absence of significant improvements in waste management infrastructure in coastal countries, the amount of plastic entering the world's oceans could double by 2025 (Jambeck *et al.*, 2015). Attention to plastic pollution has become vital because of its irreversible effects on human health, coastal tourism, ocean health, food safety and quality, and climate change. In addition, residues from plastic degradation present in the environment can have persistent impacts (Webb *et al.*, 2013). Hence, studies on the contamination of small plastic debris are critical. This information will then serve as input to determine the severity and references for mitigation actions to reduce pollution levels.

2.2 Marine Plastic Pollution

Comparing the spatial and temporal patterns of small plastic debris to those found in other countries will address the gap and determine whether small plastic pollution is a substantial environmental problem in Malaysia that demands prompt attention. Many studies on marine plastic pollution have been conducted in various countries worldwide. From all the research conducted, it was found that the dominant type of marine debris was plastic, with numerous sizes and shapes.

The chronological review of the research conducted on beach plastic debris shows the preliminary studies started in the early 90s. However, attention to this field was given more importance from the year 2000. This is due to the increase in plastic manufacturing and the forecast demand for plastic-based products, which increases annually. The plastic waste that will end up in the marine environment is expected to be high as well, and all the studies that have been conducted prove the contamination of plastic in the ecosystem.

In 1994, Khordagui & Abu-Hilal (1994) investigated the litter on the shorelines of the Arabian Gulf and the Gulf of Oman, UAE, and the results showed plastic fragments constituted 27.1% of the 22771 items noted. In addition to that finding, fishing floats and nettings represented 16.9% of the total items examined. Thus, it can be concluded that the marine debris on beaches is mainly fragmented plastic and discarded fishing equipment.

Further study on other 11 beaches of the Gulf of Oman along the Omani coast in 2004 also found plastic debris in the first rank (Claereboudt, 2004). Additionally, a study conducted on the Jordanian shores of the Gulf of Aqaba (Red Sea) between 1994 and 1995 on a monthly basis discovered that more than half of the litter found was made up of plastic. There are three primary sources of these plastics, which are beachgoers, cargo, and passenger ports (Abu-Hilal & Al-Najjar, 2004).

The most abundant types of waste observed on 43 beaches in the Orange Country are hard plastics, pre-production plastic pellets, and foamed plastics. The beaches in this study covers from the remote shorelines to the high use sandy beaches. The main sources identified are from overboard disposal from boating activities, runoff from land-based activities, wind current from upland sources, and littering by beachgoers (Moore *et al.*, 2001). Moreover, the researchers discovered that the three most remote beaches on Midway Atoll and Moloka'i had the highest occurrence of small plastic debris out of nine coastal locations throughout the Hawaiian Archipelago (McDermid & McMullen, 2004).

Furthermore, according to the findings of a study conducted on the amount and type of small debris items deposited on the beaches of the Hawaiian Islands from 1990 to 2006, based on the annual deposition rate in regard to El Nino and La Nina events, plastic constitutes 71% of all collected items. Over the 16 years, the results indicate that this problem has not lessened in severity (Morishige *et al.*, 2007). These studies show the increase in the amount of plastic debris on beaches over time and the importance of continued monitoring to determine the severity of plastic pollution in the marine ecosystem. Thus, attention also needs to be given to analysis of the beach pollution levels in Malaysia.

According to a study on the distribution of stranded and buried litter on beaches along the Sea of Japan, plastic was found to be the most abundant type of litter on beaches along the Sea of Japan. Plastic makes up 40 – 80 percent of the total litter found in the environment. Aside from that, resin pellets were discovered on 12 different beaches (Kusui & Noda, 2003). On the other hand, quantification of plastic litter on four sandy beaches in Mumbai, India, shows that the major contributing factors to the abundance are beach usage for different activities such as recreational, religious, and fishing, which suggests that land-based sources provide significant inputs to plastic pollution on these beaches (Jayasiri *et al.*, 2013). Research conducted on other countries' shorelines also supported these findings on marine debris sources, which will be discussed subsequently in the following sections.

In Brazil, research was conducted to assess the marine debris accumulation on beaches. The study along the tropical beaches located south of Salvador City, found plastics and styrofoam to be major debris (Santos *et al.*, 2009). This finding is supported by the study conducted by Costa *et al*., (2010), which also shows the presence of plastic type fragments and pellet plastics on urban beaches in the northeast. These outcomes concluded that plastic pollution on Brazil's shorelines has become a threat to ensuring a healthy aquatic ecosystem.

Research on South Korean beaches in 2013 and 2014 also proved that the shorelines were also polluted with plastic debris of various sizes, such as large micro, meso and macroplastics (Lee *et al.*, 2015). The small plastic debris analysis on the coast of Guangdong, South China, indicated that plastic debris on the beach was increasingly abundant with decreasing size. Fragmentation is believed to cause stranded plastic debris to reduce in size (Fok *et al.*, 2017).

Going forward in the timeline, the smaller sized plastics such as meso and micro-sized plastics are given attention by the researchers. The first study on microplastics in Singapore was published in 2006, which documented the presence and abundance of microplastics in nine different locations along Singapore's coastal line. This study identified the sources of plastic debris are from on-going waste disposal practices of industries and recreational activities, and discharge from ships (Ng & Obbard, 2006).

Plastic debris undergoes fragmentation, which leads to the formation of small plastic debris. The fragmented plastic debris tends to accumulate on the marine sediments. High concentrations of microplastics in sediments of the Belgian coastal zone were found, but no clear relationship was identified between local anthropogenic activities and microplastic concentrations (Claessens *et al.*, 2011).

Some recent research, such as on the beach sediment of the Algerian western coast, has found a significant difference between the number of plastic debris and beach location. These findings were gathered with a significant amount of fragments and pellet types of marine debris. High plastic concentration was registered on the beach located close to the coastal village (Taïbi *et al.*, 2021). Besides that, 89% of the total litter amount found along 24 beaches of the Central Caribbean Coast of Colombia was plastic(Rangel-Buitrago *et al.*, 2021).

The Philippines is one of the countries with the highest plastic waste inputs into the ocean. Research at Talim Bay shows that the beach has a high level of plastic contamination. The most abundant plastic litter was plastic wrappers as sachets, which is an ubiquitous packaging type in the Philippines (Paler *et al.*, 2019). On the other hand, a study of 21 beaches in Palawan, Philippines showed 17 sites were contaminated with plastic litter. The plastics sampled were predominantly fishing line (nylon), food packaging, and fragments (Sajorne *et al.*, 2021).

While in Sri Lanka, the study conducted in 2018 was the first assessment of marine debris washed ashore on 22 beaches along the coast. The finding of this research shows that the beach typology greatly influenced the quantity of debris and packaging materials comprised 55% of the beach debris (Jang *et al.*, 2018). Furthermore, in addition to several studies that have been conducted to quantify the plastic debris along Indian beaches, the latest study focused on marine litter along Mandavi beach, Gurajat. The plastic material is observed in various dimensions and thicknesses (Behera *et al.*, 2021).

In addition to the individual research conducted in different countries, there are also a few reviews conducted on the overall assessment by bringing together most of the literature published on the topic. These findings of these reviews show that there is overwhelming evidence that plastic pollution is a threat to marine biodiversity (Derraik, 2002). The topics analyzed in literature review papers basically consist of synthesis of various topics, such as the occurrence of plastic debris in the environment, documented impacts of marine pollution, and the fate of persistent organic pollutants (POPs) (Arthur *et al.*, 2008; Auta *et al.*, 2017; Bamford *et al.*, 2008; Bhuyan *et al.*, 2020). The findings will be discussed in more detail in the following sections accordingly.

2.3 Malaysian Shorelines

Malaysia is divided into Peninsular or West Malaysia and East Malaysia, the Borneo states of Sabah and Sarawak. Peninsular Malaysia (131 598 km^2) is bordered by the mainland of Thailand in the North, Strait of Johor in the South, Strait of Melaka in the West, and the South China Sea in the East (Sham, 1998). Malaysia with coastal areas of about 63,665.3 km^2 and a total coastline length of 4,492 km has beautiful beaches and offshore islands (Maizatun & Mariani, 2011; Tang & Pradhan, 2015).

Malaysia experiences two monsoons a year, the Northeast Monsoon from November to February, with a transitional period in April to May followed by the advent of Southeast Monsoon from May to September. Another transitional period occurs from October to November, and the whole cycle starts again. The wettest season coincides with the northeast monsoon, and during this period the Peninsula's east coast is often closed off by high seas. The monsoon winds are also linked to changes in rainfall. The average rainfall in Malaysia is 2500 mm annually and the average temperature is 27°C (Ong, 1998; Sham, 1998).

Islands are known as "Pulau" among Malaysians. Most of the islands in Malaysia are unpopulated, small, and remote. They support rich marine life because of their isolated positions. However, some of them are habitable and passable (Ahmad Masduki *et al.*, 2016; Ilya, 2007). The most popular islands in West of Peninsular Malaysia are Pulau Langkawi, Pulau Pangkor, and Pulau Besar, while Pulau Perhentian, Pulau Redang, and Pulau Tioman are famous islands along East of Peninsular. The islands in the West are famous for the township developments as compared to those in the East which are well known for their underwater world (Ilya, 2007).

Thus, many islands of Peninsular Malaysia are developed into tourist spots due to the high demand and tourism opportunities by attracting a continuous number of arrivals. Being a tropical country, the majority of islands are rich with corals and marine life which become the utmost tourist attraction to generate a massive income for the country. Malaysia's island tourist sector is believed to be the major attraction specifically for international tourists from Australia, Europe, New Zealand, and North America (Ahmad Masduki *et al.*, 2016; Farizawati *et al.*, 2014; Sazali *et al.*, 2012).

Water-based tourism on islands and beaches is considered an everlasting market for the tourism industry due to the plenteousness of natural resources and picturesque views. In congruence with the objective of establishing the maritime boundaries as one of the world-class tourist spots, a substantial amount of investment has been budgeted to develop the islands and coasts of Malaysia (Mohamad *et al.*, 2015). An aggregate number of 25 small islands are considered popular destinations which drive valuable profits for the tourism industry (Ahmad Masduki *et al.*, 2016). Yet, island tourism also posed negative impacts on the marine environment.

2.3.1 Status of Malaysian Marine Pollution

The researchers on marine pollution revealed that Malaysian beaches are also contaminated with numerous types of plastic waste, similar to other famous beaches worldwide, as discussed in the previous sections. However, the study on plastic pollution in Malaysia is much less compared to other countries, such as India, China, the Philippines, Sri Lanka, and Brazil. The earlier studies conducted in this field mainly focused on the macro-type plastic debris found on Malaysia's shorelines.

According to numerous studies on Malaysian beach pollution, plastic is the most prevalent type of debris found on the shorelines. In addition, there is evidence demonstrating a significant deposition of small plastic debris in the beach sediments (Azman *et al.*, 2021). Malaysia, as a rapidly developing country, makes extensive use of plastic. As a result, it is critical to comprehend the impact of plastic waste on the environment, particularly the coastal environment. Therefore, the objective of this study is to determine the plastic waste abundance by size and location.

In 2010, a study on Port Dickson beaches indicated that the waste on these beaches highly depends on economic activities on the shorelines. The different functions of beaches, recreational and fishing, affect the composition and abundance of marine debris differently, although these beaches are located in the west of Peninsular Malaysia (Khairunnisa *et al.*, 2012). Supporting this study, the research conducted in 2014 on other four beaches in Port Dickson revealed plastic debris scaled high, up to 41% of the total debris (Yi & Kannan, 2016).

A comparative study was conducted to determine the prevalence of buried plastic debris on Malaysian shorelines by comparing six recreational and fish-landing beaches, which reveals different types of debris related to the function of the beach. Recreational beaches, have an abundance of plastic film, foam, and fragment, whereas predominant types of plastics found in fishing beach areas included line, foam, and film (Fauziah *et al.*, 2015).

While in Sarawak, the first study on beach pollution was conducted in 2015 at two beaches in Kuching. In this study, the findings revealed that plastic particles were found at both sampling sites (Noik & Tuah, 2015). Furthermore, in 2012, the type and abundance of marine debris at four public beaches in Sarawak were studied (Mobilik *et al.*, 2014). This researcher further continued the study at these beaches by analyzing the influence of different monsoon seasons on the presence of marine debris on these four beaches (Mobilik *et al.*, 2013).

In addition to the studies in Sarawak, Mobilik *et al*., (2017) conducted similar research on two beaches situated on the west coast of Sabah. The finding from this study also shows that the plastic category was the most abundant item which may derive from land-based sources. Furthermore, the recent papers published on marine debris along the Pahang coastline also found plastic to be the most dominant marine litter (Azman *et al.*, 2021).

So, as a result, the Malaysian beaches were found to be polluted with plastic waste. Thus, the focus of this research was on the residues of these plastics found in the marine environment. Large-sized plastics were gradually broken down into smaller debris known as mesoplastics and remained in the ecosystem for a considerable time, allowing them to travel through the food web. The following section will discuss further on the mesoplastics.

2.3.2 Marine Debris on Malaysian Beaches

Malaysian beaches are under threat of pollution due to the state's rapid economic development and growing population. Although marine debris is found on Malaysia's shores, it has received less attention than water quality and toxic pollution issues. As a result, marine debris has been under-studied in Malaysia, hampered information on its abundance and dispersion (Fauziah *et al.*, 2021).

There is no specific law or regulation in Malaysia to manage pollution on the shorelines. The management of marine debris comes under the Solid Waste and Public Cleansing Management Act 2007. Instead, marine debris management on tourism beaches falls under the enforcement of the state authorities and other appointed contractors on private beaches. However, fish landing beaches are highly vulnerable to marine debris contamination because there are no specific regulations on waste management, and there is a lack of law enforcement (Fauziah *et al.*, 2021).

The studies on the abundance of marine debris in Peninsular Malaysia have been conducted at fourteen different locations, while in Sabah and Sarawak at seven different beaches. These shorelines consist of fishing, recreational, and public beaches. One of these studies focused on the marine park. Conclusively, most studies on plastic pollution concentrated on famous tourist beaches, while less popular shorelines were mainly disregarded (Azman *et al.*, 2021; Fauziah *et al.*, 2021).

The number of studies conducted on beaches on Malaysian islands is minimal, with only a few studies being conducted on islands such as Pulau Tioman, Pahang, and Pulau Payar, Kedah (Fauziah *et al.*, 2019). Moreover, none of these studied areas are from isolated islands or undisturbed beaches. Therefore, this study focused on the abundance of mesoplastics on beaches in four different islands.

2.3.2.1 Knowledge and Gaps of Marine Debris in Malaysia

The abundance and distribution of marine debris in selected Malaysian beaches was only been reported over the last decade and has focused on the types of debris collected. The source of these marine debris is from the tourism, fishing industries, and debris migrated from inland. Furthermore, there are numerous uptakes of marine debris by animals have been documented from case studies in Malaysia (Fauziah *et al*., 2021).

While there are many studies on the composition and quantity of marine debris, there is little information on marine-based sources, inflows and outflows to and from other territories, and the units of measure used in these studies are often difficult to commensurate (tonnes/km, items/m^2, items/m^3, etc.). The analysis of gaps in existing studies on marine debris in Malaysia highlights the need for more research in this area (Fauziah *et al*., 2021).

2.4 Types of plastic debris on beaches

Plastic is the main type of marine debris found along the beaches. Various studies worldwide and in Malaysia prove the presence of plastic debris on the coastal beaches. Many types of plastic have been hoarded in the environment for decades and the concentration continues to increase in the marine ecosystem (Carson *et al.*, 2011). Plastic debris can be divided according to size into nanoplastics, microplastics, mesoplastics, macroplastics, and megaplastics (Mistri *et al.*, 2017; Sellegri *et al.*, 2016; Young & Elliott, 2016).

Large plastics are mainly found in the form of primary products, while small plastics are found either from primary sources or as a result of the degradation process. The increase in plastic in the environment is due to increased plastic usage. Plastic manufacturing and usage have increased progressively over the past 50 years, with global manufacturing reaching over 300 million tonnes in 2014 (Anderson *et al.*, 2016). In recent years, as new applications for plastics in everyday life have emerged, the variety and quantity of plastic items found in the marine environment have increased dramatically (Zhu, 2015; Zurcher, 2009).

Plastics are used in various aspects of daily life and contribute to a large part of the waste stream. The main types of plastics used extensively worldwide are polyethylene (PE), polyvinylchloride (PVC), nylon, polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), and polyurethane (PUR) (Anderson *et al.*, 2016; Andrady, 2011; Bhuyan *et al.*, 2020; Lagarde *et al.*, 2016; Shah *et al.*, 2008; Wang *et al.*, 2016; Zurcher, 2009). Table 2.1 shows the different types of plastics and their uses.

Table 2.1: Types of plastics and their uses

Classification	Use
Polyvinylchloride (PVC)	Automobile seat covers, shower curtains, raincoats, bottles, visors, shoe soles, garden hoses, and electricity pipes
Nylon	Polyamides or Nylon are used in small bearings, speedometer gears, windshield wipers, water hose nozzles, football helmets, racehorse shoes, inks, clothing parachute fabrics, rainwear, and cellophane
Polyethylene (PE)	Plastic bags, milk and water bottles, food packaging film, toys, irrigation, and drainage pipes, motor oil bottles
Polystyrene (PS)	Disposable cups, packaging materials, laboratory ware, certain electronic uses
Polyethylene terephthalate (PET)	Used for carbonated soft drink bottles, processed meat packages peanut butter jars pillow and sleeping bag filling, textile fibers
Polypropylene (PP)	Bottle caps, drinking straws, medicine bottles, car seats, car batteries, bumpers, disposable syringes, carpet backings
Polyurethane (PUR)	Tyres, gaskets, bumpers, in refrigerator insulation, sponges, furniture cushioning, and life jackets

Sources: (Andrady, 2011; Bhuyan *et al.*, 2020; Shah *et al.*, 2008; Wang *et al.*, 2016)

Overall, the trend indicates that plastic manufacturing and consumption will continue to rise, contributing to an increase in the amount of small plastic debris found in aquatic environments (Anderson *et al.*, 2016). Plastic pollution in the marine environment has been an issue of concern since the 1970s, but the focus has shifted to small-sized plastic pollutants in recent years. Nevertheless, the occurrence of small plastic pollution has been confirmed in organisms, water, and sediment globally (Murphy & Quinn, 2018)

2.4.1 Mesoplastics

This research focuses on mesoplastics in the beach sediments as there is significant evidence of plastics' existence and negatively affects beach health, as identified in previous studies. Mesoplastics are generally referred to as small plastic debris or small pieces of plastic. Plastic waste of a size larger than microplastics and less than macroplastics are classified as mesoplastics.

There is still no standard to define mesoplastics, and the term is not used consistently. Different authors have used various diverse size classes. According to several previous researches from the year 2004 to 2020 on small plastic debris, mesoplastics can be defined as plastic debris found on sandy beaches within the size of 1 – 30 mm. Table 2.2 shows the summary of research done on mesoplastics and the size-based definition of mesoplastics as proposed by different authors.

Table 2.2: Summary of mesoplastics studies

<table>
<tr><th>Size (mm) / Year</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th><th>21</th><th>22</th><th>23</th><th>24</th><th>25</th><th>26</th><th>27</th><th>28</th><th>29</th><th>30</th></tr>
<tr><td>2004</td><td colspan="15">(McDermid & McMullen, 2004)</td><td colspan="15"></td></tr>
<tr><td>2007</td><td colspan="4"></td><td colspan="26">(Browne et al., 2007)</td></tr>
<tr><td>2008</td><td colspan="4"></td><td colspan="21">(Bamford et al., 2008)</td><td colspan="5"></td></tr>
<tr><td rowspan="3">2009</td><td colspan="4"></td><td colspan="16">(Barnes et al., 2009)</td><td colspan="10"></td></tr>
<tr><td></td><td colspan="19">(Ryan et al., 2009)</td><td colspan="10"></td></tr>
<tr><td></td><td colspan="14">(Zurcher, 2009)</td><td colspan="15"></td></tr>
<tr><td rowspan="3">2013</td><td colspan="4"></td><td colspan="16">(Jayasiri et al., 2013; Lippiatt et al., 2013)</td><td colspan="10"></td></tr>
<tr><td colspan="10">(Hidalgo-Ruz & Thiel, 2013)</td><td colspan="20"></td></tr>
<tr><td colspan="25">(Heo et al., 2013)</td><td colspan="5"></td></tr>
<tr><td rowspan="2">2014</td><td colspan="3"></td><td colspan="7">(Isobe et al., 2014)</td><td colspan="20"></td></tr>
<tr><td colspan="4"></td><td colspan="6">(Collignon et al., 2014)</td><td colspan="20"></td></tr>
<tr><td rowspan="3">2015</td><td colspan="4"></td><td colspan="6">(Isobe et al., 2015;
Lavers et al., 2016)</td><td colspan="20"></td></tr>
<tr><td colspan="4"></td><td colspan="21">(Lee et al., 2015)</td><td colspan="5"></td></tr>
<tr><td colspan="4"></td><td colspan="16">(Zhao et al., 2015)</td><td colspan="10"></td></tr>
<tr><td rowspan="2">2016</td><td colspan="4"></td><td colspan="21">(Fastelli et al., 2016; Young & Elliott, 2016)</td><td colspan="5"></td></tr>
<tr><td colspan="2"></td><td colspan="28">(Lavers et al., 2016)</td></tr>
<tr><td rowspan="4">2017</td><td colspan="15">(Gündoğdu & Çevik, 2017)</td><td colspan="15"></td></tr>
<tr><td colspan="4"></td><td colspan="21">(Jabeen et al., 2017)</td><td colspan="5"></td></tr>
<tr><td colspan="4"></td><td colspan="6">(Fok et al., 2017)</td><td colspan="20"></td></tr>
<tr><td colspan="4"></td><td colspan="16">(Becherucci et al., 2017; Mistri et al., 2017)</td><td colspan="10"></td></tr>
<tr><td>2018</td><td colspan="4"></td><td colspan="16">(Liu et al., 2018)</td><td colspan="10"></td></tr>
<tr><td>2019</td><td colspan="4"></td><td colspan="21">(Lestari & Trihadiningrum, 2019)</td><td colspan="5"></td></tr>
<tr><td>2020</td><td colspan="4"></td><td colspan="16">(Karuppasamy et al., 2020)</td><td colspan="10"></td></tr>
</table>

Small plastic debris contributes to over 80% of the ocean debris. In the last four decades, the concentration of these particles appears to increase significantly in the surface waters of the ocean according to the UN environment program. Although a global problem, only 43% of the countries are actively involved in studies of small plastic. About half the global population lives within 100 kilometers of the coastline and population growth is greatest in that zone. This means that the amount of plastic debris entering the ocean from land-based sources is likely to increase unless significant changes are made to waste management practices on the land. As the world population grows and more products containing mesoplastics are placed on the market, the amount of mesoplastics entering the marine and coastal environment is likely to increase (Moghavvemi *et al.*, 2016; Thushari & Senevirathna, 2020).

Mesoplastics have been observed throughout the world in the open sea, on beaches, and also in sediments. High numbers of mesoplastics are found in the area near beaches as compared to the open sea. The study at Hawaiian beaches identified a measurable amount of mesoplastics at all remote beaches sampled despite difference in the sand type, current patterns, wind exposure, and wave action. Small plastic debris is likely to affect every beach in the North Pacific, regardless of whether the beach is isolated or in close proximity to dense human population centers or shipping traffic (McDermid & McMullen, 2004).

In like manner, the first report on plastic quantification at Mumbai beaches revealed that more than 75% of plastics in beach sediment are within the size range of 1–20 mm. The beaches are significantly more contaminated by small fragments than by virgin plastic pellets. There is a statistically significant difference in particle abundance with respect to season (Jayasiri *et al.*, 2013). Similarly, in the study performed on beaches located on the Northeastern Levantine coast of Turkey, the presence of mesoplastics was established (Gündoğdu & Çevik, 2017).

In addition, the research conducted by Ryan *et al*., (2018) on 82 South African beaches in 1994, 2005, and 2015 reported more than 73,500 meso debris items were collected, with 99% being plastic. Supportively, the findings from the research on 23 beaches in Kenya between July and September 2019, showed that plastics were the most abundant litter encountered on all the beaches. Beaches close to urban areas had a higher number of litter categories compared to remote beaches that only had plastics (Okuku *et al.*, 2020).

According to the research carried out by Isobe *at al*., (2014) and supported by Andrady (2011), the degradation of mesoplastics is found on beaches and less offshore. Trapping of mesoplastics occurs near the shore because of transportation by coastal waters, wind and wave actions, where mesoplastics tend to move onshore while microplastics tend to degrade on beaches and then spread throughout the offshore (Isobe *et al.*, 2014).

The abundance of mesoplastics can be used to infer the levels of microplastic pollution (Lee *et al.*, 2015). The analysis on the abundances of meso- and micro-plastics shows a strong correlation, microplastics were abundant in areas where the mesoplastics abundance was high. Furthermore, it was suggested that mesoplastic surveys could be used to identify microplastic hot spots (Lee *et al.*, 2013). Macroplastic debris can be fragmented into meso-sized plastic debris, which can then further break down into micro- and nanoplastic debris (Lee *et al.*, 2017).

Similarly, there is a strong correlation between the concentrations of micro- and mesoplastics based on the study conducted at eight sandy beaches along the shoreline of Tuticorin, Tamil Nadu. The prevalence of plastic litter varies among the study sites depending on the intensity of fishing and other human activities (Jeyasanta *et al.*, 2020). A recent study in Malaysia has identified the Canary Islands as highly affected by marine plastic pollution, but also, for the first time, shows that stranded plastic accumulates in restricted areas of sandy coastlines (Reinold *et al.*, 2020).

Quantitative monitoring and analysis are still lacking to study small plastic debris. Recently, an increase in attention to small plastic debris in the marine environment has been noticed by researchers. However, there is limited information and research on the amount, location, and environmental impacts of small marine plastic debris to support and ease research on this (Arthur *et al.*, 2008). Number of studies have been conducted to assess the presence of small plastic debris on beaches, yet only a few researches were conducted in Malaysia, even though the abundance of marine debris is becoming a severe issue on Malaysian beaches.

2.4.2 Gaps in Studies on Mesoplastics

Once plastic marine debris enters the ocean, it is exposed to sunlight and begins to degrade into smaller fragments (Andrady, 2017). Furthermore, it is abraded by sand or pebbles, wind, and waves, becoming increasingly smaller, until it finally turns into micro- or nanoplastics (Song *et al.*, 2015). The number of plastic particles increases exponentially as the size of the plastic decreases during this process. Plastic become more difficult to be removed and collected from the beach sediments as it becomes smaller. Thus, it is critical to ensure larger plastics are out of the environment, particularly marine ecosystem (Lee *et al.*, 2017).

Prior to initiating prevention and removal efforts, it is critical to conduct size-based monitoring of plastic marine debris in several oceanic compartments. Microplastics have been the subject of an increasing amount of research because they are more readily ingested by marine organisms and have a high potential for causing harm to biota via either the microplastic itself or persistent bioaccumulation of toxic chemicals.

The consensus definition of microplastics is particles < 5 mm, whereas far fewer studies have focused on mesoplastic marine debris, and the size fraction varies among studies. Most plastic debris enter into the ocean as macroplastic debris, and there, it undergoes fragmentation. During this process, macroplastic debris directly produces microplastic particles via surface weathering, but also produces mesoplastics (Lee *et al.*, 2017; Song *et al.*, 2015).

The research on mesoplastic debris has an important role for understanding the distribution of mesoplastics and their fate on each beach. Quantifying microplastics by sorting, extracting, and identifying small particles is time consuming and costly. Meanwhile, mesoplastic debris monitoring requires less complicated procedures and much less time to classify and identify the debris. More importantly, citizen science can contribute to mesoplastic debris monitoring for both sampling and identification; it is easy to pick up, and is associated with a smaller counting error (Lee *et al.*, 2013; Lee *et al.*, 2017). Hence, the current study provides valuable data on the pollution level and profile of mesoplastic debris that can be used to advance the understanding of plastic marine debris.

2.4.3 Morphotypes of Mesoplastics

The structure of mesoplastics commonly found in the marine environment are mainly fragments, lines, film, foam, and pellet types (Agamuthu *et al.*, 2019; Alshawafi *et al.*, 2017; Fauziah *et al.*, 2015; Garcés-Ordóñez *et al.*, 2020; Tsang *et al.*, 2017). These types of plastic debris have been classified based on the findings of previous studies on small plastic debris in the marine environment. The descriptions of the types of mesoplastics are summarized in Table 2.3.

Table 2.3: Types of mesoplastics

Types	Descriptions
Fragment	Irregular shaped hard particles having the appearance of being broken down from a larger piece of plastic.
Foam	Near spherical or granular particles, which deforms readily under pressure and can be partly elastic, depending on the weathering state.
Film	A flat, flexible particle with smooth or angular edges.
Line	Long fibrous material that has a length substantially longer than its width (Lines are sub-classified into filament and fibers).
Pellet	A hard particle with a spherical, smooth, or granular shape

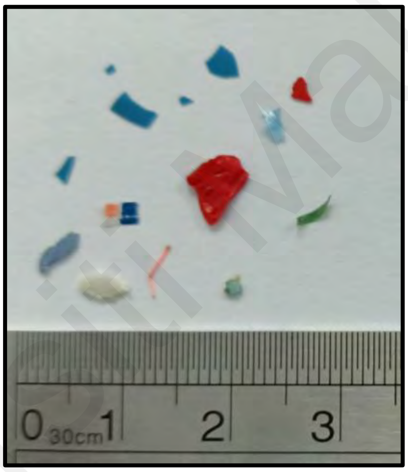

Plate 2.1: Different types of mesoplastics

2.4.3.1 Fragment

Fragment type mesoplastics are formed from the breakdown of a larger piece of plastic. The fragment is a small fraction of polymers derived from multiple sources of manufactured plastic products that undergo some form of the fragmentation process. These plastics degrade slowly due to several factors, such as exposure to UV radiation, sand abrasion, and waves and wind actions (Derraik, 2002; Gregory & Andrady, 2003).

Plastic fragments are widely reported as the most predominant marine debris in literature. This is supported by the findings on the strandline of urban beaches in the northeast of Brazil, where 96.7% of the beach contaminants are from fragmented plastics. This study determined the plastic fragments are formed from the breakdown of larger plastic items deposited on the beach (Costa *et al.*, 2010). Conversely, the survey conducted on beaches in Sarawak supported this finding. The plastic fragment found on these beaches are in the form of various shapes and sizes (Noik & Tuah, 2015).

2.4.3.2 Foam

Foam is a form of cellular plastic that has a porous cellular structure and the cells are bound together. Foam is resilient, lightweight, and stiffer than other types of plastic. Foam type mesoplastics enter the environment mainly from the breakdown of styrofoam materials (Di & Wang, 2018; Lee *et al.*, 2017). Nearly all surveys conducted on the shoreline reported foam as the major plastic debris found at the beaches. There are a variety of sources for the presence of foam fragments in the beach environment. Based on the physical appearance of foam debris, the origin of the waste can be identified, and these findings have been recorded in studies resulting in foam mesoplastic accumulation on beaches.

These foam particles mostly originate from the bait and fish boxes discarded by fishermen. In addition, the fragments of foam from packaging materials and food containers littered by beach users is also the main contributor to the presence of foam type mesoplastics in the marine environment (Andrady, 2011; Chanda & Roy, 2006; Gregory & Andrady, 2003; Lee *et al.*, 2017; Ng & Obbard, 2006). Besides, several studies also suggested that styrofoam buoys from aquaculture were the main source of heavy meso-foam pollution (Heo *et al.*, 2013; Lee *et al.*, 2017).

2.4.3.3 Film

A film is a planar form of plastic that can be bent, folded, or creased without cracking. The plastic film generally appears in transparent irregular shapes but thinner and flexible compared to fragment mesoplastics. The initial usage of films was as industrial packaging material, however since the availability of cheap high clarity grades of polyethylene film, the usage has been broadened. The film became commonly used as packaging for food and beverages, cosmetics, pharmaceuticals, toiletries, textiles, and stationery, as well as for display and non-packaging purposes for electrical construction, musical instruments, horticultural and agricultural applications (Claessens *et al.*, 2011; Jabeen *et al.*, 2017; Shah *et al.*, 2008).

2.4.3.4 Line

Line type mesoplastic is a continuous thread consisting of a single filament that is produced by the process of extrusion and manufactured in various colours such as green, blue, white, and fluorescent. These types of mesoplastics are cheap but stronger which only degrades over time with exposure to sunlight and heat. Line plastics are majorly used in the manufacturing of fishing net, brush filling, and rope making (Kershaw *et al.*, 2011; Thevenon *et al.*, 2014).

The most common type of line plastic debris is nylon which is made from monofilament lines. Plastic nylon has a high resistance to abrasion and chemical attack that are very suitable for the manufacturing of gears and small bearings in the marine fishery. Lines are also discarded from fleece clothing, diapers, and cigarette butts. Nowadays, clothes are made of synthetic plastic fibers like nylon and polyethylene terephthalate (PET) that once washed get loose from clothes and pass-through sewage treatment plants until they reach the sea (Derraik, 2002).

2.4.3.5 Pellet

Pellets are tiny spherical mesoplastic with a size of 2 – 7 mm. Pellets are comprised of various types of polymers such as polystyrene, polypropylene, and polyethylene (Hammer *et al.*, 2012). Most commonly, pellets are found in a clear or white cylindrical shape. Pellet type mesoplastics also consist of plastic resin known as nurdles. Nurdles are small granules with a maximum 5 mm diameter and in a tubular shape. Nurdles are used as raw material for the production of plastic supplies specifically in the product molding process for items such as plastic bags, toys, and bottles. The smaller size of nurdles often contributes to its accidental discharges into the environment during transportation and manufacturing (Hammer *et al.*, 2012; Young & Elliott, 2016). The residue of nurdles in the water stream travel through the river and other surface run-offs towards the sea. Nurdles are highly persistent and therefore are widely distributed in the sea and also found on beaches (Barnes *et al.*, 2009; Derraik, 2002; Di & Wang, 2018; Hammer *et al.*, 2012; Lavers *et al.*, 2016).

Virgin plastic pellets are reported as ubiquitous beach contaminants in the peer-reviewed literature and frequently found on sandy beaches (Costa *et al.*, 2010). There are also many evidences of pellet type small plastic debris ingested by variety of organisms. Besides that, beyond the effects of chemical leaching and pollutant adsorption plastic pellets may change the physical properties of beaches that they contaminate by increasing permeability and lowering subsurface temperatures (Carson *et al.*, 2011). Virgin plastic production pellets are typically 2 – 5mm in diameter (Auta *et al.*, 2017). Pellet mesoplastic enter the marine environment routinely via incidental losses during ocean transport or through run-off from processing facilities (Andrady, 2011; Costa *et al.*, 2010; Ryan *et al.*, 2018).

2.5 Sources of Mesoplastics

Despite studies conducted internationally, Malaysia lacks data on the exact quantities and types of plastic litter and their pathways in the environment. This is because the sources and pathways of marine debris in Malaysia are highly diverse, making it difficult to determine the exact quantities of waste generated by each route. Additionally, economic activities that occur along the pathway of marine debris directly affect the quantity and distribution of marine debris.

Mesoplastic debris in the marine environment consists of particles of different sizes, shapes, chemical properties, and density. Mesoplastics are divided into two groups; primary and secondary mesoplastics. Primary mesoplastics that enter the environment directly are tiny particles designed for commercial use as well as meso-fibers shred from clothing and other textiles, such as fishing nets (Cole *et al.*, 2011).

2.5.1 Primary Mesoplastics

The primary mesoplastics enter the ocean readily as mesoscale particulate materials. Most primary mesoplastics in the environment are generated from industrial and domestic products. Examples of primary mesoplastics include microbeads found in personal care products, plastic pellets used in industrial manufacturing, and plastic fibers used in synthetic textiles (Auta *et al.*, 2017; Cole *et al.*, 2011; Li *et al.*, 2016; Moore, 2008).

Besides that, mesoplastics in the form of virgin plastics prils or pellets enter the oceans via accidental spills during transport and with runoff from plastics processing operations. Primary mesoplastics have also been produced for use in air blasting technology (Cole *et al.*, 2011; Heo *et al.*, 2013). Small beads that are used in sandblasting are washed into the oceans. These mesoplastics may even carry metal residue picked up from their use (Auta *et al.*, 2017).

2.5.2 Secondary Mesoplastics

Secondary mesoplastics are formed from the breakdown of larger plastics such as water bottles, both at sea and on land (Ryan *et al.*, 2009). This typically happens when the larger plastics undergo weathering through exposure to conditions like wave action, wind depreciation, and ultraviolet radiation from the sun. The fragmentation of plastic items is occurring in the environment as a result of various physical, biological, and chemical processes that reduce the structural integrity of plastic debris (Browne *et al.*, 2007).

Weathering is the most important process causing the breakdown of plastics (Arthur *et al.*, 2008). According to Corcoran *et al*., (2009) beaches are the optimal settings for plastic fragmentation due to the presence of both chemical and mechanical weathering. Another important process is photodegradation caused by sunlight. The ultraviolet radiation in sunlight causes oxidation of the polymer matrix, resulting in the breakage of the chemical bond (Barnes *et al.*, 2009). Compared to the cold temperatures of the marine environment, plastic debris on beaches degraded more quickly due to the higher oxygen availability and direct exposure to sunlight, resulting in the loss of structural integrity (Browne *et al.*, 2007; Moore *et al.*, 2001).

Furthermore, plastic particles are vulnerable to fragmentation from a combination of mechanical forces, for example, abrasion, wave action, and turbulence. The introduction of biodegradable plastics is also a source of mesoplastics. Biodegradable plastics composed of traditional synthetic polymers plus starch and vegetable oils and are designed to degrade faster (Derraik, 2002; Thompson *et al.*, 2004). However, if the plastics are inappropriately disposed of, the synthetic polymer, which is not biodegradable, will accumulate and fragment in the environment (Li *et al.*, 2016).

2.5.3 Beach Topography

The accumulation rate of marine debris on beaches is known to be inversely correlated with its geographical distance to a population center, and directly proportional to the number of beachgoers, with other factors being the natural condition and processes, such as erosion, topography, local tides and winds (Barnes *et al.*, 2009; Ribic *et al.*, 2012). Beaches that lack strong prevalent winds often possess greater abundance of beached debris, accumulating during high-tide lines (Costa *et al.*, 2010; Oigman-Pszczol & Creed, 2007). Moreover, the distribution pattern of debris on beaches is frequently found in patches owing to the beach topography, with smaller and lighter items more easily dispersed or buried (Agamuthu *et al.*, 2019).

Studies on the presence of small plastic debris on shoreline sediment have focused on different beach profiles, such as low and high tide lines, and berms. The study conducted by Sathish *et al*., (2019) found that small plastic concentration at the high tide line twice more than the low tide line because the low tidal area remains immersed during most part of the day. In addition, the research on the microplastics conducted by Hengstmann *et al*., (2018) and Kim *et al*., (2015) also got similar results for beach samples of the high tidal zones.

Despite of that, the small plastic found at the berm also comparatively higher compared to low tide zone and lower than high tide line. The high accumulation of plastic debris on the high tide lines because of particles suspended in the water will be left on shore during every receding tide, whereas berm debris may be deposited primarily during storms, or as wind-blown debris from the high tide line (McDermid & McMullen, 2004). This supported by the research conducted on Fauziah *et al*., (2015), berm area has the highest number of accumulated plastic debris as compared with high tide and low tide.

Foam is the most abundant type of plastic debris found at the backshore. Styrofoam is a lightweight material that is often found bound to other materials at strandlines and can be blown toward the backshore by wind (Lee *et al.*, 2017). This finding is supported by the result of research conducted by Heo *et al*., (2013) with regard to the abundance of styrofoam including both at the high strandline and cross-sectional line. The accumulation of small plastic debris in the berm area is due to the wind and wave action, which pushed above the deposited debris on the beach sediment (Morishige *et al.*, 2007).

2.5.4 Transportation of small plastic debris

The buoyant characteristic of plastic pollutants enables it to be carried longer distances by prevailing winds, ocean currents, and tides (Wessel *et al.*, 2016). This debris then can be deposited along seashores, even on isolated islands (Jang *et al.*, 2018). This supported by the research on the presence of small plastic fragments in marine sediment along the Alang-Sosiya ship-breaking yard, India described plastic fragments are believed to have resulted directly from the ship-breaking activities at the site (Reddy *et al.*, 2006). The study of microplastics pellets along the Chennai coast also proved that the wind and current during November were the driving forces for the transportation and deposition particles from the sea to beaches (Veerasingam *et al.*, 2016a).

However, contradict findings were obtain in the study conducted by Yi & Kannan, (2016). High energy conditions such as wind and waves in the beaches correlated with less debris deposition on the beaches. This may be due to the fact that wind and waves drive away the lighter, floating materials from landing on the beaches. Thus, the focus of this study is to investigate the pollution level of Malaysian islands located in Strait of Malacca and South China Sea.

2.5.5 Wave and Tidal Movement

The changes in the monsoon have a significant effect on the amount of small plastic debris found on the beaches. The study conducted on Sri Lanka's beaches shows high small debris density during the northeastern monsoon (Jang *et al.*, 2018). In addition, a study conducted at beaches in Hong Kong revealed that the abundance of marine debris was significantly higher in the wet season than in the dry season (Cheung *et al.*, 2016).

A similar study on seasonal variation in the quantity of floating plastic in Banderas Bay, Mexico, discovered that the amount of plastic trash was much higher during the hurricane season than during the dry season, indicating that the ocean is becoming more polluted, consistent with previous findings. Additionally, this study also revealed that rainfall might play a significant role in the discharge of plastics into the bay from land-based sources (Pelamatti *et al.*, 2019).

There are relatively few studies on the effect of the monsoons on marine debris levels in Malaysia. However, these results prove that the amount of stranded debris on beaches is significantly influenced by wave and tidal movement. The study conducted at local beaches in Pahang also proved that the seasonal changes in the tidal current particularly Northeast Monsoon shows a significant increase in the marine debris density (Azman *et al.*, 2021). Consequently, the significant prevalence of marine debris on beaches along Peninsular Malaysia's east coast has been ascribed to the region's exposure to robust South China Sea wave currents and tides (Fauziah *et al.*, 2021).

Furthermore, the research conducted on beaches in Terengganu, Pahnag, Negeri Sembilan, Johor, Sabah and Sarawak shows that the high accumulation of plastic debris is mainly due to the high waves during the monsoon season (Azman *et al.*, 2021; Fauziah *et al.*, 2021; Mobilik & Hassan, 2016). However, more research is needed to determine how the monsoon influences the distribution and abundance of marine debris on beaches in Peninsular Malaysia.

It has also been proven that the amount of stranded debris on beaches is significantly influenced by waves, as evidenced by the findings of research done in Malaysia. The significant prevalence of marine debris on beaches along Peninsular Malaysia's east coast has been ascribed to the region's exposure to robust South China Sea wave currents and tides.

2.5.6 Landfill Leachate

There is also evidence showing the presence of mesoplastics from the landfill leachate. According to the findings of a study conducted in the Galuga Landfill Area in Indonesia, mesoplastics were found in all surface water samples collected from leachate influent and effluent. This investigation suggested that the leachate might contaminate the aquatic environment with micro and mesoplastic (Nurhasanah *et al.*, 2021). As the islands' location in this study is situated surrounding Peninsular Malaysia, there are high possibilities for the accidental release of leachate from the landfills to reach these beaches.

The release of the leachate mesoplastics may be more significant during periods of heavy rain. Plastic debris in sludge can be carried over and released into the aquatic ecosystem (Nurhasanah *et al.*, 2021). Besides that, chemical impacts of leachates from diverse plastic products were found to cause toxicity induced by monomers, residues of production processes, and additives (Eriksen *et al.*, 2018).

2.5.7 Plastic Degradation

The formation of small plastic debris in the size of mesoplastics occurred by degradation of the larger size plastics. Degradation occurs when plastic litter on the shore is exposed to sunlight, temperature, humidity, pollutants, biological attacks, and physical stress (Masry *et al.*, 2021). Thus, the beach setting has been considered the most suitable environment on earth for plastic degradation (Cooper & Corcoran, 2010). Plastics degrade in the environment through four mechanisms: photodegradation, thermo-oxidative degradation, hydrolytic degradation, and biodegradation by microorganisms (Wang *et al.*, 2016; Webb *et al.*, 2013).

Oxidation from exposure to solar UV radiation increased plastic degradation, and with additional abrasion, resulted in breakages along fractures, eventually leading to plastic embrittlement (Corcoran *et al.*, 2009). According to the environmental conditions and the type of plastic, mechanical forces such as wind action, current, and tides can result in fragmentation and dissolution of the plastic (Masry *et al.*, 2021). The study conducted at several marine sediments in Hong Kong proved that weathering rates in the beach and ocean are different. Under intense UV irradiation and physical erosion by waves, plastic debris can persist in beach sediments for a more extended period (Tsang *et al.*, 2017; Veerasingam *et al.*, 2016a).

In addition, the transport process in coastal waters favors the degradation of mesoplastics. The mesoplastics drifting close to the coast are likely to be washed ashore on beaches, and easily return to the ocean by tides and waves. This selective onshore transport of mesoplastics works persistently until they degrade on beaches into microplastics. Once mesoplastics degrade into fragments smaller than a few millimeters, these microplastics are free of the near-shore trapping, and thus able to spread offshore. (Isobe *et al.*, 2014).

2.5.8 Land-based Sources

Land-based plastic debris can enter the aquatic environment in a variety of ways. The majority of marine plastics come from land-based sources like untreated sewage, litter, stormwater, and industrial facility discharges. Plastics can be easily blown into waterways by the wind and washed out into the sea, either accidentally or intentionally, due to their lightweight properties (Bamford *et al.*, 2008; Kienitz, 2013; Opfer *et al.*, 2012). the common land-based type of marine plastic debris is single-use packaging materials (Thompson *et al.*, 2009).

Besides that, municipal landfill near rivers and stream in coastal areas are one of the most significant land-based sources of marine debris. Plastics escape from disposal facilities due to poor landfill management and insufficient waste management facilities. Plastic bags and food packaging, in particular, can be blown into water streams or directly into the sea. Many estuaries near waste treatment sites in the United States have been found to be severely contaminated with waste. Plastics may also be released during collection and transportation, particularly if dumping trucks are not adequately covered (Allsopp *et al.*, 2006; Sheavly, 2007; Thia-Eng *et al.*, 2000). Plastics can be blown away from trucks or waste containers and enter water bodies (Barnes *et al.*, 2009).

Andrady (2011) discovered that the primary source of small plastics is fragmentation of large plastic debris. Plastics can degrade in the presence of sufficient sunlight and high temperature, which can break off chemical bonding and increase their fragility. This process, however, will be hampered in the marine environment due to low temperatures and insufficient sunlight (Bamford *et al.*, 2008). As a result, large items cannot completely decompose and must be broken down into smaller pieces through physical, chemical or even biological action. Plastic items are typically fragmented into small pieces as a result of physical abrasion and wave action (Barnes *et al.*, 2009). Therefore, it is well understood that a variety of factors contribute to mesoplastic pollution, and massive amount of this debris have entered and accumulated in the ocean.

2.5.9 Sea-based Sources

The dominant sea-based sources of mare debris are shipping, military fleets, fishing, and research vessels, offshore oil and gas platforms, and aquaculture installations (Kershaw *et al.*, 2011; Kienitz, 2013). In many cases, the major marine debris at the lower latitudes comes from sea-based sources such as fishing vessels and container ships, which are washed shoreward (Kienitz, 2013; Programme *et al.*, 2005).

The main plastic pollution in certain areas, such as the major shopping lines and remote islands, is from vessels (Kershaw *et al.*, 2011). Guidelines from the United Nation Environment Program, UNEP, (2005) estimate that around 5 million plastic items ate discarded from ships and other vessels. Fishing gear and nets, food and beverage containers, plastic bags, and other household trash are among the plastic items commonly discarded from vessels. Fishing nets and gears are one of the most common types of plastic debris found in the ocean, representing 50 to 90% of all marine litter (Kershaw *et al.*, 2011; Programme *et al.*, 2005).

Plastics can enter the aquatic environment at sea through accidental loss or deliberate dumping. Due to a lack of awareness about the consequences and impacts of such direct disposal, fishermen typically dump ship-generated trash into the sea (Hammer *et al.*, 2012). Furthermore, cargo containing plastics may be lost from commercial ships, especially during severe weather. Plastic toys and resin pellets, for example, may leak from the containers and end up in the ocean (Bamford *et al.*, 2008).

For recreational, research vessels, and military, more domestic waste is expected to be released into the ocean. These ships usually carry larger numbers of people for comparatively long periods of time. If daily garbage generated onboard is not properly managed and given the constraint on storage, the trash can end up in the marine environment (Sheavly, 2007). The consecutive sections discuss the impact of small plastic debris on the marine ecosystem.

2.6 Impacts of Small Plastics Pollution

2.6.1 Environmental Impacts

Small marine plastics cause the ingestion, suffocation, and entanglement of hundreds of marine species. For example, seabirds, whales, fish, and turtles mistake plastic waste for food and starve to death as their stomachs fill with plastic debris. Plastic debris also causes lacerations, infections, impaired swimming ability, and internal injuries to the marine organism (Bhuyan *et al.*, 2020; Kasavan *et al.*, 2021; Thushari & Senevirathna, 2020). Therefore, it is critical to understand how plastic waste affects marine ecosystems as plastic production rises. The following section will discuss the impacts of small plastic debris on aquatic organisms in detail.

2.6.1.1 Entanglement

The entanglement in macroplastic items is widely recognized in vertebrates (Wright *et al.*, 2013). Entanglement cases were mainly recorded between the individual organisms and fishing nets or plastic rope in fishing gears. The entanglement effect is comparatively higher than the ingestion by biota in coastal and marine systems. Entanglement of macroplastic debris can be lethal or sub-lethal. As the direct results of entanglement, coastal and marine biotic organisms die or get injured lethally. Sub-lethal effects cause reducing capturing and swallowing food particles, impairing reproduction ability, loss of sensitivity, the inability to escape from predators, loss of mobility, decreased growth, and body condition. Comparatively, sea turtles, marine mammals, and all types of sea birds are at higher risk of entanglement by plastic pollution (Thushari & Senevirathna, 2020).

2.6.1.2 Ingestion

The tiny size and low-density mesoplastic are possible to be ingested by lower trophic organisms. An increase in the abundance of small plastic debris in the marine environment affects its bioavailability. In addition, mesoplastics' colour may influence the likelihood of ingestion due to prey item resemblance (Wright *et al.*, 2013). Entanglement is one of the more visible impacts of plastic debris, affecting a large number of marine. More than 180 species of organisms have been documented to ingest plastic debris, including fish, turtles, marine birds and mammals (Laist, 1997; Ryan *et al.*, 2009; Wang *et al.*, 2016).

2.6.1.3 Toxicity

Toxic chemicals associated with plastic debris pose another risk. Plastic toxicity is primarily associated with the accumulation, transfer, and release of these pollutants. Plastic in the marine environment absorbs pollutants and becomes more toxic over time. These toxic mesoplastics then accumulate in aquatic food chains and are stored in the fatty tissues of predators. Thus, going up the food chain, the concentration of the pollutant increases. The build-up of hazardous materials in an organism's tissue is called bioaccumulation. At the same time, biomagnification refers to the rise in the concentration of a toxicant going up the food chain trophic levels.

2.6.2 Impacts on Human Health

The impact of mesoplastics on human health id not major attention as it possesses only an indirect impact on the community. Thus, the effect on human health have not been well deliberated, and no studies specifically address this issue, despite the fact that plastic debris has been identified as a potential human health hazard. The mesoplastics found in the environment are contaminated with pathogenic microbes which can cause health problems for humans due to particle toxicity. In addition to that, direct contamination of mesoplastics in the water sources and human foods such as seafood, enters the human digestive system, which in turn causes carcinogenic diseases (Lestari & Trihadiningrum, 2019; Raha *et al.*, 2020).

Furthermore, plastics floating on the sea surface may create safety and aesthetic problems. Residents and visitors to the coast ate at risk of serious injuries if they come into contact with sharp materials, including small fragments of plastic during bathing, boating, and fishing. Plastic pollution can have significant impact on the economy of coastal regions and fishing industries. Plastic waste detrend the aesthetic value of tourist destinations, leading to decreased tourism-related revenues and major economic costs related to the maintenance and cleaning of the sites (Abu-Hilal & Al-Najjar, 2004; Browne *et al.*, 2007).

2.6.3 Impacts on Climate Change

Ina addition to the discussions in the previous sections, plastics also contribute to global warming. Most of the plastics such as ethylene and propylene are made of fossil fuel materials. Plastic manufacturing, including the extraction and transportation of fossil fuel, generates billions of tonnes of greenhouse gases. Plastic, which is a petroleum product, if incinerated, releases carbon dioxide into the atmosphere, thereby increasing carbon emissions. Furthermore, greenhouse gases have disastrous effects on the ocean. The ocean will become more acidic by absorbing carbon dioxide. This will affect the entire marine food chain and habitat for many vulnerable corals and marine species (Rai *et al.*, 2020).

2.6.4 Maintenance and Clean-up Cost

Apart from environmental destruction and direct expenses, marine waste consequentially costs the authorities and communities a considerable amount of money and efforts to reinstate the contaminated area. If the esthetical value of an area is threatened, it will force the authorities to bear the costs of cleaning and maintenance of the beach. However, the costs of sustaining the biological system and removing marine debris are lower as compared to the benefit it may gain. As a tourist attraction and recreational spot, the cleanliness of the coastal area plays a major role in attracting more visitors. Thus, maintaining the beaches free from pollution becomes very crucial to support tourism activity as well as conserving marine nature (Khairunnisa *et al.*, 2012).

2.7 Beach Survey

Shoreline or "beach" surveying is one of the most widely used and well-established methods of determining marine plastic pollution in bodies of water. As opposed to at-sea surveys, shoreline surveys provide estimates of plastic in coastal waters and are significantly more cost-effective (Angelini *et al.*, 2019). Quantitative analysis on the present of small plastics debris or mesoplastics mainly focuses on the identification of debris accumulation along the shoreline and quantifying changes of accumulation over time (Azman *et al.*, 2021).

Although there is no specific standard to study the mesoplastic accumulation on beaches, most studies conducted in this field refers to the method established by National Oceanic and Atmospheric Administration (NOAA) (Azman *et al.*, 2021). There are inconsistencies in the comparability of studies due to the absence of standard sampling, analysis, and reporting methods and techniques. In addition, many different units of measurement were applied to represent the data on weight, density, concentration, and other parameters. Consequently, comparing the results available between studies is a challenge.

Furthermore, beach selection with varying distance from major litter source for beach survey can provide useful insight into the origins of plastic debris (Ryan *et al.*, 2009). The selection of sampling sites in this study from different islands and spatial representation of various locations in peninsular Malaysia, will determine how the sources of plastic litters contribute to the accumulation of small plastic debris on the beaches. The procedures of sampling, extraction, enumeration, and identification used in this study will provide some guidelines for standardizing the methodologies used in future microplastic surveys.

2.8 Gaps in Standard Methodologies

The environmental, economic, and social costs associated with marine debris are enormous on a global scale. However, inadequate scientific research, assessment, and monitoring are significant obstacles in addressing this issue. In addition, studies on the sources, fates, and impacts of marine debris are lacking. Efforts to prevent and reduce the impacts of marine debris require scalable, statistically rigorous, and standardized monitoring protocols. Although several countries currently monitor marine debris, the protocols used vary widely, preventing cross-regional or cross-temporal data comparisons.

2.9 Management of Plastic Pollution

Every day around the world, millions of single-use plastics are discarded. The linear model of take, make, and dispose needs to be shifted to a more circular economy in the plastic value chain, where the products are designed to be reused and recycled. This will eventually reduce the consumption rate. To address plastic pollution, new materials are being developed, such as bioplastics, made from natural materials, biodegradable plastics that are broken down by living organisms, and compostable plastics, which are designed to be decomposed in a composting facility. This innovation is still in the early stages and requires proper management and disposal (Rai *et al.*, 2020). Beyond these solutions, consumer behavior changes, product and technological innovations, and comprehensive legal framework and tax incentives are needed (Schnurr *et al.*, 2018). The sources of mesoplastics and their potential measures are given in Table 2.4.

Table 2.4: Sources of Mesoplastics and Its Potential Measures

Category	Source	Potential Mitigation
Consumer	Tyre dust	Technological advances, road surface
	Littering of small plastic items (cigarette filters, torn corners of packaging, small film wrappers, etc.)	Enforcement of fines for littering, consumer education, EPR on design
	Domestic laundry. Wastewater effluent	Wash with top-load machines. Wastewater containment, single-fiber woven textiles. Textile coatings
Commerce	Industrial abrasives	Improve containment and recovery and require alternatives
	Laundromat exhaust	Improved filtration
	Agriculture – degraded film, pots, and pipes	Improve recovery, biodegradable plastics
Waste management	Fragmentation by vehicles driving over unrecovered waste	Improved waste management
	UV and chemically degraded terrestrial plastic waste	Improved waste management
	Sewage effluent (synthetic fibers)	Laundry filtration, textile industry innovation
	Combined sewage overflow (large items)	Infrastructure improvement
	Mechanical shredding of roadside waste during regular cutting of vegetation (mostly grass)	Better legislation and law enforcement; valorization of waste products
Production	Microplastics in cosmetics	Removing them from products. Replace with benign alternatives
	Mismanaged preproduction pellets	Regulate pellet handling. Operation clean sweep

Source:(Eriksen *et al.*, 2018)

2.9.1 Bioremediation of Plastics

Plastic is non-biodegradable and therefore pollutes the environment when it is discarded irresponsibly. Although the problem of plastic pollution remains unsolved, different techniques are being considered for reducing its environmental impact, including the physical and chemical breakdown of plastics. However, these techniques have advantages and drawbacks. The current approach to the process of plastic biodegradation is by using microbes. Microorganisms play a critical role in the biodegradation of plastic materials, including synthetic polymers (Shah *et al.*, 2008; Sharma, 2018; Thushari & Senevirathna, 2020).

Bioremediation is a process of adding organisms to an environment for promoting the degradation of harmful or undesirable elements of that ecosystem. The discovery of microbial degradation of plastics has been broadening for decades. Microbial degradation of plastic is a promising eco-friendly approach that represents a great opportunity to deal with waste plastic materials with no tremendous impacts. Naturally presence microbes have been discovered to be capable of degrading a wide range of plastics. However, lacking of essential understanding and inadequate technological availability, became a challenge to rationalize the finding to the field application (Naik & Dubey, 2017; Urbanek *et al.*, 2018).

Plastic biodegradation is dependent on complex interactions between environmental and biotic factors, such as photo-oxidation, UV-radiation, and temperature. This will impact the molecular structure of the plastic, which affects vulnerability to microbial attack. Biodegradation can be divided into deterioration, fragmentation, and assimilation. Enzymes and microorganisms are different biotic factors which can act at each of the three stages of biodegradation (Kumari & Chaudhary, 2020; Sanz-Lázaro *et al.*, 2021; Thushari & Senevirathna, 2020).

Throughout biodeterioration, abiotic and biotic factors such as light and secreted hydrophobic change the polymer surface and expand its surface area. The polymer properties are altered for colony and biofilm growth. The next step is biofragmentation, where the polymer is transformed into oligomers and monomers. During this stage, microbes produce enzymes that breakdown the polymer down into its monomer components. In the final phase, assimilation may occur when the microbes metabolize the monomers into biomass, carbon dioxide, and water (Rai *et al.*, 2020; Sheth *et al.*, 2019).

CHAPTER 3: METHODOLOGY

3.1 Research Location

In this study, four islands were selected as the main research locations. These islands were chosen to represent the different parts of Peninsular Malaysia. Pulau Langkawi and Pulau Besar were selected to represent the West of Peninsular Malaysia, while Pulau Perhentian and Pulau Sibu represent the East of Peninsular Malaysia. The islands at West and East of Peninsular Malaysia are located in the Strait of Melaka and the South China Sea, respectively. The locations of the islands are shown in Figure 3.1 and the coordinates of these islands are given in Table 3.1.

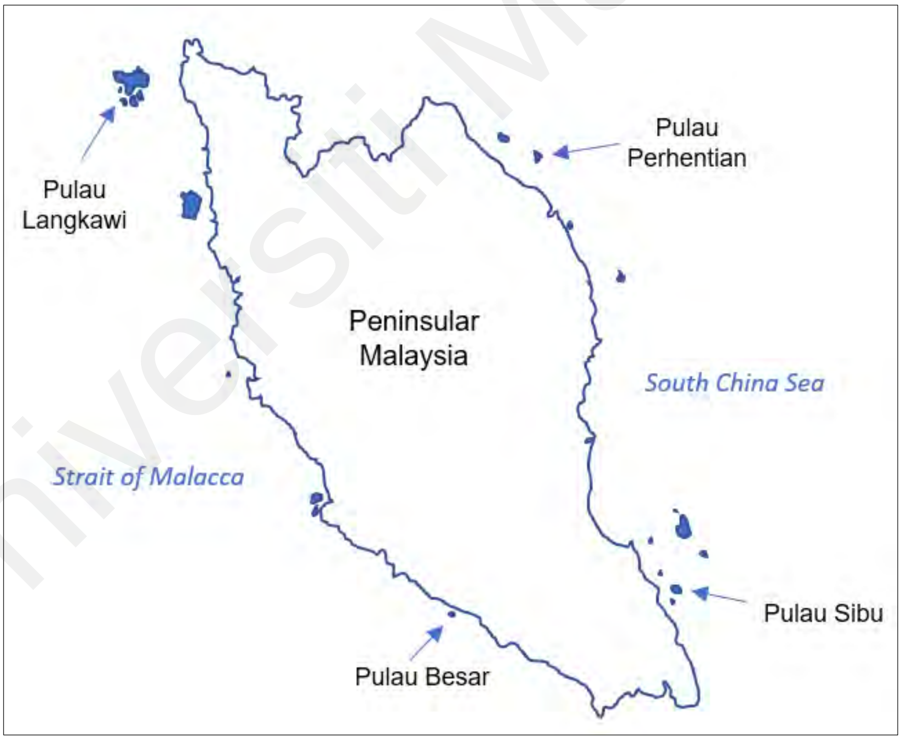

Figure 3.1: Locations of selected islands in this study

Table 3.1: Coordinates of the selected islands

Research Locations	Coordinates	
	Latitude	Longitude
Pulau Perhentian	5°53'58.86"N	102°45'36.76"E
Pulau Sibu	2°12'54.14"N	104° 4'27.42"E
Pulau Besar	2° 6'42.05"N	102°19'39.63"E
Pulau Langkawi	6°21'56.08"N	99°46'26.68"E

3.2 Sampling Design

At each island, two coastal areas were selected as the main sampling sites. The sandy beaches were randomly chosen considering the accessibility to sampling sites and spatial representation for each coast (Lee *et al.*, 2015). Besides that, the sampling sites were selected based on their environmental features, hydrodynamic conditions, meteorological characteristics, and topographical conditions as recommended by various reports (Jayanthi *et al.*, 2014; Veerasingam *et al.*, 2016a; Veerasingam *et al.*, 2016b; Vianello *et al.*, 2013). The two sampling beaches included one beach that faces the open sea (Straits of Melaka or the South China Sea) while another beach facing the mainland of Peninsular Malaysia. The location of the sampling sites is illustrated in Figure 3.2.

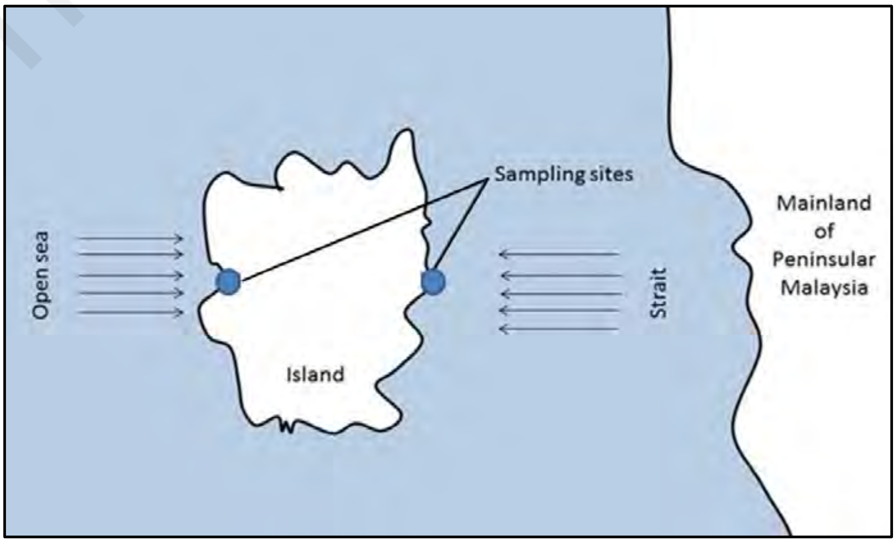

Figure 3.2: General map of sampling locations at each island

There are eight sampling sites in this study. Systematic sampling techniques were applied in this study in accordance to the method by Zhao *et al*., (2015). The samplings were conducted once bimonthly for six months (May, July, September) with 56 - 64 days intervals from the previous sampling date (Lippiatt *et al.*, 2013).

However, the fourth sampling for all the sites was carried out in the month of February 2017 with four months gaps from the previous sampling date due to the changes in monsoon especially on the East coast of Peninsular Malaysia. This phenomenon prohibited safe access to the islands such as Pulau Perhentian and Pulau Sibu. Besides that, the weather on the West coast of Peninsular Malaysia was also not favorable for sampling from the month of January 2017 until the end of March 2017 due to unpredictable raining seasons and natural disasters (flooding) in the areas.

The number of beach users, the main type of beach activities, weather conditions during the sampling periods, and types of beach sediment were observed and recorded. Besides that, the coordinates of the sampling points were documented using the GPS (Appendix I). The length and width of the selected beaches were also measured. The descriptions of all the sampling sites are represented in Table 3.2 and Table 3.3.

Table 3.2: Descriptions of sampling sites

Islands	Direction	Sampling sites	Coordinates		Width of the beach (m)	Sediment type	Major activities
			Latitude	Longitude			
Pulau Langkawi	FTM	Penarak Beach	6°18'30.10"N	99°51'47.17"E	210.63	Sandy	Fishing Jetty
	FTS	Tengah Beach	6°16'48.20"N	99°43'47.72"E	1150	Sandy	Recreational
Pulau Besar	FTM	Jeti Beach	2° 6'56.67"N	102°20'4.93"E	127.57	Sandy / Pebble	Tourist Jetty
	FTS	Makam Sultan Ariffin Beach	2° 6'33.28"N	102°19'52.13"E	185.53	Sandy	Recreational
Pulau Perhentian	FTM	Tanjung Butong Beach	5°56'15.17"N	102°43'13.18"E	140.96	Pebble	Undisturbed
	FTS	Pinang Seribu Beach	5°54'34.54"N	102°46'10.29"E	69.04	Sandy	Undisturbed
Pulau Sibu	FTM	Pasir Teluk Penetap Beach	2°13'1.09"N	104° 4'10.98"E	336.95	Sandy	Tourist Jetty
	FTS	Pasir Belakang Beach	2°13'12.83"N	104° 4'13.18"E	77.89	Sandy /Muddy	Recreational

* FTM = Facing towards the mainland of Peninsular Malaysia; FTS = Facing towards the open sea

Table 3.3: The observational data collected during the samplings

Islands	Sampling sites	Sampling date	Time	Temperature (^oC)	Weather condition	Wind direction	Site usage	Average no. of beach user per transect
Pulau Langkawi	Penarak Beach	11/6/2016	10.30 am	31	Sunny	West-northwest	Medium	6
		13/8/2016	3.00 pm	30	Sunny	West	High	8
		8/10/2016	10.30 am	26	Light rain	West	High	7
		11/2/2017	3.00 pm	31	Cloudy	West	Medium	6
	Tengah Beach	11/6/2016	1.00 pm	32	Sunny	West-northwest	High	8
		13/8/2016	4.15 pm	30	Sunny	West	High	8
		8/10/2016	1.00 pm	28	Light Rain	West-northwest	High	7
		11/2/2017	4.15 pm	27	Cloudy	West	High	8
Pulau Besar	Jeti Beach	4/6/2016	8.30 am	25	Haze	East - northeast	Low	2
		6/8/2016	8.30 am	25	Cloudy	North east	Low	2
		1/10/2016	3.15 pm	32	Cloudy	West	Low	3
		4/2/2017	8.30 am	26	Cloudy	North West	Low	3
	Sultan Ariffin Beach	4/6/2016	2.00 pm	32	Haze	East	High	8
		6/8/2016	9.45 am	28	Cloudy	East	High	7
		1/10/2016	4.30 pm	29	Light Rain	West	Medium	4
		4/2/2017	9.45 am	32	Sunny	West	Medium	6

Table 3.3: The observational data collected during the samplings (Continued)

Pulau Perhentian	Tanjung Butong Beach	21/5/2016	12.00 pm	30	Haze	South west	Low	1
		16/7/2016	8.30 am	25	Cloudy	South west	Low	2
		17/9/2016	1.30 pm	30	Sunny	Calm	Low	1
		18/2/2017	3.00 pm	31	Sunny	East - northeast	Low	2
	Pinang Seribu Beach	21/5/2016	1.30 pm	32	Sunny	North	Low	1
		16/7/2016	10.00 am	29	Sunny	South west	Low	2
		17/9/2016	2.15 pm	31	Sunny	East - northeast	Low	0
		18/2/2017	4.30 pm	26	Cloudy	East - northeast	Low	2
Pulau Sibu	Pasir Teluk Penetap Beach	28/5/2016	12.30 pm	33	Sunny	South	Low	2
		23/7/2016	12.30 pm	32	Sunny	South	Low	2
		24/9/2016	12.30 pm	31	Sunny	South-southwest	Low	3
		25/2/2017	6.00 pm	27	Partly sunny	North	Low	1
	Pasir Belakang Beach	28/5/2016	11.00 am	32	Sunny	South- southeast	Medium	5
		23/7/2016	11.00 am	30	Sunny	Southwest	Medium	6
		24/9/2016	11.00 am	28	Cloudy	West	Medium	4
		25/2/2017	4.30 pm	32	Cloudy	West-southwest	Medium	4

*Site usage	Low – average number of beach user per transect below 3
Medium - average number of beach user per transect between 4 – 6
High - average number of beach user per transect between 7 – 1

3.3 Small Plastic Debris (Mesoplastics)

3.3.1 Beach Sediment Collection

3.3.1.1 Establishing Quadrat

Samples of small plastic debris or mesoplastics in the beach sediments were collected during calm conditions within three hours of low tides (Heo *et al.*, 2013; Lippiatt *et al.*, 2013; Losh, 2015b; Ng & Obbard, 2006; Sheavly, 2007; Stolte *et al.*, 2015; Wessel *et al.*, 2016). According to the monitoring protocol, the sampling needs to be done at the low tide stage to expose the largest amount of beach area especially the low tide strandline to be visible (Sheavly, 2007). The shoreline section transects and quadrats at the sampling sites were established according to the National Oceanographic and Atmospheric Administration (NOAA) Marine Debris Shoreline Survey Field Guide and United Nations Environment Programme (UNEP) shoreline survey guidelines (Figure 3.3) (Lippiatt *et al.*, 2013; Opfer *et al.*, 2012).

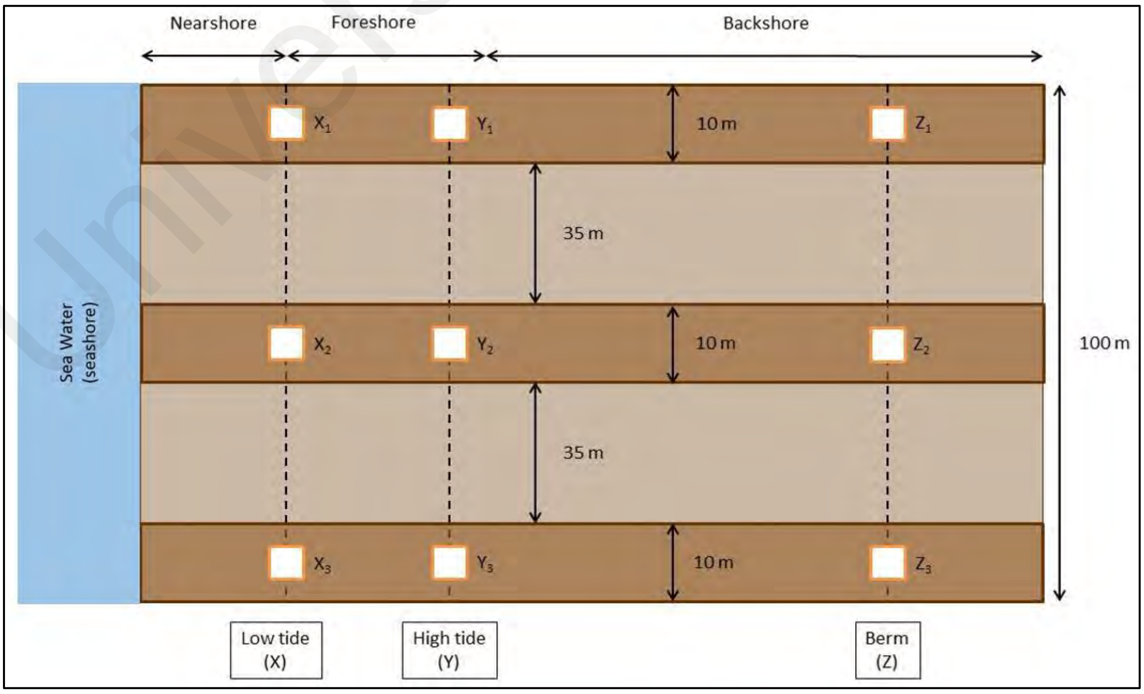

Figure 3.3: The schematic diagram of the beach sediment sampling point

A shoreline of 100 m was selected as the sampling area from the overall beach length (Losh, 2015b; Opfer *et al.*, 2012). The 100 m shoreline was set parallel to the water line and divided into three transects belts each 10 m wide. The interval between the transects is 35 m as shown in Figure 3.3. The length of the transect perpendicular to the waterline was measured from low tide terrace to berm scarp (Fauziah *et al.*, 2015). Measuring tape (100 m) was used to measure the length of the sampling area, as well as, the width of the beach (Losh, 2015a).

According to Ryan *et al.*, (2009) sieving, a strip transect from the most recent strandline to the back of the beach is more reliable to characterize mesoplastics abundance. Thus, triplicates samples extending from the berm (Z), high tide (Y) to low tide (X) terrace were collected. Hence, there were nine sampling points per beach.

3.3.1.2 Sample Collection

At each of the nine points, a quadrat of 50 cm × 50 cm (2500 cm^2) was marked (Cheung *et al.*, 2016; Fauziah *et al.*, 2015; Fauziah & Nurul, 2015; Hidalgo-Ruz & Thiel, 2013; Jayanthi *et al.*, 2014; Jayasiri *et al.*, 2013; Lavers *et al.*, 2016; Zurcher, 2009). Then, larger natural items such as algae, seaweed, leaves, and wood (>10 mm diameter) were removed from the sampling quadrats (Hidalgo-Ruz & Thiel, 2013; Wessel *et al.*, 2016).

At each point, 12.5 L of beach sediment that consists of sand and small gravel were scooped up within quadrat to a depth of approximately 5 cm, which are found in the uppermost section of the sedimentary cover (de Carvalho & Neto, 2016; Fauziah *et al.*, 2015; Heo *et al.*, 2013; Lee *et al.*, 2013; Nel & Froneman, 2015; Song *et al.*, 2015; Zhao *et al.*, 2015). The samples were placed into a bucket for analysis. The geographical position of the quadrat on the crest of the berm was used to re-establish the sampling areas, marked with wood stakes for reoccurrence sampling (Fauziah *et al.*, 2015).

3.3.2 Sieving of Samples

The sediment, in small portions, was then transferred to another empty bucket to be mixed with saline solution (seawater) and stirred gently for two minutes so that large plastic was not broken into smaller pieces and to allow buoyant particulates or low-density mesoplastic particles to float to the surface of the solution (Fok & Cheung, 2015; Ng & Obbard, 2006; Nor & Obbard, 2014). The sediment was then allowed to settle before the supernatant was poured through a series of metal sieves (Claessens *et al.*, 2011; Fauziah *et al.*, 2015; Jayanthi *et al.*, 2014).

The type of sieves used in this research is American Standard Sieves. The sieves were 200 mm in diameter with aperture sizes of 4.75 mm, 2.80 mm, and 1.00 mm. These sieves were arranged in an order of decreasing sequence of size from top to bottom (Fauziah *et al.*, 2015; Fauziah & Nurul, 2015). Particles which retained from each sieve tray (1- 30 mm) were placed in separate labelled zipper plastic bags and brought to the laboratory for sorting purpose. In the case of wet sand, sieving was conducted after air drying in the laboratory (Lee *et al.*, 2015).

3.3.3 Classification and Quantification of Samples

The plastic marine debris was classified into mesoplastics (1 – 30 mm). The technique used to classify the samples was visual sorting and separation (Hidalgo-Ruz *et al.*, 2012). Particles smaller than 1 mm (microplastics) were not included because they cannot be identified and counted with the naked eye (Lee *et al.*, 2015). Careful visual sorting of residues is necessary to separate the plastics from other materials. This is done by direct examination with the naked eye and with the aid of a dissecting microscope (Claessens *et al.*, 2011; Hidalgo-Ruz *et al.*, 2012).

Collected plastic fragments from each sieve tray were washed with distilled water to remove substances that adhere to their surface. The floating debris was picked out using stainless-steel forceps and transferred to petri dishes (Hidalgo-Ruz *et al.*, 2012; Zhang *et al.*, 2015). Samples were then oven-dried for 1 hour at 65°C. After drying, the mesoplastics were separated, identified, and classified into film, foam, fragment, line, and pellet (Fauziah *et al.*, 2015). The particles were placed in separate containers and labeled accordingly (McDermid & McMullen, 2004).

3.3.4 Calculation

The particle numbers of the debris items were recorded for all categories in each size class. The abundances of the mesoplastics were expressed in items/m^2 (Lee *et al.*, 2015) by applying the formula proposed by Kumar *et al*., (2016) with some modification:

$$C = \frac{n}{W \times L}$$

where

C : abundance of debris items (# of debris items/m^2);

n : number of mesoplastics collected;

W : width (m) of quadrat section used during sampling;

L : length (m) of quadrat

Thus, the equation for this research will be as given:

$$(\#\ \text{of debris items/m}^2) = \frac{n}{(0.5\ \text{m} \times 0.5\ \text{m})}$$

$$= \frac{n}{0.25\ \text{m}^2}$$

3.4 Coastal Water Quality

In this study, the physicochemical and biological parameters of the seawater were measured and classified based on Malaysia Marine Water Quality Criteria and Standard (MMWQS) (Al-Badaii *et al.*, 2013). These parameters were measured to identify the effects of mesoplastics on water quality.

3.4.1 Seawater Collection

The seawater samples were collected from various coastal areas at the selected islands of Peninsular Malaysia. The sampling frequency that was adopted in this monitoring was bimonthly sampling at the predefined time as discussed in the previous section. The samplings were done in the month of May, July, and September, with 56 to 64 days interval. Due to changes in monsoon, particularly on Peninsular Malaysia's east coast, the fourth sampling for all sites was carried out in February 2017, four months after the previous sampling date.

Triplicates water samples were collected from two points mainly, 3 m and 6 m away from the shoreline. These distances represent the coastal environment where they are in contact with the beach sediments. At each point, samples were taken from three different depths, upper (0.5 m), middle (1 m), and bottom layers (1.5 m). The schematic diagram of the seawater sampling points is illustrated in Figure 3.4. The positions of the sampling points were accurately located by using a hand-held Global Positioning System (GPS).

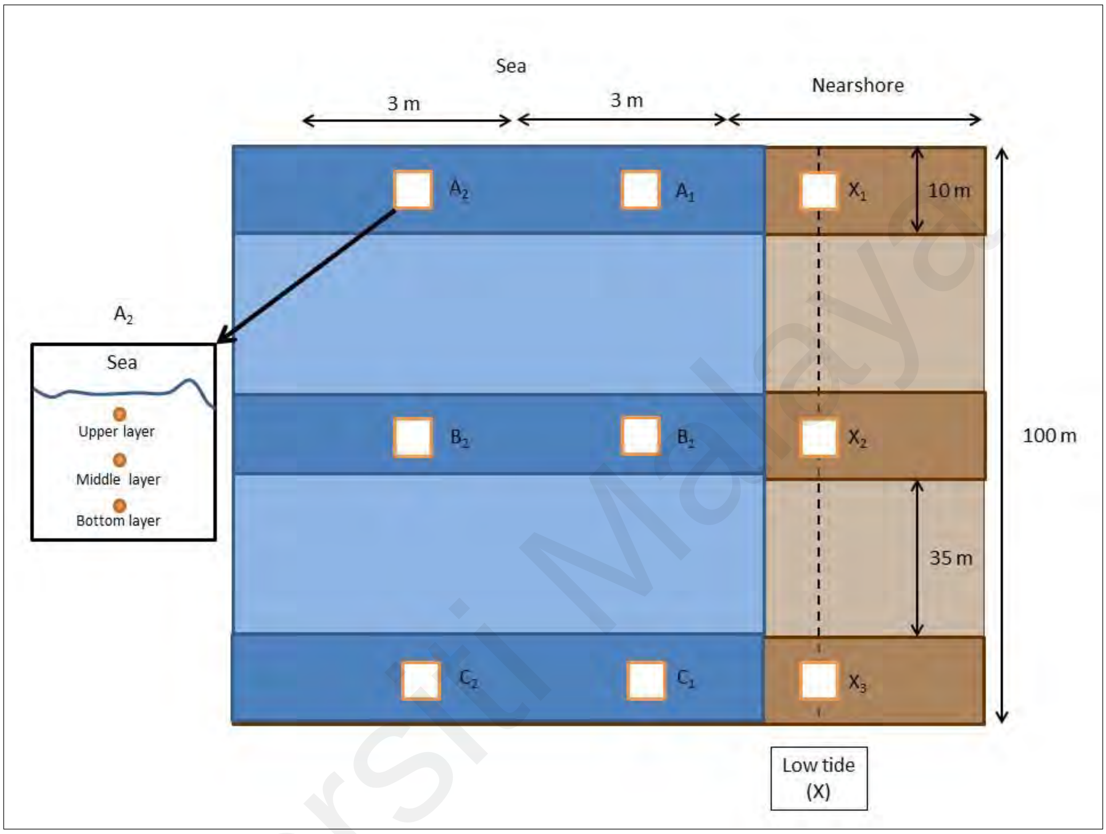

Figure 3.4: The schematic diagram of the seawater sampling points

Immediately after collection, the water samples were transferred into clean polythene bottles which were acid washed and rinsed with distilled – deionized water thoroughly before use (Al-Badaii *et al.*, 2013; Sreenivasulu *et al.*, 2015). The bottles were labelled by describing the name of the sampling area, date, time, sampling point's coordinate, and depth it was sampled. Then, the bottles were stored in an icebox within 24 hours prior to laboratory analysis according to the Standard Methods of APHA, 1998.

3.4.2 Physicochemical Analysis

A series of physicochemical parameters for all seawater samples were identified in this study. All the parameters studied were summarized in Table 3.4.

Table 3.4: Summary of physicochemical parameters and its analysis method

No.	Parameters	Units	Instruments	Methods
1	Temperature	ºC	YSI Pro-plus Handheld Multiparameter	*In-situ* measurem ents
2	pH	-		
3	Dissolved Oxygen (DO)	mg/l		
4	Conductivity	μS/cm		
5	Salinity	ppt		
6	Total dissolved solids (TDS)	mg/l		
7	Pressure	mmHg		
8	Oxidation-reduction potential (ORP)	mV		
9	Turbidity	NTU	Turbidity meter	Laboratory analysis
10	Total suspended solids (TSS)	mg/l	Gravimetric (Parsons *et al*, 1984)	
11	Ammonium	mg/l	Spectroquant® UV/VIS Spectrophotometer Pharo 300	
12	Nitrate (NO_3)	μg/l		
13	Phosphate	μg/l		
14	Silicate	μg/l		
15	Biochemical Oxygen Demand (BOD)	mg/l	APHA (1998)	

3.4.2.1 *In-situ* Measurements

The parameters such as temperature, pH, dissolved oxygen (DO), conductivity, salinity, and total dissolved solids (TDS) were recorded directly in the field at each sampling station as in-situ parameters using a portable water quality multiprobe (YSI Pro-plus Handheld Multiparameter). Samples were stirred gently, and stable readings were recorded. The turbidity of the seawater samples was measured using a turbidity meter. The equipment was calibrated prior to use based on the manufacturer's instructions.

3.4.2.2 Laboratory Analysis

Total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), and nutrient analyses were conducted in the laboratory. Nutrient analysis for ammonium, nitrate, phosphate, and silicate was carried by using the spectrophotometer (Spectroquant® UV/VIS Spectrophotometer Pharo 300).

(a) ***Biochemical Oxygen Demand (BOD_5)***

Standard procedures were adopted for assessing biochemical oxygen demand (BOD_5) from water samples collected (APHA, 1976). Biochemical oxygen demand (BOD_5) was analyzed as described by the 5-day test (Al-Badaii *et al.*, 2013). The collected water samples were diluted 200× with prepared BOD dilution water. Then, the pH was adjusted to pH 6.5 – 7.5 with the addition of acid or alkali solutions. The samples were filled into the BOD bottles and the DO_0 was determined by using a DO meter. The BOD bottle was filled with samples to the rim and trapped bubbles were avoided. The BOD bottles were incubated at 20ºC for 5 days. After Day 5, the DO_5 was determined using the following formula:

$$BOD_5 = DO_5 - DO_5 \times \text{dilution factor}$$

$$\text{Dilution factor} = \frac{\text{bottle volume (300 ml)}}{\text{sample volume}}$$

(b) ***Total Suspended Solid (TSS)***

The total suspended solids (TSS) is a gravimetric measurement that was determined by total solids dried to obtain constant weight. The filter was prewashed with 20 ml of distilled water three times. The mass of an empty porcelain dish (filter) was measured.

Then, 25 ml samples were filled into the porcelain dish and the weight was measured and recorded as initial weight. The samples were placed in the oven for 24 hours at 103 - 105ºC for evaporation. Once the temperature was stabilized, the porcelain dish was measured for final weight. The total suspended solids (TSS) were calculated using the following formula:

$$\text{mg TSS/L} = \frac{\{[\text{weight of filter} + \text{dried residue (g)}] - \text{weight of filter (g)}\} \times 1000}{\text{L of sample}}$$

3.5 Microbial Profiling

3.5.1 Total Heterotrophic Bacterial Count

Triplicates of 120 ml of seawater samples at each sampling point were collected for microbiological analysis. The test for detection and counting of microorganisms was done by adopting the standard plate count method (viable plate count) using membrane filtration as a direct measurement of microbial growth. A standard plate count reflects the number of viable microbes and assumes that each bacterium grows into a single colony.

3.5.1.1 Preparation of Media and Saline Solution

The heterotrophic marine bacteria were cultured using Zobell Marine Agar 2216. Normal saline solutions were used for pre-enrichment and dilution of seawater samples. The normal saline solution was prepared by dissolving 8.5 g of sodium chloride (NaCl) in 1000 ml of distilled water. The solution was sterilized by autoclaving for 15 minutes at 121°C.

3.5.1.2 Enumeration

A membrane filter was used to filter 100 ml of the seawater sample. The specification of the membrane filter used was 47 mm diameter and the mean pore was 0.45 µm diameter (APHA, 1976). The filtered samples were inoculated in 100 ml normal saline solution as pre-enrichment for three hours' incubation time at 37°C before proceeding to the next step. Filtration of the water samples retains microorganisms but allows water to pass, thus enabling microorganisms' collection upon filtering. After three hours, the mixtures of the filter paper and saline solution were shaken vigorously to homogenize it.

The suspension was then diluted until 10^5 and cultured into Zobell Marine Agar 2216. A series of dilutions were plated to insure a countable plate. Thus, serial tenfold dilution was prepared, and triplicate plates of each medium were made from each dilution. 0.1 ml of sample from the last three dilutions were taken with a sterile micropipette and directly poured onto the surface of Zobell marine agar plates. Using a sterile bent glass rod, an inoculum was distributed over the surface of the medium by rotating the dish by hand. The inoculum was let to absorb completely into the medium before incubating. All the plates were incubated for 24 – 48 hours at 37°C. Each plate was marked with the sample number, dilution, and date before the examination.

After incubation, the total count of the bacteria was taken. The exact number of colonies on the plates was counted. The plates with 30 and 200 colonies were chosen. This technique is based on determining the number of colonies forming units (CFU) grown on agar (Bogomolny *et al.*, 2013; Shrinithivihahshini *et al.*, 2014). The numbers of CFU per ml of the original sample were calculated using the following equation:

$$\text{CFU/ml} = \frac{\text{number of colonies}}{(\text{sample volume}) \times \text{dilution factor}}$$

3.5.2 Total Coliforms

For total coliforms analysis, the most probable number (MPN) method was adopted. Three test tubes containing 9 ml Lauryl Tryptose Broth (LTB) at different concentration was set up in triplicates. By inoculating 10 ml of samples in double strength concentration, 1 ml sample for single strength, and 0.1 ml sample for another set of single strength concentration of media, all sets of tubes were incubated at 30 - 37ºC for 48 hours. After 48 hours, all positive tubes were observed based on the turbidity of the broth and the presence of gas inside the Durham tubes. All positive tubes were recorded to obtain the code. This code is then being referred to MPN Table for total coliform calculations.

The positive tubes were cultured onto Eosin Methylene Blue (EMB) agar to test whether they are from the faecal coliforms group. A positive culture is indicated by the growth of dark purple colonies with green metallic sheen after incubation at 30 – 37 ºC (24 hours). One colony of each positive culture from EMB was inoculated into the brilliant green bile lactose (BGBL) broth and incubated for 48 hours at the same temperature. Positive tubes indicate the presence of *E. coli* in the samples (broth becomes turbid with gas collected inside Durham tube).

3.6 Statistical Analysis

All data obtained in this study which includes abundance and composition of mesoplastics, seawater quality, and abundance of microbes were statistically calculated, analyzed, evaluated, and compared. Statistical analyses of data were carried out using the statistical package 'IBM SPSS Statistics 23' and Microsoft Excel. Analysis of variance (ANOVA) was carried out to determine the significant differences between sampling stations (Al-Badaii *et al.*, 2013). The correlations between the abundance of mesoplastics, seawater quality, and abundance of microbes were also determined.

CHAPTER 4: RESULTS AND DISCUSSION

In this study, eight beaches located at four different islands around Peninsular Malaysia were selected for mesoplastics, coastal water quality, and microbial abundance analysis. The results and findings of this study are discussed in the following sections.

4.1 Beaches in Pulau Langkawi

Pulau Langkawi is located in the Northern West of Peninsular Malaysia. This island is situated in the Straits of Melaka which is one of the busiest shipping lanes in the world and across the straits is Sumatera Island (Indonesia). Tengah Beach and Penarak Beach in Pulau Langkawi were spatially chosen to represent the different locations on the island. Tengah Beach is famous for recreational activities while Penarak Beach is a fishing village. The locations of the sampling sites are illustrated in Figure 4.1.

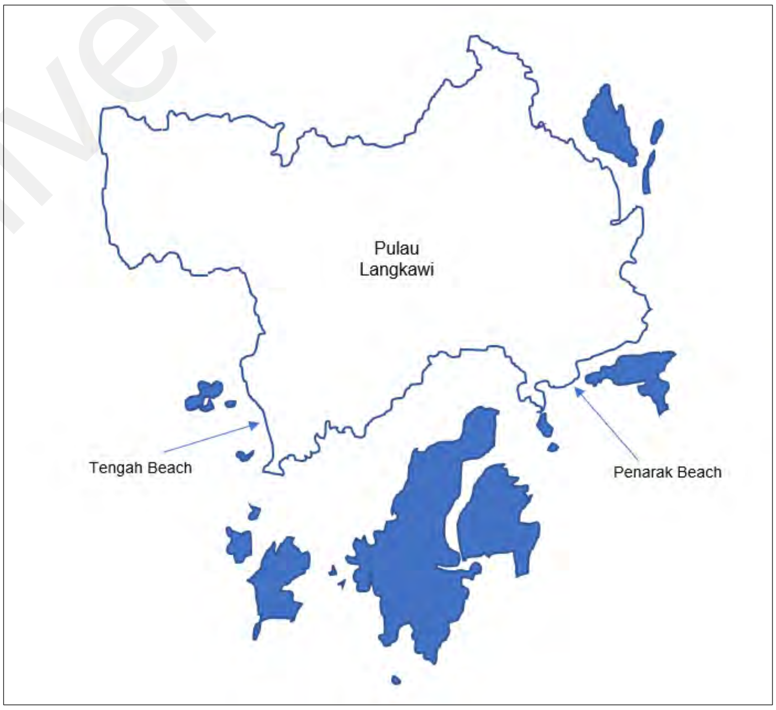

Figure 4.1: Location of sampling sites at Pulau Langkawi

4.1.1 Tengah Beach

Tengah Beach is one of the famous tourist attractions in Pulau Langkawi. This beach is located on the Western coastline of Pulau Langkawi and adjacent to Cenang Beach. These two beaches are located next to each other and separated by a cliff. Tengah Beach is about 18 kilometers from Kuah town which is the center point of Pulau Langkawi. This beach is about 900 meters long with a white sandy shoreline. Tengah Beach (Plate 4.1) is well-known among local and also foreign tourists. During weekends, a high number of visitors can be observed at this beach as many beach-based activities are available such as parasailing and jet ski riding.

Plate 4.1: Tengah Beach, Pulau Langkawi

Although at a glance Tengah Beach looks clean and unpolluted, the northern end of the beach is not very well maintained. During the site observation, some construction activities were taken place where building materials and other wastes were dumped at northern end. But, other sections of this beach are adequately preserved and well maintained. The waters along the beach is clear blue most of the time (first until third samplings) except during the monsoon when it tends to get a little murky due to stronger waves and water current at the shoreline (final sampling).

There are several chalets, spas, restaurants, and hotels along the beach, as well as, shops selling apparel, accessories, souvenirs, and gift items along the road (Jalan Pantai Tengah) that runs parallel to the beach. There are also some beach bars located right on the beach itself. Furthermore, many kiosks offer various kinds of watersport activities to the tourist which include Jet Skiing and Banana Boating along the beach. Some kiosks also offer boat tours to nearby islands such as Pulau Beras Basah, Pulau Rebak Kecil, and Pulau Singa Besar.

4.1.1.1 The Abundance of Mesoplastics at Tengah Beach

The abundances of mesoplastic at Tengah Beach were analysed and the data were presented in Figure 4.2. The total number of mesoplastics collected at this beach was 100 ± 7 items/m^2. The number of mesoplastics collected during the first and second samplings at Tengah Beach are of the same quantity which are 27 ± 2 items/m^2 respectively. These two samplings were conducted within a two months interval. The first sampling was held in the month of June 2016 while the second sampling was in August 2016.

Consistent visits of tourists and on-going beach activities might be the main contributor to the presence of mesoplastics at Tengah Beach. According to Agamuthu *et al*., (2012), the presence of marine debris on the shoreline may be contributed by the recreation, smoking-related events and waterway activities carried out at that beach (Jayasiri *et al.*, 2013).

However, during the third sampling, number of mesoplastics collected decreases to 13 ± 2 items/m^2. The amount was much lower as compared to the previous two samplings. The number of mesoplastics collected during the fourth sampling was 33 ± 4 items/m^2. Based on the results of all sampling events, the most abundant mesoplastics debris was found during the last sampling which was in February 2017. During this time, there were heavy rain and flood in the northern part of Peninsular Malaysia due to changes in the monsoon and this might serve as the main factor for the high accumulation of mesoplastics at Tengah Beach.

According to the study carried out by Mobilik *et al*., (2014), the monsoon season acts as an effective carrier of floating debris from the neighboring country to the Malaysian marine environment. As Tengah beach facing towards the open sea of the Straits of Melaka, the mesoplastics from the Sumatera Island might be transported across the strait and deposited along this beach (Mobilik & Hassan, 2016).

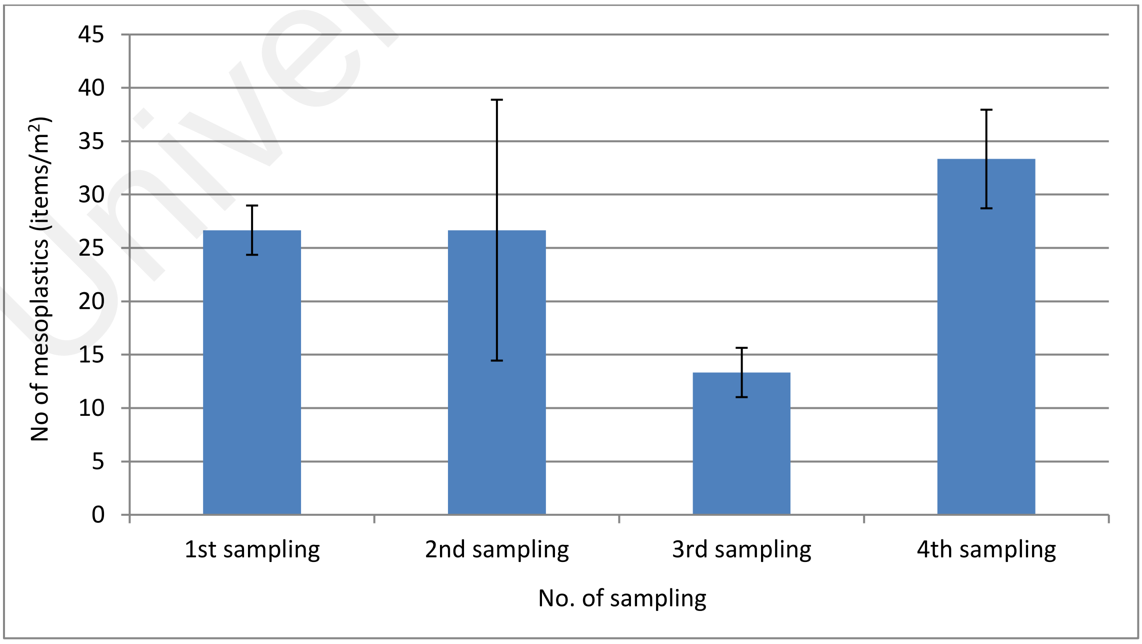

Figure 4.2: Quantity of mesoplastics at Tengah Beach

A One-Way ANOVA statistical analysis indicates that there were significant differences (P > 0.05) between the number of mesoplastics debris and the sampling months. The significant differences can be seen in the first and third samplings with a p-value is < 0.05. Besides that, there is a significant difference in the abundance of mesoplastics between third and fourth samplings ($p < 0.05$) (Appendix B). The distributions of mesoplastics according to their sizes and type at Tengah Beach (items/m^2) are shown in Figure 4.3.

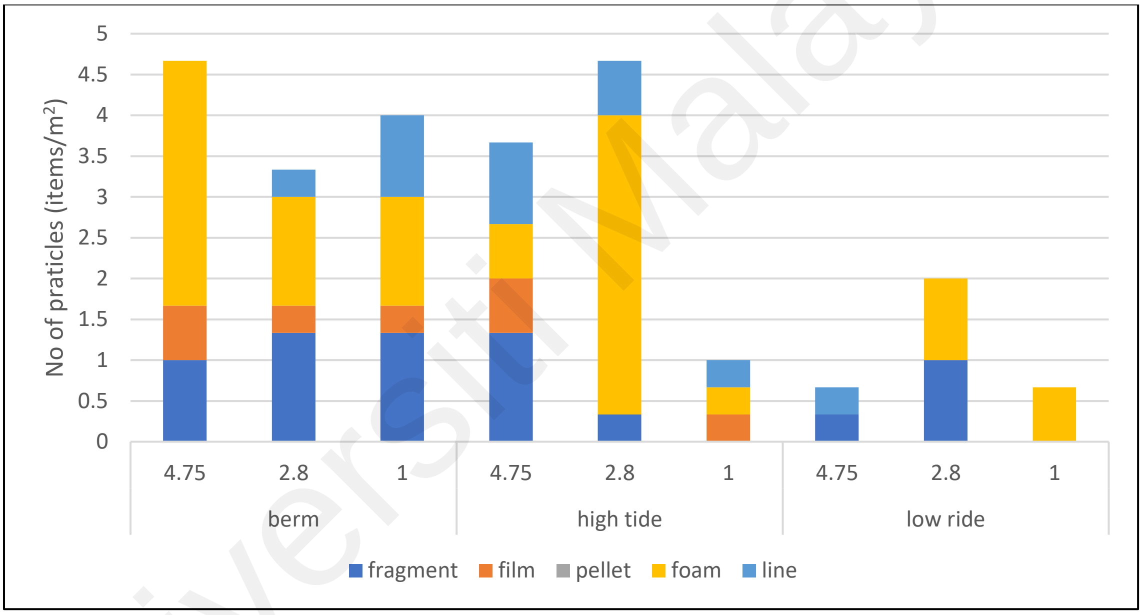

Figure 4.3: Composition of mesoplastics at Tengah Beach attributes

At Tengah Beach, 12 ± 5 items/m^2 of mesoplastics were found at the berm of the beach, 9 ± 3 items/m^2 at high tide area, and 3 ± 2 items/m^2 at low tide area. The results show that sediments collected from the berm area contain more plastic components compared to the foreshore regions (high tide and low tide). The high accumulation of mesoplastics at the berm of the beach is due to the high number of beachgoers in this area. The berm area which composed of sand makes it favorable for picnicking and other beach activities.

Therefore, a great quantity of plastic debris along the berm might be owed to plastic littering by beach users. Besides that, the highest tides could transfer more amount of marine debris between the tidal terrace and the water (Fauziah *et al.*, 2015; Ramos & Pessoa, 2019).

In terms of size, most of the debris found was within the range of 4.75 mm to 2.80 mm with 9 ± 6 items/m^2 and 10 ± 5 items/m^2, respectively. Mesoplastic of size 1.00 mm were found 6 ± 4 items/m^2. Mesoplastics with a size of 2.80 mm is highly dominant at Tengah Beach. These mesoplastic wastes might have been transported into the sea through the drainage systems from urban development at Tengah Beach which ended up deposited on the shoreline by the wave currents and may also have been disposed of directly onto the beach.

In addition, the beach activities at the berm areas discarded large and macro size plastics which often get degraded into small pieces after a certain period of time due to weathering and eventually get buried within the sand. A similar scenario has been reported on other beaches where plastics became buried within the sand as a result of beach sand runoff, particularly during high winds or rainfall (Gregory & Andrady, 2003).

The most common types of mesoplastics found during the sampling events were film, foam, line, and fragment. No pellet type mesoplastic was found at Tengah Beach. There are differences in the abundance of these four types of mesoplastics. In terms of quantity, the foam was dominant 12 ± 1.22 items/m^2, followed by fragment, 7 ± 0.57 items/m^2, line, 4 ± 0.40 items/m^2 and film 2 ± 0.28 items/m^2. Foam type of mesoplastics was found to be the most at the high tide area. The dominance of foam on the shoreline might be due to its lightweight and buoyancy characteristics, which is easily transported and trapped in upper shore sediments by swash and coastal wind (Lo *et al.*, 2018).

The second highest mesoplastics found at Tengah Beach are fragments. Since plastic fragments can be from pieces of all kinds of plastic materials, their number is expected to be high. The reason for its pronounced presence might be attributed to the indiscriminate use of consumer plastic materials such as bottles, plates, food wrappers, plastic bags, and toys. As this beach serves as a recreational site, many activities such as picnicking are being held which might contribute to the presence of plastic debris.

Perhaps, Tengah Beach is affected by tourist attractions similar to other tourist beaches on Pulau Langkawi. It can be agreed that a great number of people and tourist activities occurred at Tengah Beach, which in turn directly resulted in the presence of discarded waste on the shoreline, especially plastic debris that was found buried in the sand.

Many shops, restaurants, and hotels are observed operating along the beach. It is possible that indiscriminate waste disposal and dumping into drainage systems may have given rise to the concentration of mesoplastics on this beach. Such problems may be easily induced by restaurants and make-shift food sellers that are often not fully aware and careless about proper waste disposal systems.

4.1.2 Penarak Beach

Penarak Beach is located in the east of Pulau Langkawi, facing towards the mainland of Peninsular Malaysia. There is a fishermen's village nearby this beach, which is located just about ten minutes' drive from the jetty terminal and Eagle Square (a landmark of Pulau Langkawi). Penarak Beach is famous for its scenic beauty. Its manmade landscape, such as business premises, for example, seafood restaurants, fishing jetties, and fishing community settlements, are the main tourist attractions here. Besides that, the natural and calm beach features such as limestone caustic and scenic environment attract more beachgoers to visit Penarak Beach.

4.1.2.1 The Abundance of Mesoplastics at Penarak Beach

The total number of mesoplastics found at Penarak Beach was 601 ± 17 items/m^2. The abundance of mesoplastics at this beach for all four sampling periods are shown in Figure 4.4.

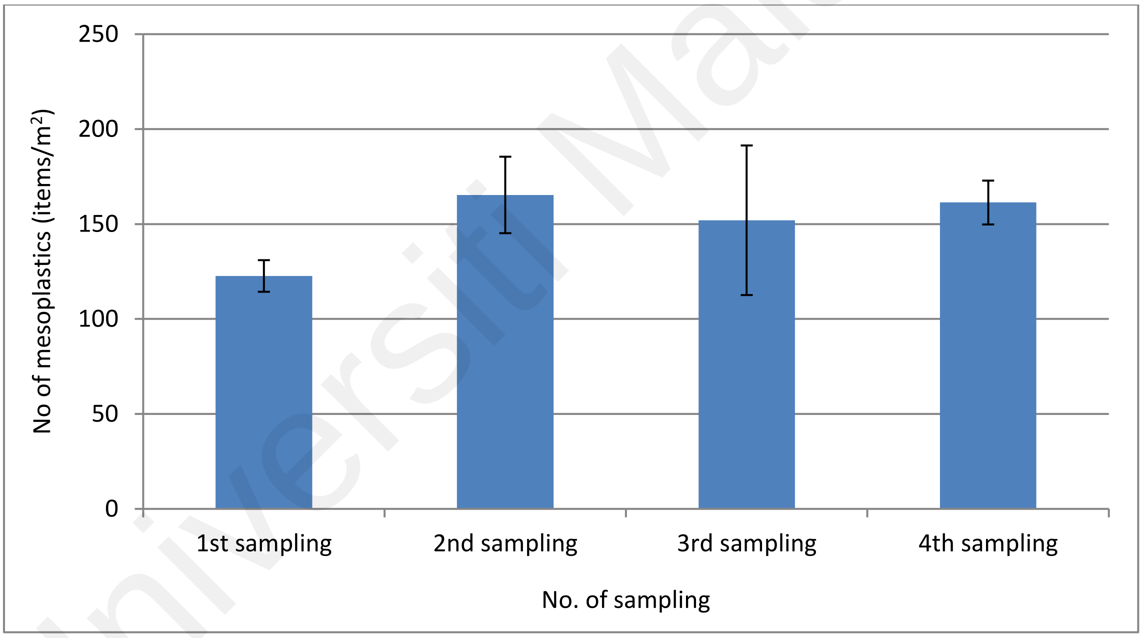

Figure 4.4: The trend of mesoplastics abundance at Penarak Beach

At Penarak Beach, 122 ± 8 items/m^2 of mesoplastics were collected during the first sampling. The highest numbers of mesoplastics were collected during the second sampling with 165 ± 20 items/m^2 particles. While for the third and fourth samplings 152 ± 40 items/m^2 and 161 ± 12 items/m^2 of mesoplastics were collected, respectively. According to the statistical analysis of variance (ANOVA), there are no significant differences in the abundance of mesoplastics between various sampling periods ($p = 0.18$) at Penarak Beach (Appendix C).

The high number of mesoplastics collected on Penarak Beach indicates that more anthropogenic activities occurred on the beach and nearby areas. This might have contributed to the accumulation of plastic debris. During the visit, it was obvious that a large number of plastic products used in fishing activities were discarded carelessly along the beach area. Those plastic debris are also the residue from offshore fishing-related activities that were thrown overboard and eventually washed ashore, as proposed by Dowarah & Devipriya (2019) in their study on the beaches of Puducherry, India.

In addition, the survey conducted by Khordagui & Abu-Hilal (1994) along the Arabian Gulf and Gulf of Oman reported that the abundance of plastic found in the areas was linked to marine-based sources, specifically fishing activity. The discarded plastic from fishery products was transported and dispersed to long distances by surface waves, winds, tides, and then finally washed ashore (Abu-Hilal & Al-Najjar, 2004). This larger plastic debris may be degraded into smaller sizes and eventually buried in the sands, as found on Penarak Beach.

The highest number of mesoplastics collected from the berm area was 85 ± 8 items/m^2, followed by 43 ± 11 items/m^2 at the high tide zone and 23 ± 8 items/m^2 at the low tide zone. The results are shown in Figure 4.5. Samples collected from the berm area contain more plastic components as compared to the foreshore regions (high tide and low tide). The distribution of mesoplastics based on type shows that foam debris is the most abundant at Penarak Beach with 62 ± 5 items/m^2. Berm area has the most abundant foam plastic as it was categorized as low-density debris. The use of beach berm for anthropogenic activities might also have been contributed to the distribution of foam in that area.

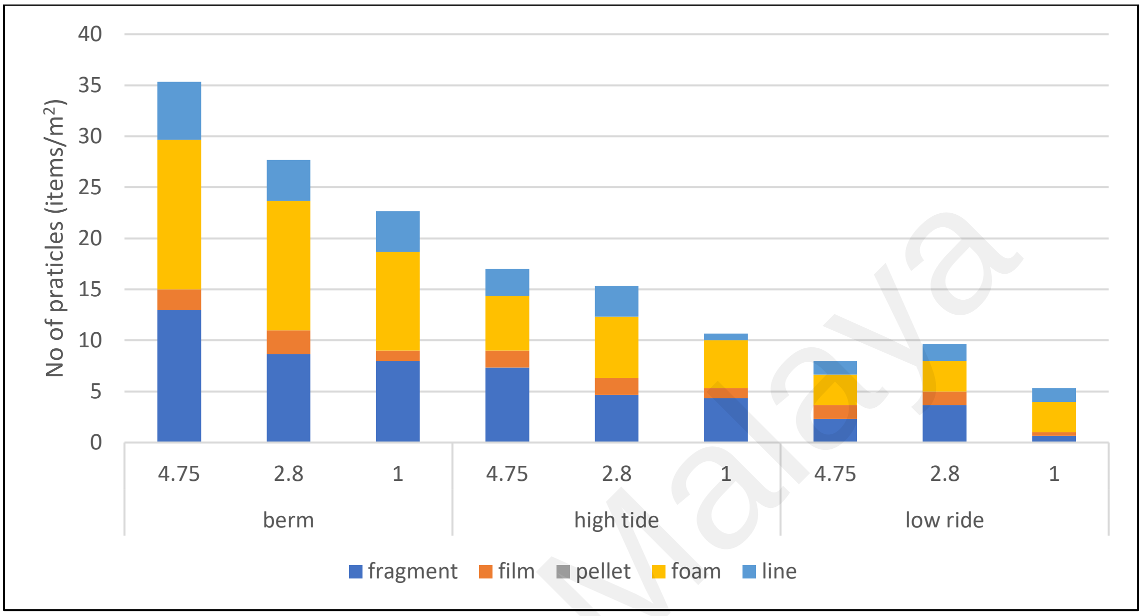

Figure 4.5: Composition of mesoplastics at Penarak Beach attributes

Lightweight debris, such as styrofoam, can be easily transported landward by the wind and deposited at the backshore or on the berm. This phenomenon was also reported at the Cliffwood beach located in New Jersey, USA, and at northeast Brazilian beaches (Iñiguez *et al.*, 2016; Ramos & Pessoa, 2019; Ryan *et al.*, 2009). Furthermore, styrofoam food containers and fishing storage containers are generally considered to be one of the main sources of foam-type mesoplastics in the marine environment (Zhang *et al.*, 2017).

The second highest mesoplastics found at this beach are fragments with 53 ± 4 items/m^2, followed by line and film at 24 ± 2 items/m^2 and 13 ± 1 items/m^2, respectively. No pellet type mesoplastic was recorded at this beach. The presence of fragments on Penarak Beach is mainly due to the fragmentation of large size plastics into smaller pieces. In the beach sediment, plastics tend to break into small debris through the photodegradation process, usually by the action of sunlight (Andrady, 2011). The degradation of these particles can also be caused by biological breakdown, chemical weathering, or physical forces such as wave actions (Hidalgo-Ruz *et al.*, 2012). Sometimes, these plastics debris enter the sea environment where it is broken down into smaller pieces and deposited on the beach sediments through tidal movement (Jang *et al.*, 2014).

Boating and fishing activities at Penarak Beach may be the source of mesoplastics like line and film. This is mainly due to the presence of fishing villages along Penarak Beach. This fact is agreeable with findings by Claereboudt (2004) that fishing often contributes to the high amount of debris on the beach. According to Henderson *et al*., (2001) the amount of derelict fishing debris in seawater and on beaches has increased worldwide as a result of the switch from natural to synthetic plastic fibers over the last three decades. Wet strength and water absorption were the primary advantages that synthetic fibers were designed to meet in the fishing industry (Gregory & Andrady, 2003). Hence, more plastic lines that were found in the study area can be concluded to be due to the high usage of synthetic fibers in fishing activities.

A total of 60 ± 12 items/m^2, 53 ± 16 items/$m^{2,}$ and 39 ± 9 items/m^2 mesoplastics were within the size range of 4.75 mm, 2.80 mm, and 1.00 mm, respectively. The most predominant size of plastic debris on Penarak Beach was more than 4.75 mm. Data shown revealed that mesoplastics fragments were recorded in all quadrats at Penarak Beach. This is due to the weathering of mesoplastics particles in the beach sediments. In addition, large plastic marine debris can be easily removed during beach cleaning, but smaller mesoplastics are often left unnoticed. These mesoplastics tend to accumulate underneath the beach sediments, as revealed in this study. Plastic wastes found in beach sediments have a long residence time and are heavily fragmented due to high UV radiation and physical abrasion by waves (Tsang *et al.*, 2017; Veerasingam *et al.*, 2016b).

4.2 Beaches at Pulau Besar

Pulau Besar is located in the south-west of Peninsular Malaysia. Jeti Beach and Sultan Ariffin Beach were selected for sampling on this island as shown in Figure 4.6. Among the two beaches represented in this study, Sultan Ariffin Beach faces the open sea (Strait of Melaka) while Jeti Beach faces the mainland of Peninsular Malaysia.

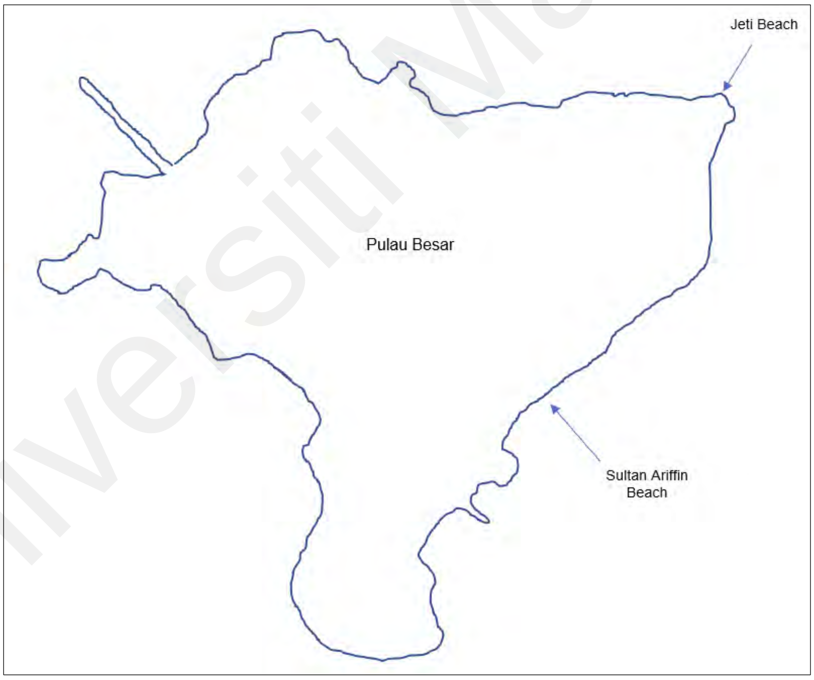

Figure 4.6: Location of sampling sites at Besar Island

4.2.1 Jeti Beach

Jeti Beach is used as a jetty for small tourist boats to transport visitors to the island from the mainland (Plate 4.2 & 4.3). Most of the visitors to this island spend their time on this beach while waiting for their boat to the mainland. Jeti Beach faces the mainland of Peninsular Malaysia. This shoreline has a beautiful beach that is about 128 m in length and is composed of pebble type sediments.

Plate 4. 2: The jetty in Jeti Beach

Plate 4.3: Jeti Beach, Pulau Besar

4.2.1.1 The Abundance of Mesoplastics at Jeti Beach

The total number of mesoplastics collected at Jeti Beach are 20 ± 4 items/m^2 and the abundances of mesoplastics for all the four sampling periods are shown in Figure 4.7.

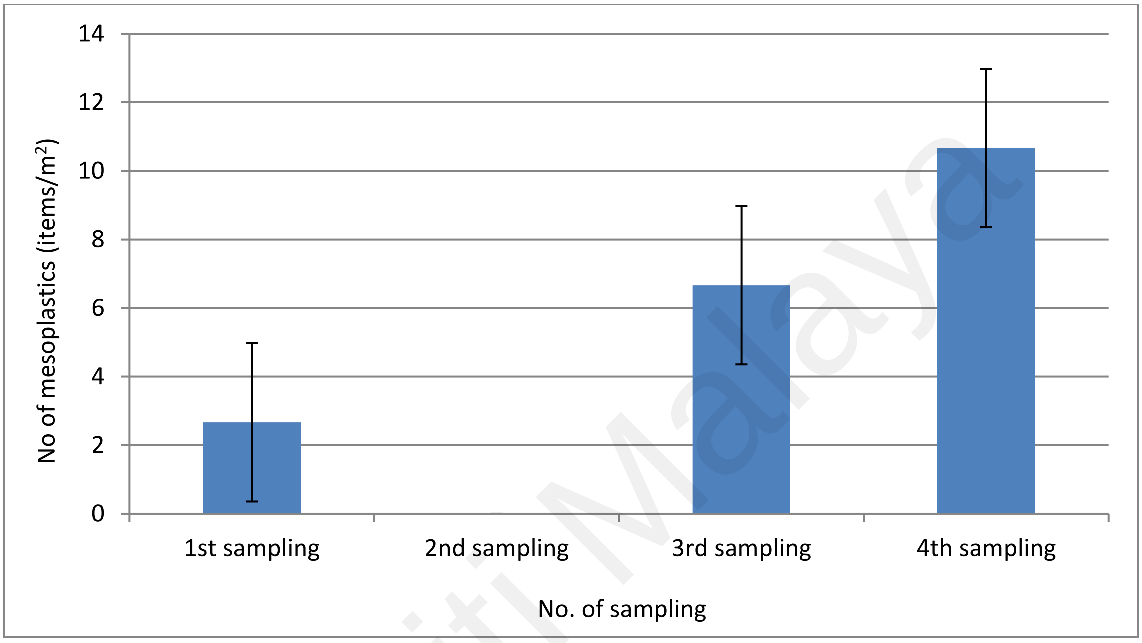

Figure 4.7: Trend of mesoplastics abundance at Jeti Beach

A much lower number of mesoplastics were found in Jeti Beach as compared to other beaches in this research. During this first sampling, only 3 ± 2 items/m^2 of mesoplastics were obtained and no mesoplastics were found during the second sampling. Regular beach cleaning activities carried out at this island contributed to a lesser amount of mesoplastics presence in the sediment samples collected here. Though beach cleaning generally targets larger debris, the occurrence of small plastic debris can also be reduced by regular beach cleaning because this will eliminate the degradation of large plastics into smaller particles in the marine environment. This is supported by the research by Zurcher (2009) that the removal of larger debris affected the accumulation of small plastics on beaches, since they often become trapped amongst the larger debris.

At Jeti Beach, routine beach clean-ups are conducted twice a day by appointed contractors while monitoring is done by the Melaka Municipal Council. In addition to that, some waste bins are provided by the local authorities along the beach area, which are emptied regularly. Moreover, this area is not highly influenced by extreme weather events such as storms which might bring in marine debris onto the beach. Since Jeti Beach is located closer to the mainland of Peninsular Malaysia, its exposure to strong storms, waves and wind is not significant. The study conducted on water quality at Pulau Besar, indicates weak winds as the causative factor affecting the dynamics of the water column at the study area (Zainol *et al*., 2019).

The trend of mesoplastic abundance increased during the third and fourth samplings, with 7 ± 2 items/m^2 and 11 ± 2 items/m^2, respectively. The increasing trend of mesoplastic particles during the last two samplings is due to the sampling periods that fall in the months of October and February, which is during the Northeast monsoon season. Heavy rainfall, storms, and strong wave conditions were recorded during this period due to heavy onshore wind at Jeti Beach.

There is a significant difference between the recorded number of mesoplastics in the sampling periods with $p = 0.009$. The T-test revealed that there was a notable difference between the first and fourth samplings as well, with a p-value of 0.01. In addition, there are also significant differences between the amount of mesoplastics collected during the second sampling with third ($p = 0.007$) and fourth samplings ($p =0001$). The statistical analysis of ANOVA for this beach is attached in Appendix D.

The composition of mesoplastics at Jeti beach attributes are presented in Figure 4.8. The highest number of mesoplastics were collected at the berm area followed by a high tide shoreline with 3 ± 3 items/m^2 and 2 ± 2 items/m^2, respectively. There are no mesoplastics found at the low tide shoreline. The presence of mesoplastics at the berm of this beach is greatly contributed by beachgoers littering of small plastics on the beach.

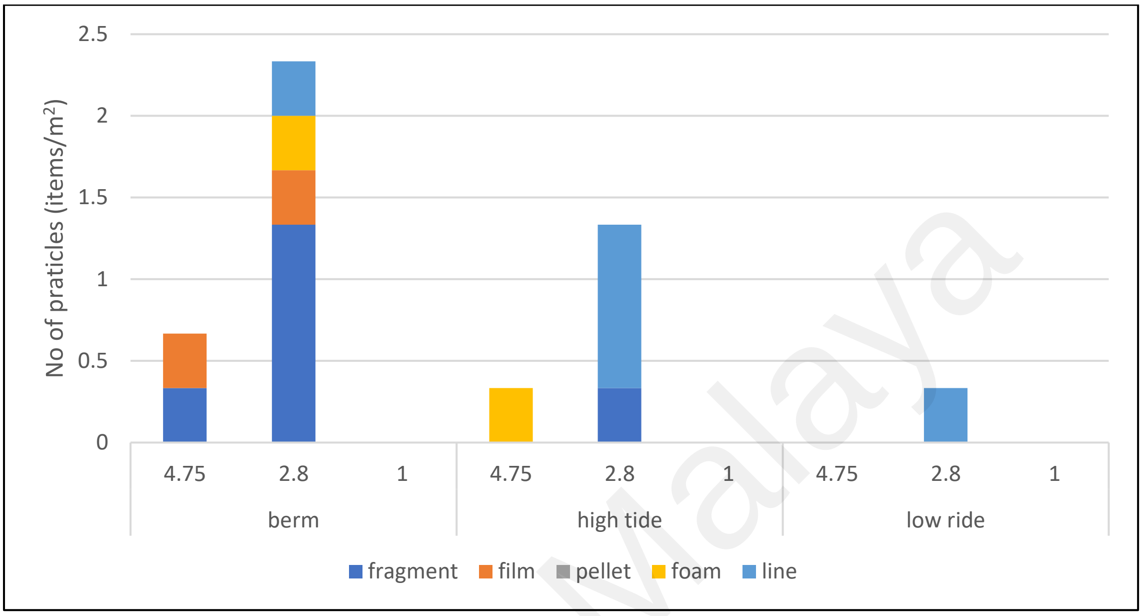

Figure 4.8: Composition of mesoplastics at Jeti Beach attributes

Additionally, the study conducted by Fauziah *et al*., (2015) agrees that finer debris was more abundant in the berm area, and a low rate of exportation from the area, lead to an accumulation of those items in smaller sizes. The zero number of mesoplastics at the low tide area indicates that small mesoplastics debris was unlikely to accumulate within the low tide region. This could be due to the fact that the finer debris is constantly washed away from the area by the tidal waves (Fauziah *et al*., 2015).

According to the analysis of the mesoplastic particles size range at Jeti Beach, particles of 2.80 mm were the highest number recorded, 4 ± 3 items/m^2 followed by 4.75 mm sized particles with 1 ± 1 items/m^2. Mesoplastics smaller than 1.00 mm were not found at this beach. Moreover, the highest number of mesoplastics were found in the fragment type, followed by line type. Besides that, film and foam types of mesoplastics were each 2 ± 1 items/m^2. No pellet type mesoplastics are collected here. By comparing with other beaches in this study, the number of fragments, lines, films, and foam particles were found in a smaller number, 6 items/m^2.

4.2.2 Sultan Ariffin Beach

Sultan Ariffin Beach is a recreational beach that faces the Straits of Melaka. The main activities on this beach are camping and other water-based activities. Many camps were set up along the beach during the sampling events as shown in Plate 4.4.

Plate 4.4: Sultan Ariffin Beach, Pulau Besar

4.2.2.1 The Abundance of Mesoplastics at Sultan Ariffin Beach

The abundance of mesoplastics for all four sampling periods at Sultan Ariffin Beach is shown in Figure 4.9. The total numbers of mesoplastics collected at this beach are 320 ± 26 items/m^2.

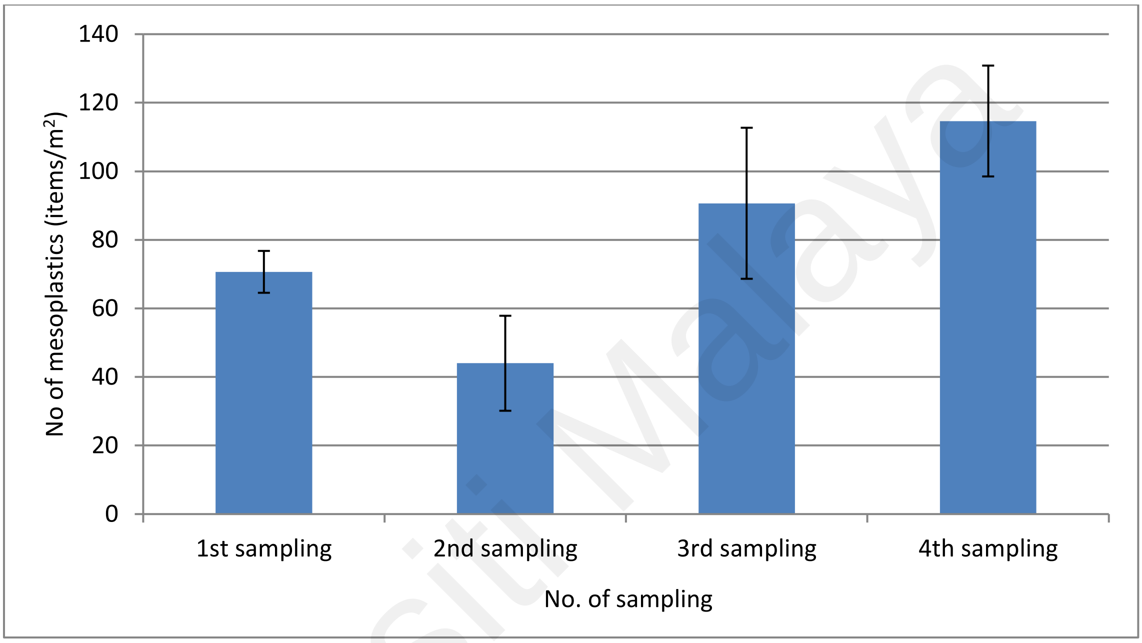

Figure 4.9: Trend of mesoplastics abundance at Sultan Ariffin Beach

At Sultan Ariffin Beach, 71 ± 6 items/m^2 of mesoplastics were collected during the first sampling and 44 ± 14 items/m^2 of mesoplastics were collected for the second sampling. The number of mesoplastics collected during the third sampling was 91 ± 22 items/m^2. Furthermore, steady acceleration in the trend of mesoplastics collected can be observed from the second sampling to fourth sampling. Recreational activities at Sultan Ariffin Beach can be the major contributing factor to the upward trend of plastic classification on the shoreline sediments. The amount of mesoplastics observed during the fourth sampling were 115 ± 16 items/m^2. The highest concentration of mesoplastics was detected during the last sampling, which was much more polluted than in the first three samplings.

The variation of mesoplastics abundance between the sampling periods was significant with $p < 0.05$. From the T-test conducted, significant differences were observed between the first and second samplings with $p = 0.04$. In addition, a p-value less than 0.05 was obtained between both first and fourth samplings ($p = 0.01$), second and third samplings ($p = 0.03$). Besides that, the second and fourth samplings also recorded a remarkable difference in mesoplastic abundance ($p = 0.004$). Statistical analysis of ANOVA at Sultan Ariffin Beach is shown in Appendix E.

At Sultan Ariffin Beach, the highest number of mesoplastics are collected at the berm, followed by the high tide shoreline area with 53 ± 13 items/m^2 and 21 ± 13 items/m^2 of mesoplastics, respectively. The least number of mesoplastics were recorded at a low tide area with 7 ± 7 items/m^2. From the collected mesoplastics debris, 32 ± 14 items/m^2 are of size 4.75 mm, 31 ± 12 items/m^2 are 2.80 mm and 17 ± 7 items/m^2 are 1.00 mm. These data are illustrated in Figure 4.10.

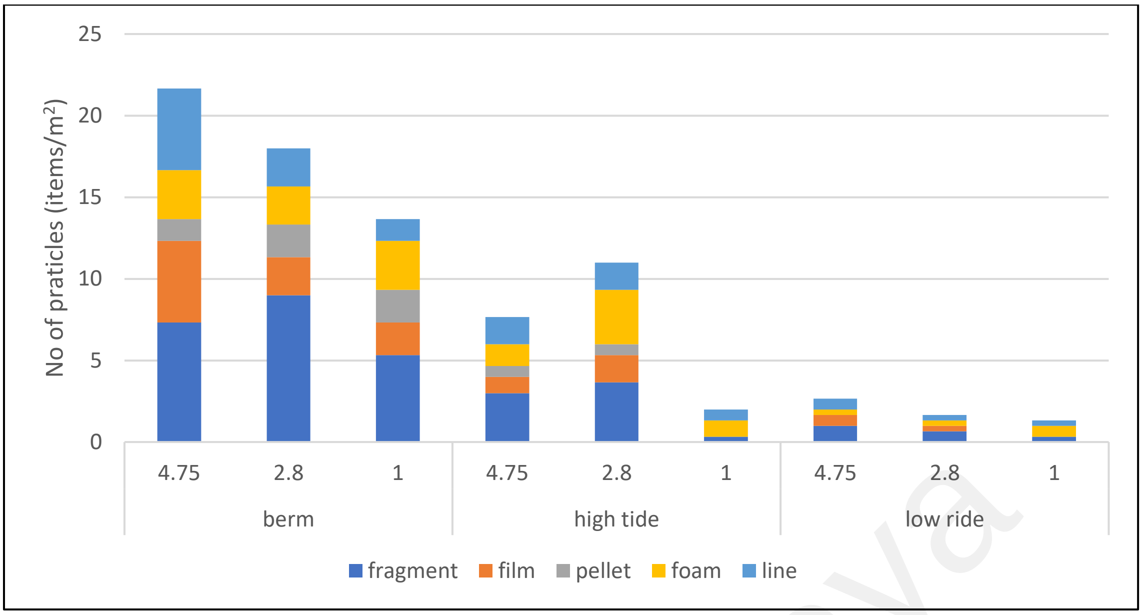

Figure 4.10: Composition of mesoplastics at Sultan Ariffin Beach attributes

Fragments are the most abundant mesoplastics collected at Sultan Ariffin Beach with 31 ± 3 items/m^2, followed by foam type with 15 ± 1 items/m^2. Fragments and fragment-like mesoplastics were most commonly found in the sediment of this beach and the highest number was collected from the berm area. This is supported by the higher fragmentation rate of plastic debris in beach sediment because temperature and solar UV intensity are relatively high (Tsang *et al.*, 2017). Recreation littering is a prevalent problem where plastic fragments following degradation may persist in the sand (Ng & Obbard, 2006).

Besides, foams that are originated from foam packaging materials and food containers (such as polystyrene) disposed of by beachgoers after picnic can also breakdown into smaller pieces of foam due to weathering as supported by by Kusui & Noda (2003). Hence, foam plastics are also abundant in the Sultan Ariffin Beach area, littered by beachgoers.

A total of 14 ± 2 items/m^2 line, and 13 ± 2 items/m^2 film were found. The plastic film may have originated from the confectionary and convenience plastic food wrappings that were casually discarded by people at the beach. These types of plastics can be disintegrated by the degradation process where the reduction in the mass or molecular weight of the plastic material can take place and eventually become smaller in size (Gregory & Andrady, 2003).

The pellet type of mesoplastics was 7 ± 1 items/m^2 at this beach. The presence of pellet type mesoplastics might be from the sea-based sources and ended up accumulated at Sultan Ariffin Beach sediments as the results of wave and tidal actions. This type of pellet resins is washed up on the island, possibly from ships or industries in other locations further away. Furthermore, studies since the 1970s have reported high levels of plastic waste, mainly pellets, found at the busiest sea and along coasts, as at the Straits of Melaka (Herrera *et al.*, 2018).

4.3 Beaches at Pulau Perhentian

Tanjung Butong and Pinang Seribu beaches were selected as the sampling sites in Pulau Perhentian. Tanjung Butong represents a beach facing the mainland of Peninsular Malaysia while Pinang Seribu faces the South China Sea. Figure 4.11 shows the location of these beaches at Pulau Perhentian. Both of these areas are undisturbed beaches that are isolated from human activities.

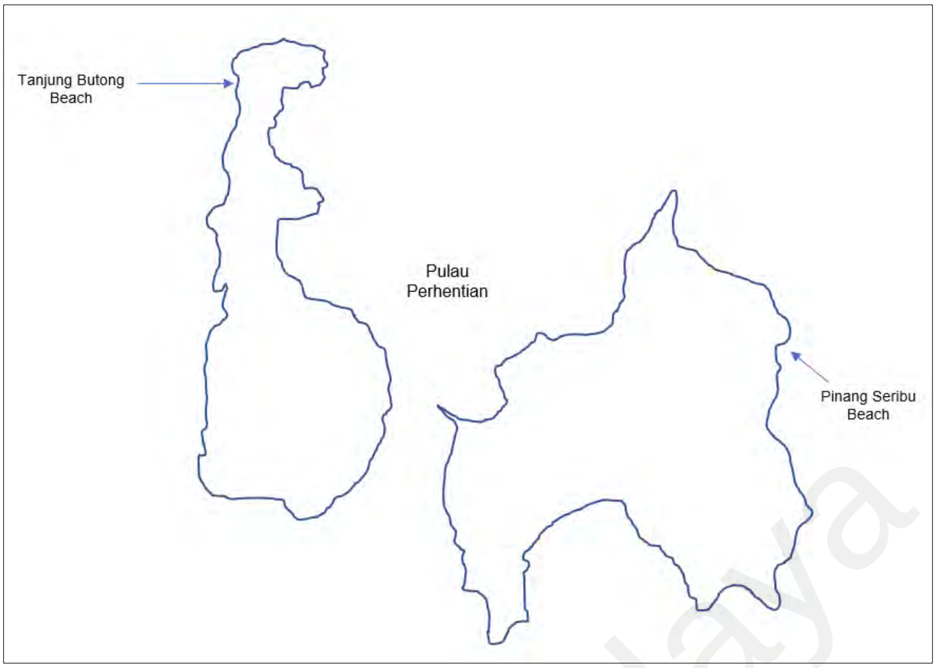

Figure 4.11: Location of sampling beaches at Pulau Perhentian

4.3.1 Tanjung Butong Beach

Tanjung Butong Beach is located at the Pulau Perhentian Kecil with some rocky outcrops headlands. The major activity at this beach is snorkelling. Tanjung Butong Beach is one of the most popular diving sites in Pulau Perhentian, which is only accessible by boat.

4.3.1.1 The Abundance of Mesoplastics at Tanjung Butong Beach

The total number of mesoplastics at Tanjung Butong Beach are 285 ± 39 items/m^2. The trend of mesoplastics collected at Tanjung Butong Beach is shown in Figure 4.12. In the first sampling, 56 ± 24 items/m^2 of mesoplastics were collected. This amount decreases in the second and third sampling with 39 ± 28 items/m^2 and 53 ± 20 items/m^2 of mesoplastics, respectively. The periodic sampling at this beach with two months interval might have contributed to the deceleration in the mesoplastic accumulation at this shoreline.

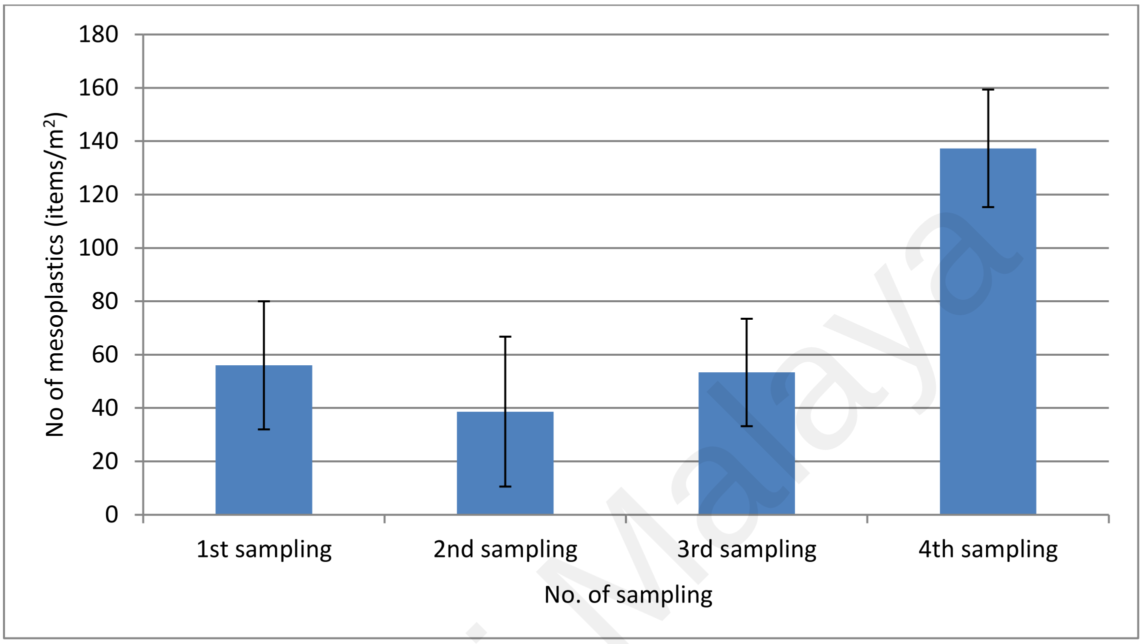

Figure 4.12: Trend of mesoplastics abundance at Tanjung Butong Beach

The number of mesoplastics collected at this beach is relatively high as compared to other beaches studied in this research. As Tanjung Butong Beach faces the South China Sea, mesoplastics at this beach shoreline are believed to be originated mainly from sea-based sources. Limited land-based originated mesoplastics are observed here as this beach is not accessible through the land. Also, the Tanjung Butong shoreline is not suitable for beach activities. In addition to that, this beach is isolated from anthropogenic activities and only scuba diving is carried out in the waters. However, it is the monsoon season that acts as an effective carrier of debris from the sea to the shoreline at Tanjung Butong Beach, to contribute to the high amount of mesoplastics at this beach.

On the other hand, the main source of mesoplastics at this beach was believed to be originated from heavy shipping activities along the South China Sea. The pollution found along the coastline areas adjacent to shipping lanes can be associated with shipping activities such as pollutants that are thrown overboard which supposedly discharged at ports (Mobilik & Hassan, 2016). Similar findings were found in the study conducted by Ng *et al*., (2006) at Singapore's coastal areas where the presence of small plastic debris in sediments is likely due to on-going waste disposal practices from recreational activities and discharge from shipping.

Besides that, there is a drastic increase in the number of mesoplastics during the fourth sampling with 137 ± 22 items/m^2. The last sampling of this study falls in the period of monsoon transition which is in the month of February where there are changes in the South China Sea currents. This may be contributed to an acceleration in the number of mesoplastics collected. The predominant water circulation brings water masses up from the sea during low tide, allowing the accumulation of sediments and solid particulates along the coastline of Tanjung Butong Beach.

There is a significant difference between the mesoplastics found during all four samplings with p = 0.003672. T-test results show that significant differences were observed between first, second, and third sampling periods compared with fourth sampling by the p-value of p = 0.012, p = 0.008, and p = 0.008, respectively. The statistical analysis of ANOVA is represented in Appendix F.

At Tanjung Butong Beach, 41 ± 17 items/m^2 of mesoplastics are found at the berm of the beach. At high and low tides shoreline, 24 ± 17 items/$m^{2,}$ and 7 ± 3 items/m^2 of mesoplastics found respectively as shown in Figure 4.13. As per size range, the highest number of mesoplastics are within the range of 2.80 mm with 32 ± 21 items/m^2 debris collected. The number of mesoplastics of size 4.75 mm are 26 ± 23 items/m^2 and for size 1.00 mm are 14 ± 1 items/m^2.

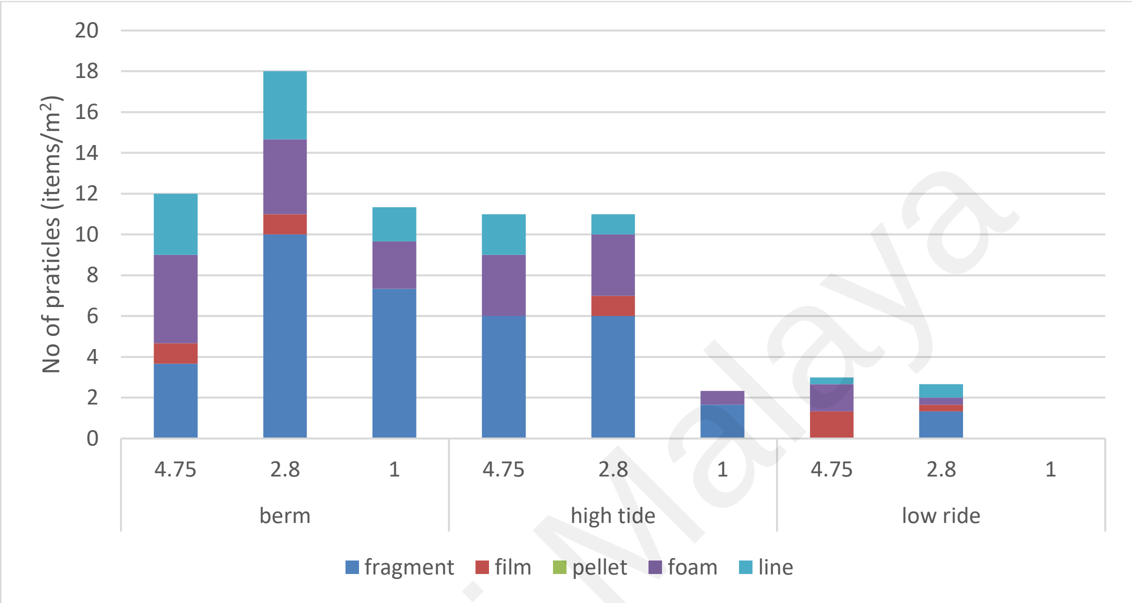

Figure 4.13: Composition of mesoplastics at Tanjung Butong Beach attributes

At this beach, the highest number of mesoplastics collected is fragment type at 36 ± 4 items/m^2. The main source of fragment mesoplastics at this beach is from a secondary source which is contributed by the degradation of large plastic debris in the marine environment. Furthermore, large plastic debris that is discarded from the nearby recreational beaches at Pulau Perhentian might be washed off to Tanjung Butong beach through seawater movement. The plastic waste tends to accumulate at the berm of the beach and over time degrades into mesoplastics. The fragmentation of beach mesoplastics relies greatly on the environmental conditions. Intense UV radiation and high temperature can lead to greater fragmentation of beached plastic debris into smaller pieces and therefore resulted to a higher count of mesoplastics (Tsang *et al.*, 2017).

The second highest type of mesoplastics collected is foam type with 19 ± 2 items/m^2. As most of the locals in Pulau Perhentian are fishermen, fishing activities are highly predominant on this island. Thus, the fishing materials are discarded into the marine environment both intentionally and unintentionally. According to Sheavly and Register (2007), the use of synthetic fishing lines has increased in recent years because of their durability. It also degrades slowly and buoyantly which becoming debris with staying power. The high buoyancy of plastic items allows them to travel in currents for thousands of miles and causes harms to the marine ecosystems (Sheavly & Register, 2007). Line and film type mesoplastics are found with 12 ± 1items/m^2 and 4 ± 1 items/m^2, respectively. No pellet type mesoplastics were collected at Tanjung Butong.

4.3.2 Pinang Seribu Beach

Pinang Seribu Beach is located in Pulau Perhentian Besar. This beach is more isolated compared to other beaches on this island. During the second sampling at Pinang Seribu, turtle marks were observed at the sandy beach. The beach is mainly used as a resting port by local boatmen. No recreational or other anthropogenic activities are conducted at this beach.

4.3.2.1 The Abundance of Mesoplastics at Pinang Seribu Beach

The total numbers of mesoplastics at Pinang Seribu Beach are 1113 ± 30 items/m^2. The trend of mesoplastics collected at Pinang Seribu Beach is shown in Figure 4.14. During the first sampling at Pinang Seribu beach, 259 ± 6 items/m^2 of mesoplastics were collected. This amount increases to 315 ± 49 items/m^2 during the second sampling, which makes it the highest amount of mesoplastics collected at this beach. However, the amount decreases in the third sampling. The total number of mesoplastics collected was only 240 ± 38 items/m^2. During the fourth sampling, 298 ± 57 items/m^2 of mesoplastics were collected.

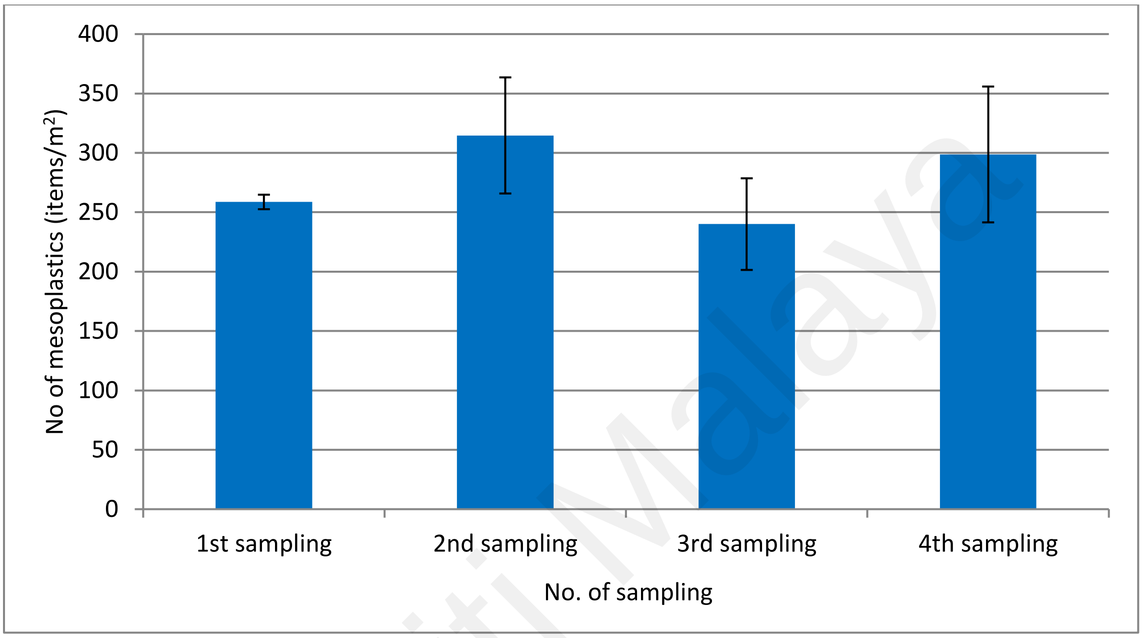

Figure 4.14: Mesoplastics abundance at Pinang Seribu Beach

At Pinang Seribu Beach, 110 ± 4 items/m^2 of mesoplastics debris are found at the berm while 111 ± 29 items/m^2 were collected from the high tide zone. This amount decreases as go down towards the sea with 56 ± 21 items/m^2 mesoplastics gathered at the low tide zone. This study found that a much higher abundance of mesoplastics accumulated at the high strandline compared to the berm at this beach. This is not consistent with the result observed from other beaches in this study where a higher abundance of mesoplastics was found accumulated at the backshore. This finding has a similarity to the study conducted by McDermid and McMullen (2004). High tide line collections contained much more plastic than berm samples, perhaps this is because particles suspended in the water will be left onshore during every receding tide, whereas berm debris may be deposited primarily during storms, or as wind-blown debris from the high tide line (McDermid & McMullen, 2004).

Analysis on the size range (Figure 4.15) shows that 96 ± 24 items/m^2 are consisting of 4.75 mm size mesoplastics. The dominating mesoplastics at this beach are within the size of 2.80 mm with 133 ± 32 items/m^2. The smallest mesoplastics are found in the size of 1.00 mm with 49 ± 12 items/m^2.

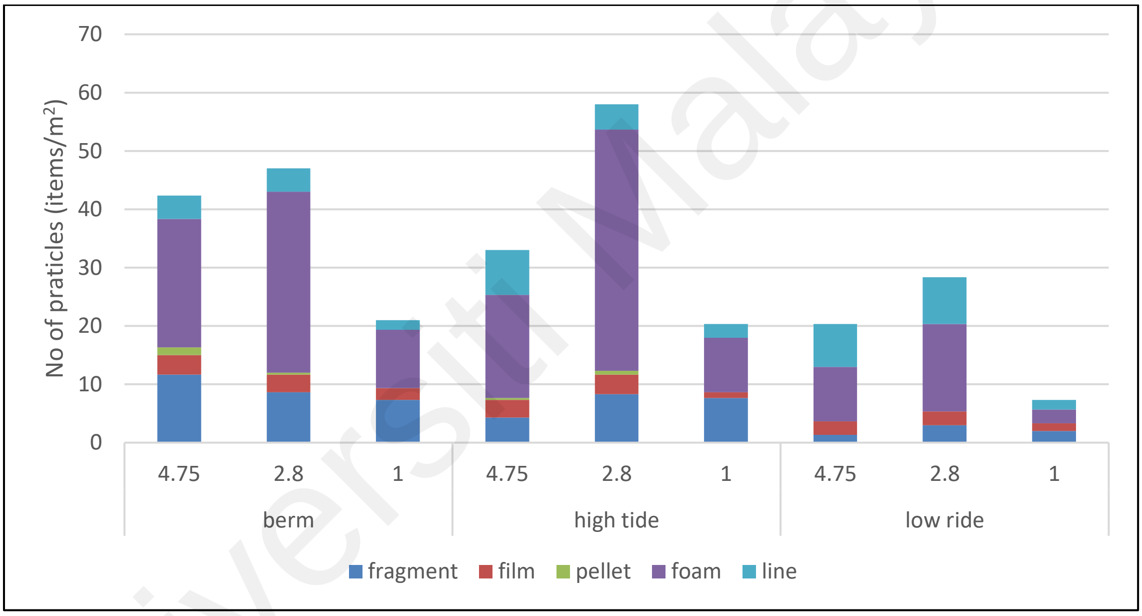

Figure 4.15: Composition of mesoplastics at Pinang Seribu Beach attributes

At Pinang Seribu Beach, quantification of the mesoplastics types across the quadrats showed the dominance of foams whereas pellet concentration took the rear. Foam type mesoplastics collected are 158 ± 12 items/m^2. A small number of pellet type mesoplastics are collected at this beach, 3 ± 1 items/m^2. Pellets that took the rear may have been predominantly eroded from industrial or other associated sites. In addition, referring to research by McDermaid & Mcmullen (2004), the pellet type mesoplastics mostly will be found at beaches that are located nearer to manufacturing factories, cargo loading docks, and shipping lanes (McDermid & McMullen, 2004).

The fragment and line types of mesoplastics are 41 ± 3 items/m^2 and 22 ± 1 items/m^2, respectively. Many previous studies supported that increase in the number of line plastics is assumed to be from the usage of fishing equipments. This includes fishing lines, nets, ropes, polyester, and vinyl strapping bands which significantly contribute to the greater number of plastic debris in this study area. Film type mesoplastics collected at Pinang Seribu Beach are 21 ± 1 items/m^2. According to a study conducted by Nor & Obbard (2014), the presence of film mesoplastics at the beaches was mainly due to the fragmentation of plastic carry bags and packaging materials (Ng & Obbard, 2006; Yuan *et al.*, 2019).

Although these two beaches at Pulau Perhentian are isolated from human activities, the highest presence of mesoplastics was observed here. Thus, there are high possibilities that this debris may be transported from other sources by ocean currents and monsoon winds before being deposited at these beaches (Tsang *et al.*, 2017; Veerasingam *et al.*, 2016a; Zhao *et al.*, 2015). The plastics debris present here might be transported from other recreational beaches in Pulau Perhentian such as Long Beach, Coral Bay, Keranji Beach, and Petani Beach via seawater and degraded from macroplastics to mesoplastics. The statistical analysis of ANOVA shows that there were no significant differences in the abundance of mesoplastics at Pinang Seribu Beach (Appendix G).

4.4 Beaches at Pulau Sibu

Pasir Teluk Penetap Beach and Pasir Belakang Beach were selected as sampling sites in Pulau Sibu. Pasir Teluk Penetap Beach faces the mainland Peninsular Malaysia while

Pasir Belakang Beach faces the South China Sea. The locations of these beaches are shown in Figure 4.16. There are few islands that surround Pulau Sibu such as Pulau Papan, Pulau Kukus, and Pulau Tinggi.

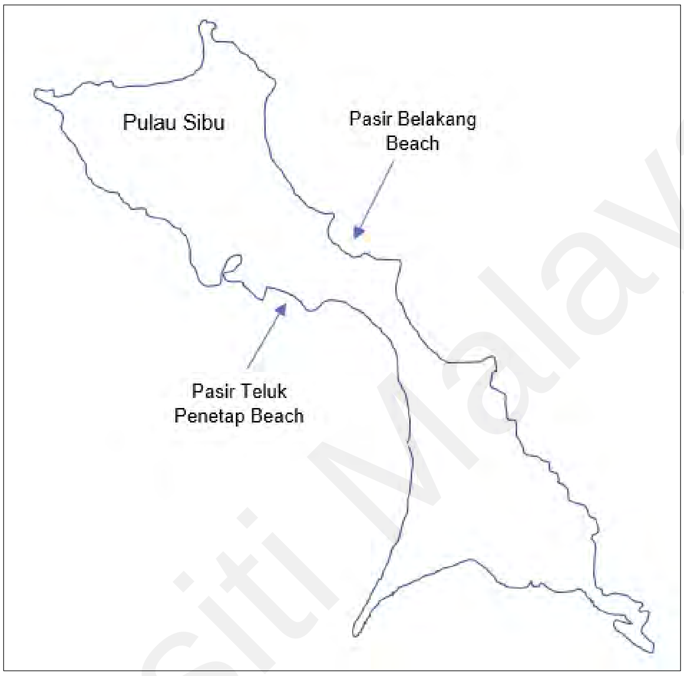

Figure 4.16: Location of sampling beaches at Pulau Sibu

4.4.1 Pasir Teluk Penetap Beach

Pasir Teluk Penetap Beach is a small jetty for tourist boats, used by several resorts on the island to bring in their customers via small boats. This beach is 77 m in length which is composed of sand and muddy type sediments. The beach is not well developed and only a small boat landing dock was built using wood. Tourists and visitors reaching here, only spend several minutes waiting for their resort representatives to bring them into the island.

4.4.1.1 Abundance of Mesoplastics at Pasir Teluk Penetap Beach

The total numbers of mesoplastics at Pasir Teluk Penetap Beach are 165 ± 14 items/m^2. The number of mesoplastics at these beaches is shown in Figure 4.17. The number of mesoplastics collected at Pasir Teluk Penetap Beach increases throughout all the four sampling periods.

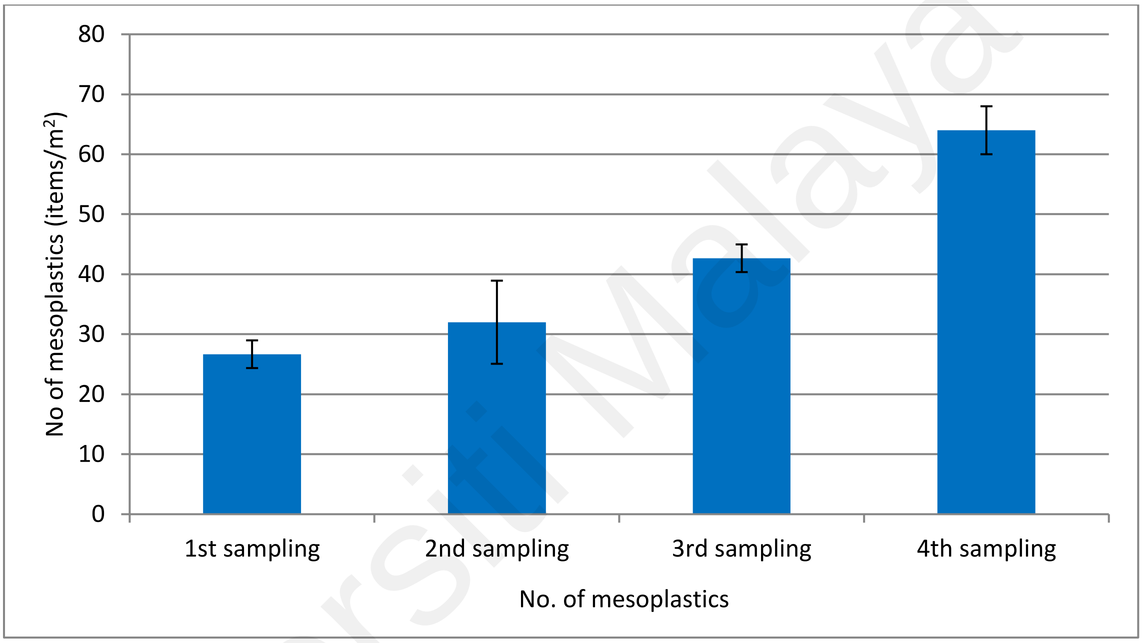

Figure 4.17: Trend of mesoplastics abundance at Pasir Teluk Penetap Beach

During the first sampling, 27 ± 2 items/m^2 of mesoplastics were collected. The number of mesoplastics collected during the second, third, and fourth samplings are 32 ± 7 items/m^2, 43 ± 2 items/$m^{2,}$ and 64 ± 4 items/m^2, respectively. The increasing trend of accumulated mesoplastics in the beach sediments shows the capability of the beach to trap mesoplastics within the sampling period intervals of two months and four months for the last sampling. The mesoplastics accumulation rate at this beach is 17 items/month.

Statistical analysis shows the significant differences between the sampling periods with a p-value of less than 0.05 (Appendix H). There is a significant difference between the first sampling and third sampling ($p = 0.001$). Furthermore, the t-test conducted shows the significant differences between first, second, and third samplings with the fourth sampling ($p < 0.05$), respectively.

At Pasir Teluk Penetap Beach, the number of mesoplastics found at the beach berm is 21 ± 5 items/m^2, at high tide shoreline are 12 ± 6 items/m^2 and at low tide, the shoreline is 7 ± 7 items/m^2. This result shows that there is an increase in mesoplastics distribution as we move away from the sea. The wave actions at the lower shoreline wash off the mesoplastics accumulated at this section while the dry sands at the berm tend to trap the mesoplastics that present. This contributed to the high amount of mesoplastics at the beach section further away from the wave actions. The wave tends to spread the accumulated mesoplastics scatter along the coastline.

According to the mesoplastics size variation, 20 ± 12 items/m^2 are of 4.75 mm, 15 ± 5 items/m^2 are 2.80 mm and 6 ± 4 items/m^2 are 1.00 mm. Bigger size mesoplastics with a size of 4.75 mm are the most at this beach. The slower degradation of mesoplastics at the beach forth contributes to this trend. The plastic waste on the beach will degrade with exposure to UV radiation and other physical processes that are controlled by the wave, current, wind, and tide actions. The result is demonstrated in Figure 4.18 below.

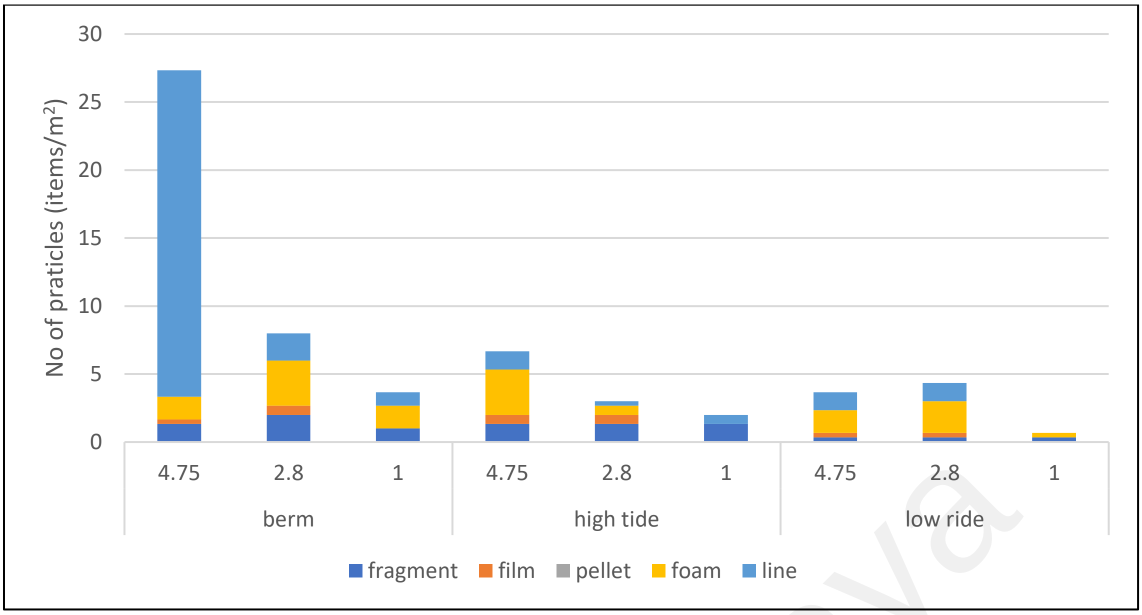

Figure 4.18: Composition of mesoplastics at Pasir Teluk Penetap Beach attributes

The most abundant type of mesoplastics collected at Pasir Teluk Penetap Beach is in the form of line with 32 ± 8 items/m^2. The line type mesoplastics at this beach is expected to be originated by degradation of fiber type material made of polypropylene such as rope and fishing nets. Although no fishing activities are carried out here, there are several beaches at Peninsular Malaysia that are close to this island that serves as fishing villages. Moreover, this beach is facing towards the mainland. So, there are high possibilities for some marine debris to be washed off and get deposited at Pasir Teluk Penetap Beach (Zhao *et al.*, 2015).

The next highest type of mesoplastics collected here are foam and fragment with 15 ± 1 items/m^2 and 9 ± 1 items/m^2, respectively. The use of materials such as disposable take-away food boxes, heat-insulated containers, and buoys contributes to extensively used foams (Fok & Cheung, 2015). The dominance of foam on the strandline may be due to its lightweight and buoyancy, so it is easy to be transported and trapped in sediments on the upper shore by swash and coastal wind (Browne *et al.*, 2007).

Mesoplastics that are observed at this beach can be present in the environment as manufactured meso-sized plastics (known as primary mesoplastics) or resulting from the continuous weathering of plastic litter, which yields progressively smaller plastic fragments (known as secondary mesoplastics). Herein, the primary source of microplastics at Pasir Teluk Penetap Beach can be from the industrial areas in Peninsular Malaysia which are located at the river downstream and discharge waste into the sea. The secondary source of mesoplastics is mainly from the photodegradation of large marine plastics discarded by the tourist.

The least number of film type mesoplastics are collected at this beach with 3 ± 0 items/m^2. Owing to its brittle and fragile nature, the film could be broken down into smaller pieces during sampling and extraction processes hence occurred at low abundance in this study. No pellet type mesoplastics were found at this beach area. The unceasing use of plastics will result in a negative impact especially on marine life once plastics are deposited into the marine environment. Small debris like synthetic line fibers, styrofoam, and pieces of film from plastic bags are frequently mistaken as food or prey by seabirds (Morishige *et al.*, 2007). Therefore, these plastics debris should be prevented from being discarded, especially as in the case of Pasir Teluk Penetap Beach.

4.4.2 Pasir Belakang Beach

Pasir Belakang Beach which is 336 m in length is a private recreational beach owned by Sari Pacifica Beach Resort. Tourists who are using this beach are the customers of this resort. There are many beach chairs and umbrellas along this beach which are provided by the resort management to their customers for recreational purposes. Many recreational activities are carried out here as the beach is just located next to the resort.

4.4.2.1 The Abundance of Mesoplastics at Pasir Belakang Beach

The total numbers of mesoplastics at Pasir Belakang Beach are 20 ± 9 items/m^2. The mesoplastics trends at this beach are shown in Figure 4.19. The number of plastic debris found on Pasir Belakang Beach are relatively lower compared to other beaches studied in this research. No mesoplastics were found at this beach for the first three samplings. During the final sampling 20 ± 4 items/m^2 of mesoplastics were collected.

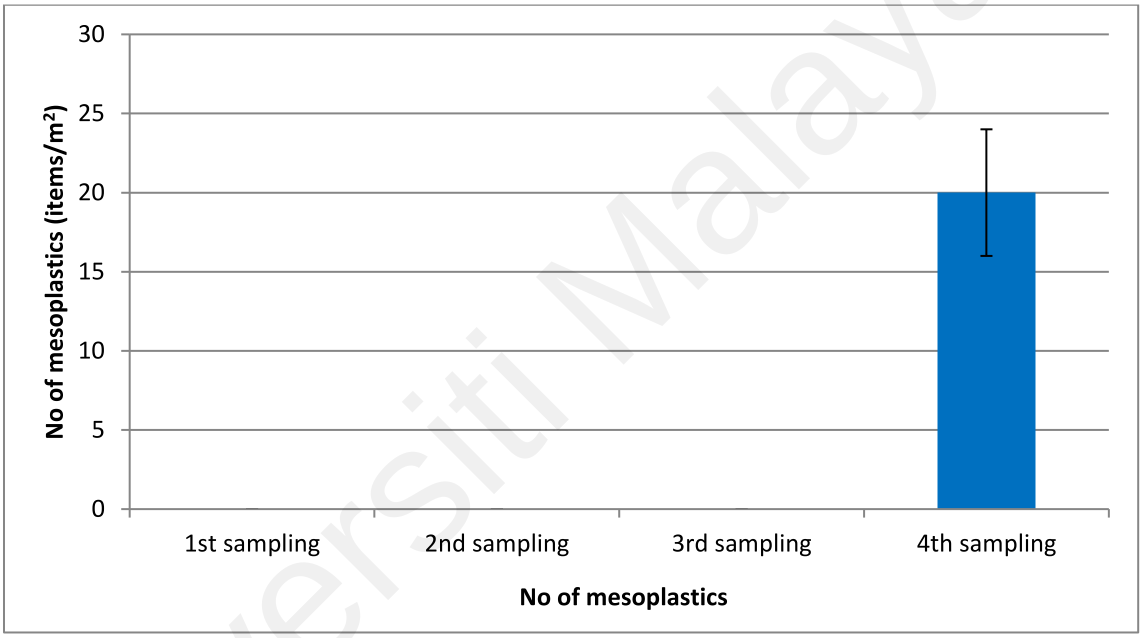

Figure 4.19: Trend of mesoplastics abundance at Pasir Belakang Beach

The absence of mesoplastics at this beach are mainly due to regular beach cleaning carried out here. As this beach privately belongs to a resort, the management solely responsible for its cleanliness. During the sampling periods, we observed scheduled cleaning activities being carried out. Assigned janitors are doing cleaning at the beach twice daily. Thus, the amount of marine debris that is deposited at this beach is very less. The formation of mesoplastics from large plastic debris requires some time for the degradation process to happen under suitable environmental conditions. This desirable condition does not occur here, thus lead to the absences of secondary mesoplastics at Pasir Belakang Beach. This illustrates the importance of beach management to ensure the cleanliness of beaches.

The number of mesoplastics collected during the fourth sampling at this beach might be from the primary source of mesoplastics which is most probably contributed by any unusual recreational activities held at this beach. Pasir Belakang Beach is an interesting area for beachgoers to perform recreational activities, hence dumping of plastic waste may have occurred intentionally or unintentionally. In addition, Moore (2008) and Kershaw (2016) had concluded that a greater amount of plastic debris was contributed by beachgoers in recreation areas.

Besides that, the sudden presence of the mesoplastics at the beach during the fourth sampling might be from the sea-based sources during the monsoon season. The statistical analysis of ANOVA shows significant differences in the mesoplastics collected at Pasir Belakang Beach with $p < 0.05$ (Appendix I).

At Pasir Belakang Beach, mesoplastics were collected only during the fourth sampling. High tide and low tide zones recorded 7 ± 3 items/m^2 and 5 ± 3 items/m^2, respectively. At the berm of the beach 8 ± 4 items/m^2 were collected. The results are shown in Figure 4.20. Despite the beach cleaning conducted here, the accumulated mesoplastics at the beach shoreline mainly due to its smaller size which is often neglected during clean-up activities. This is one of the hidden threats of marine plastic pollution where meso, micro, and nano size plastics are missed off during human beach clean-ups.

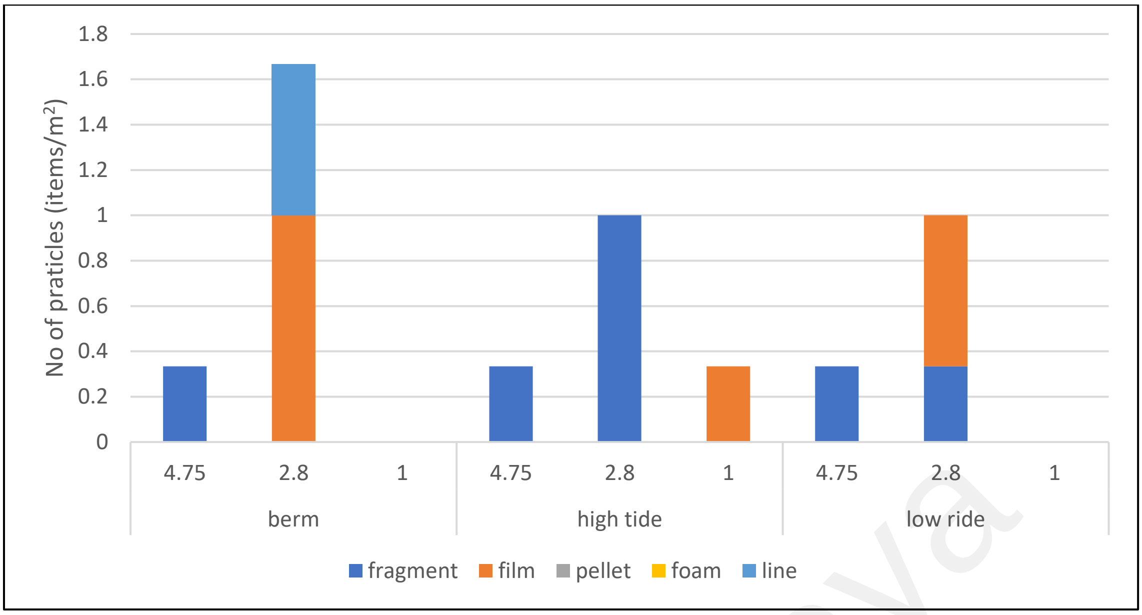

Figure 4.20: Composition of mesoplastics at Pasir Belakang Beach attributes

For the mesoplastics size distribution, 4 ± 2 items/m^2 of mesoplastics size 4.75 mm and 14 ± 7 items/m^2 of size 2.80 mm were collected. 1.00 mm mesoplastics were found, 4 ± 2 items/m^2 at this beach during the samplings. The smaller sized mesoplastics were found much less at this beach as compared to other beaches studied in this research. This is mainly due to the frequent beach cleaning activities and also might be contributed by the action of waves and tides, which wash off the accumulated mesoplastics on the shoreline. Besides, the strong tide actions can be observed at this beach as it is facing towards the South China Sea which occurs during the fourth sampling. Moreover, degradation of large plastics happens at a slow rate at this beach depending on its type and chemical composition when left exposed to beach environmental conditions.

The mesoplastic types recovered at this beach were mainly fragment, film, and line with 2 ± 0 items/m^2, 2 ± 0 items/m^{2,} and 1 ± 0 items/m^2, respectively. The recreational activities conducted at this beach can act as the primary source of fragment, film, and line type mesoplastics found. Primary mesoplastics are such as personal care products, microfiber clothing, and textiles. The secondary mesoplastic at this beach present from the breakdown of larger plastics. Fragmentation of mesoplastics occurs because of several factors such as biological, chemical, and physical. No pellet and foam type mesoplastics collected at this beach. This might due to no industrial activities conducted nearby this island and no fishing activities are conducted within this beach radius.

4.5 Comparative Study of the Beaches

4.5.1 Comparison between Mesoplastics Abundance and Beach Activities

Beach activities at all samplings sites in this study can be divided into four main categories. There are recreational beaches, fishing villages, jetties, and undisturbed beaches. The number of beach users at each site is highly dependent on the activities at each beach. The data were presented in Appendix J. Figure 4.21 and 4.22 shows the average number of beach users at each sampling site. Recreational beaches recorded a higher number of users compared to other beaches. This number decreases at fishing villages and jetties. On the other hand, very few numbers of beach users are observed at the undisturbed beaches. This is due to its inaccessibility and concealed locations.

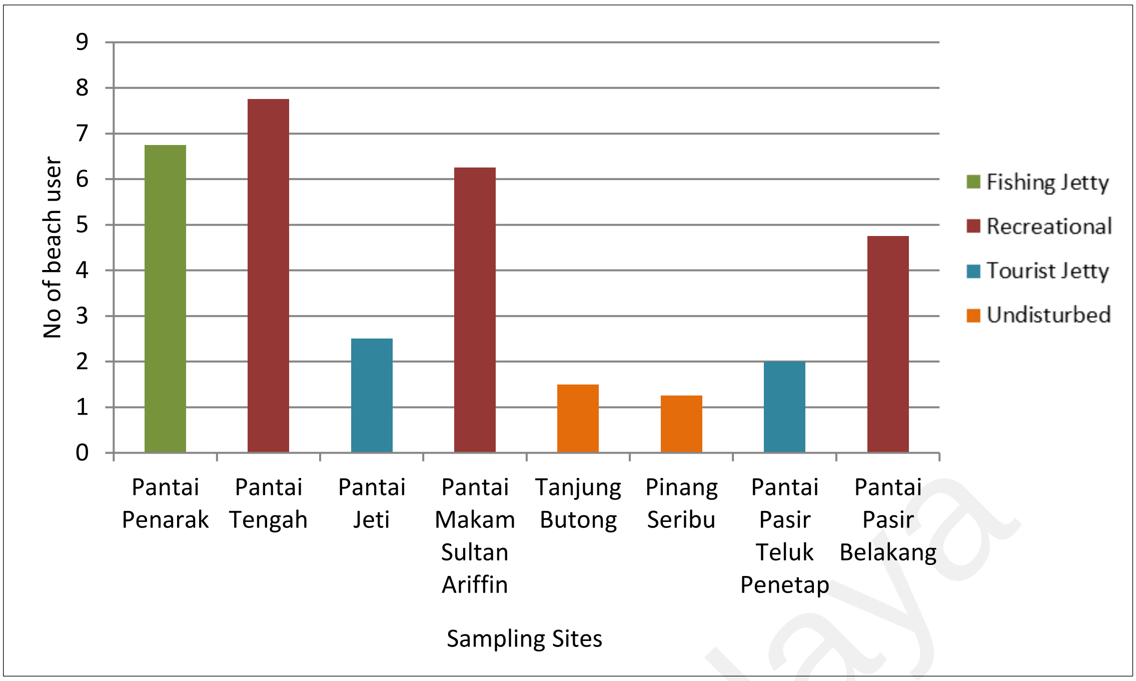

Figure 4.21: Average number of beach user at each sampling sites

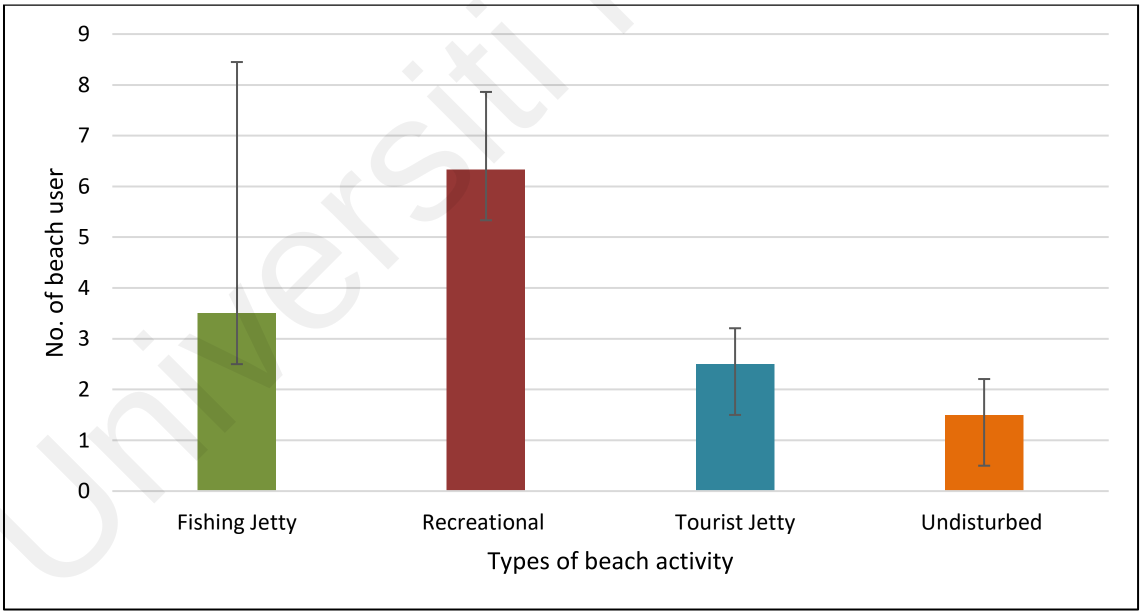

Figure 4.22: Average number of beach users at fishing

The highest number of beach users was recorded at Pulau Langkawi which an average of 15 users. This island is a favorite tourist spot among Malaysian and attracts many international tourists every year. In addition to that, both beaches selected for this study are the main attractions on this island. The second highest number of beach users was at Pulau Besar (average of 9 users). Although this island was not very famous for its aesthetic value, a high number of tourists visit this island for other activities. Pulau Sibu recorded the third highest number of beach users (average of 7 users) while the least was at Pulau Perhentian (average of 3 beach users). Although Pulau Perhentian is one of the famous islands in Malaysia, a low number of beach users was recorded to visit the selected beaches on this island.

Figure 4.23 shows the comparison between the number of beach users and an average number of mesoplastics collected at each beach. The highest number of users was at Tengah Beach (8 beach users) however, this beach was recorded among the lowest collected mesoplastics (100 ± 8 items/m^2). The trend might due to the frequent beach cleaning conducted here. As one of the famous beaches in Pulau Langkawi, beach clean-ups were regularly conducted to maintain its aesthetic value to attract more tourists. The same trend can be observed at Sultan Arifin and Pasir Belakang beaches, as a smaller number of mesoplastics collected here regardless of the high number of beach users.

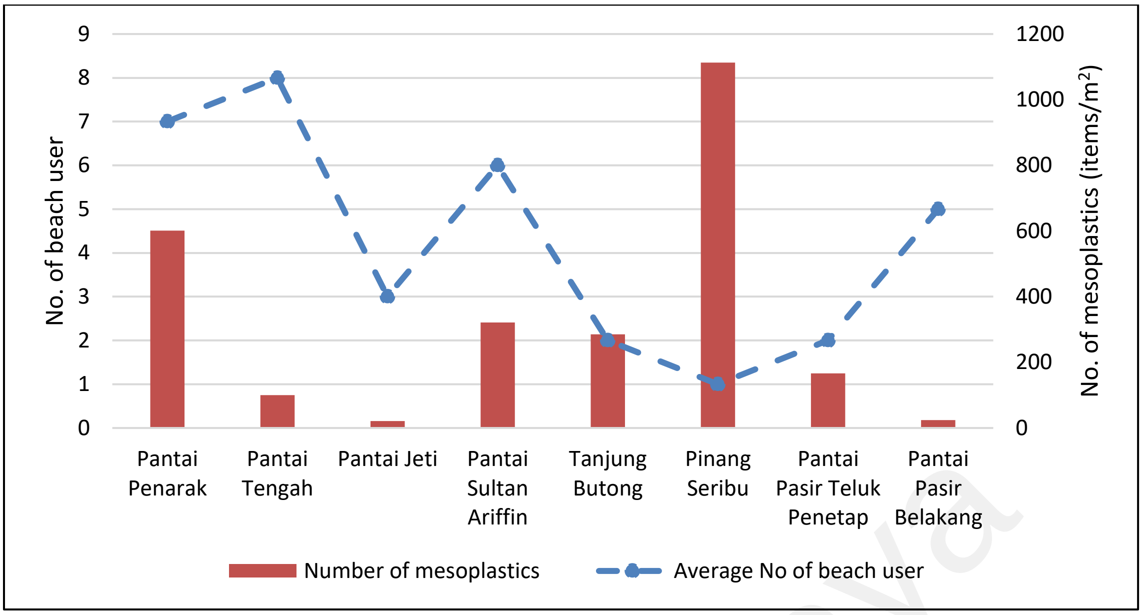

Figure 4.23: Number of beach users against the mesoplastics abundance

On the other hand, Pinang Seribu Beach recorded the highest abundance of mesoplastics with 1113 ± 30 items/m^2 even with the lowest number of beach users (average of 1 user). A very limited number of beach users observed at this beach is due to its location, and difficulty to access. Hence, this shows that the accumulated mesoplastics at this beach are mainly from sea-based sources.

4.5.2 Comparison between Mesoplastics Abundance and Sampling Period

Figure 4.24 shows the abundance of mesoplastics at the sampling beaches based on sampling periods. At all sampling sites, the final sampling results show the highest mesoplastics collections compared to the first three samplings. The fourth sampling was conducted after the monsoon changes where there was a heavy raining season and floods. This proves that natural event is one of the factors that may contribute to the presence of debris. It is in accordance with another study conducted which imposes that more debris can be found after periods of rough weather such as storms and rain (Agamuthu *et al.*, 2012; Ribic *et al.*, 2010).

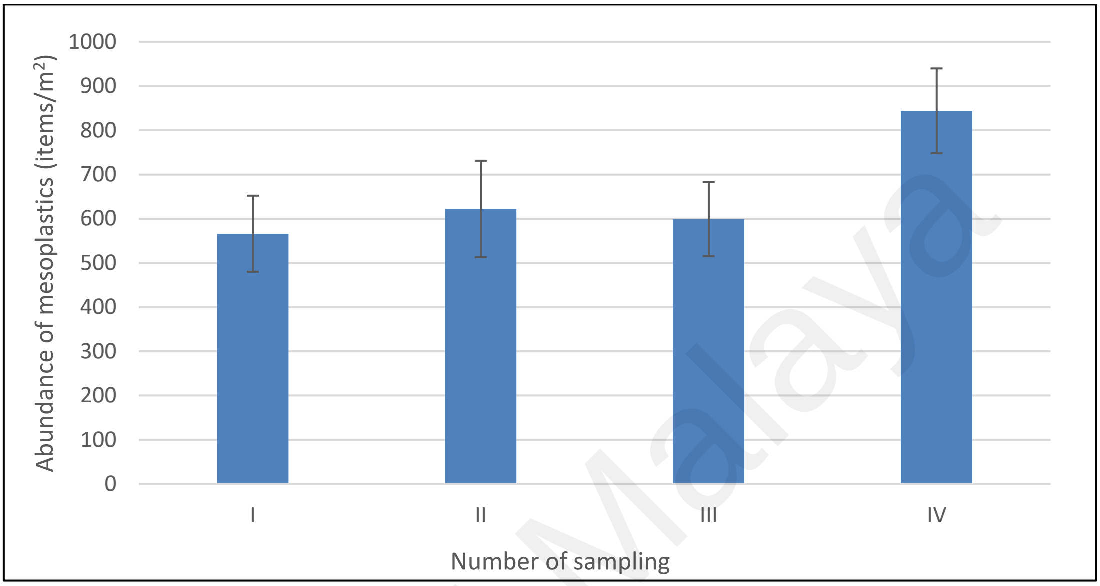

Figure 4.24: Abundance of mesoplastics according to the sampling period

In addition, the weather condition during this sampling might also influence preferential beach accumulation. Wave dynamics can further enhance the breakdown of the bigger pieces of mesoplastics leading to an increasing number of mesoplastics debris at the beaches. Plastics degradation mostly occurred onshore and then transported offshore by the action of wave (McDermid & McMullen, 2004).

4.5.3 Comparison between Mesoplastics Abundance and Beach Attributes

The assessment of mesoplastics distribution and composition has been done to identify the location of mesoplastics deposition on the beach profile. Every attribute that represents different positions of the selected beaches demonstrated a glaring presence of the mesoplastics with some degrees of variation as shown in Figure 4.25.

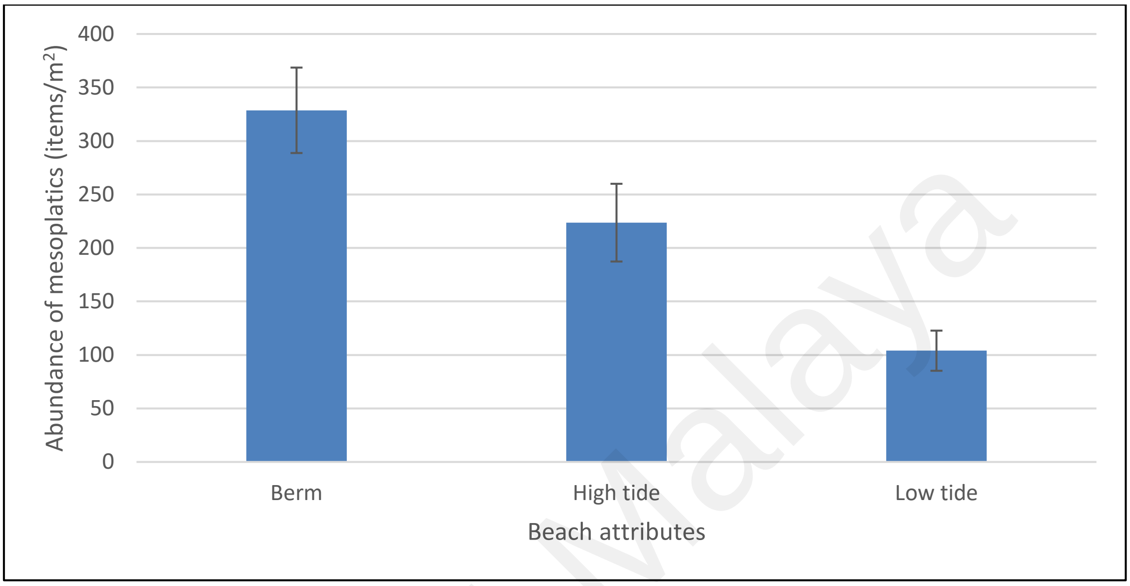

Figure 4.25: Summary of distribution of mesoplastics according to beach attributes for all sampling locations

As an overall comparison of the beach profile studied, the most quantity of mesoplastics has occurred at the berm. This finding varies from the study conducted by McDermid & McMullen (2004). They concluded that more plastic was collected at the high tide zone than in the berm area. Berm mesoplastics may be deposited primarily during storms, or as wind-blown debris from the high tide line, whereas mesoplastics at the high tide line are from particles suspended in the water that will be left onshore during every receding tide (McDermid & McMullen, 2004).

In addition, it was noted during the research that the beach sediment at all sampling sites varies from each other. Types of sediments at these beaches can be classified as sandy, pebbles, and muddy. This was taken into consideration because sediment type might affect the presence of mesoplastics as well.

4.5.4 Comparison of Mesoplastics Abundance based on Types

Mesoplastics of different shapes mainly fragments, lines, foams, films, and pellets were identified at all sampling beaches. Figure 4.26 shows the average quantity of different types of mesoplastics collected from selected beaches of Malaysian islands. The most abundant type of mesoplastics collected from the study areas was foam type (281 ± 53 items/m^2). The predominant presence of foam is from polystyrene food and beverage containers discarded along the beach because of recreational activities such as picnicking.

Besides that, most of the foam type mesoplastics are found to be carelessly discarded by the fishermen. The main sources of foam contributed by fisherman activities are residues of styrofoam fishing crates and styrofoam bait boxes. In addition, styrofoam has a lower density which can break down more readily than other plastics, accounting for its dominance among other mesoplastics. Thus, they are more abundant on most beaches.

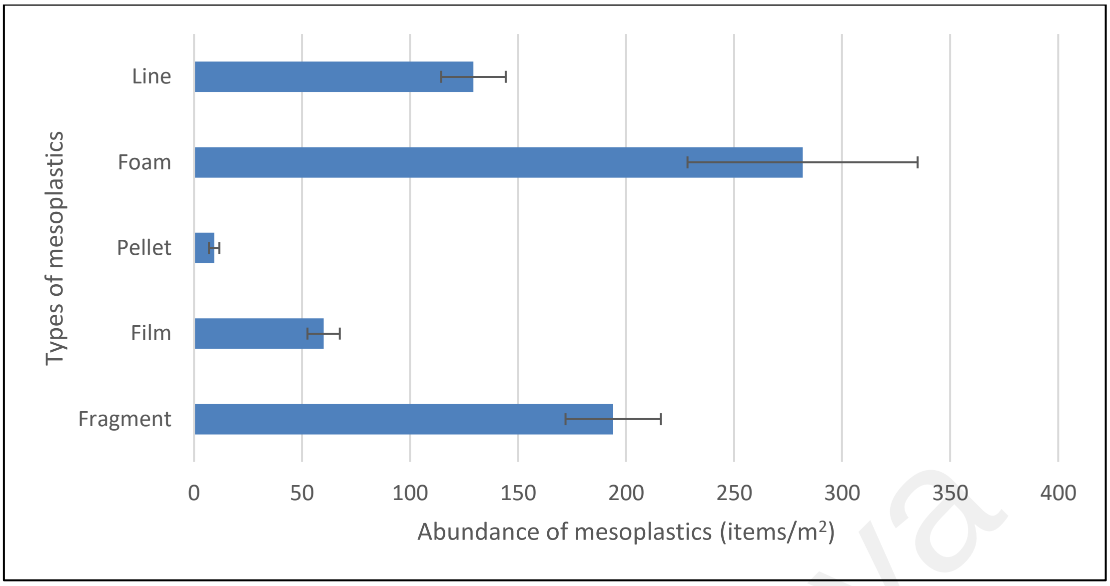

Figure 4.26: Average quantity of different mesoplastics types at all selected beaches

Fragment type mesoplastics was also found dominant at beaches in Malaysian islands, where 194 ± 22 items/m^2 were collected. The presence of high number of fragment plastics is suspected to have originated from recreational activities. The indiscriminate use of hard plastic components such as drinking bottles, food containers, toys, and household items during picnicking activities has contributed to the deposition of plastic fragments in the sands.

The presence of line type mesoplastics at these beaches are mainly from fishing activities. A total of 129 ± 15 items/m^2 of line plastics were collected from the study areas. The use of fishing equipments such as nets and ropes are most likely contributing to the high quantity of plastic line on the beach. Apart from that, the number of film plastics collected at all the beaches in this study was 60 ± 7 items/m^2. These film plastics is likely to have originated from plastic bags and food wrapper which were discarded irresponsibly by beachgoers.

The least abundant type of mesoplastics collected was plastic pellets with 9 ± 3 items/m^2. Pellet type mesoplastics only found at Pinang Seribu and Sultan Ariffin beaches. There are no pellet mesoplastics collected at other beaches in this study. However, the number of pellet type mesoplastics collected is still considered less at both beaches if compared to other types of mesoplastics. One of the potential sources of pellet mesoplastics at these beaches is mesobeads originating from personal care products such as hand and facial cleansers. This assumption is supported in a statement by Isobe (2014), spherical shape mesoplastics are unlikely formed by natural degradation of large plastic waste, they should be primary mesoplastics or mesobeads from personal care and domestic products which then enters the ocean along with effluents (Isobe *et al.*, 2014).

In addition, according to McDermid & McMullen (2004), this type of plastic pellets is known to be abundant on beaches in areas near manufacturing factories, cargo loading docks, and shipping lanes for raw materials. Sultan Ariffin Beach is located at the heavy shipping route of the West Peninsular Malaysia towards Port Klang. In addition, Pinang Seibu is also located at the South China Sea which serves as the main shipping route in East of Peninsular Malaysia. Mesoplastic beads present in cosmetic products such as scrubs, toothpaste, air-blasting media, and clothing can enter the aquatic environment through industrial or domestic drainage systems (Auta *et al.*, 2017; McDermid & McMullen, 2004).

4.5.5 Comparison of Mesoplastic Abundance based on Beaches Location

The total number of mesoplastics collected throughout this study from all sampling sites are 2631 items/m^2. Figure 4.27 shows the total number of mesoplastics collected at selected islands in West and East of Peninsular Malaysia. 1588 items/m^2 of mesoplastics were collected from islands on East coast of Peninsular Malaysia while 1043 items/m^2 of mesoplastics were collected from the islands at the West of Peninsular Malaysia.

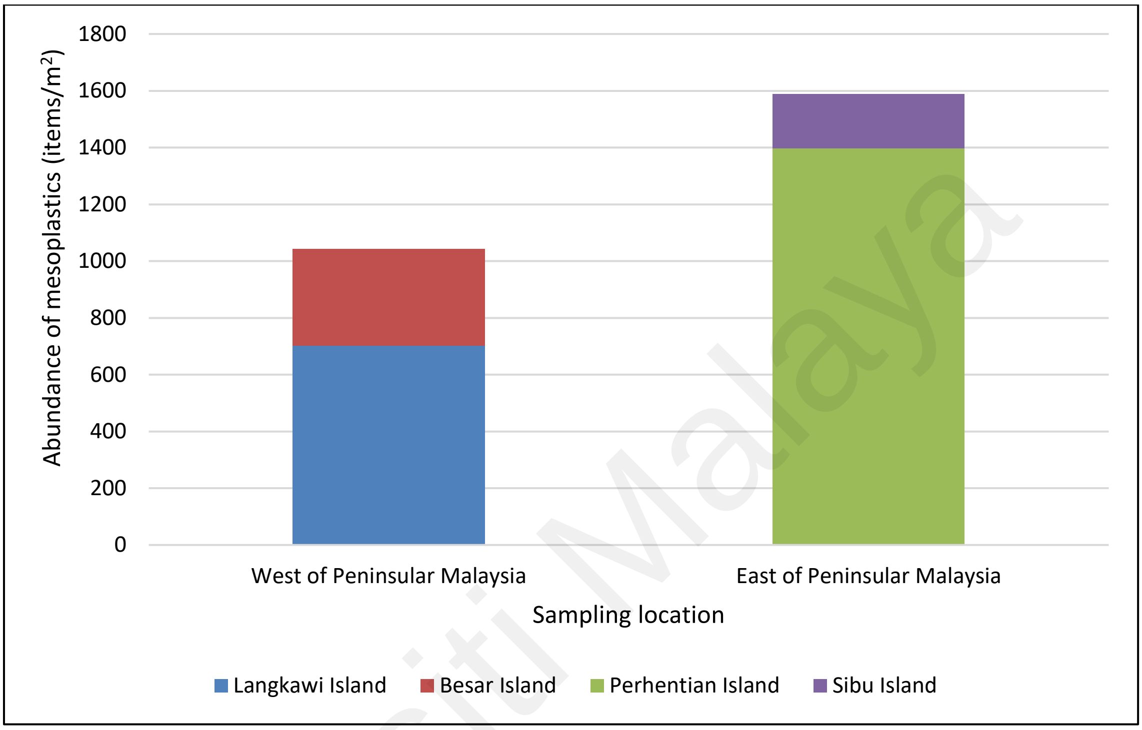

Figure 4.27: Average number of mesoplastics collected based on the island location

Although the result shows that islands in the east recorded a higher number of mesoplastics, there is no significant correlation between the location of the island and the abundance of mesoplastics. It was also established that there is a significant influence of wave that promote the abundance of stranded debris on beaches which was verified by the finding of studies conducted in Malaysia. (Fauziah *et al*., 2015; Khairunnisa *et al*., 2021). The high abundance of marine debris on beaches along the east coast of Peninsular Malaysia was attributed to the exposure of intense wave current and tides from South China Sea (Fauziah *et al*., 2021).

This is supported by the contradicting findings of different research conducted at various beaches worldwide. Many studies have discovered the presence of plastic debris on beaches, even on remote islands, regardless of their location. However, the research at Macua and Hong Kong beaches found remotely located beaches received less pollution impact from anthropogenic activities (Zhao *et al*., 2015). Furthermore, result shows that the total abundance of mesoplastics at beaches facing towards the open sea is higher compared to beaches facing towards the mainland of Peninsular Malaysia as shown in Figure 4.28.

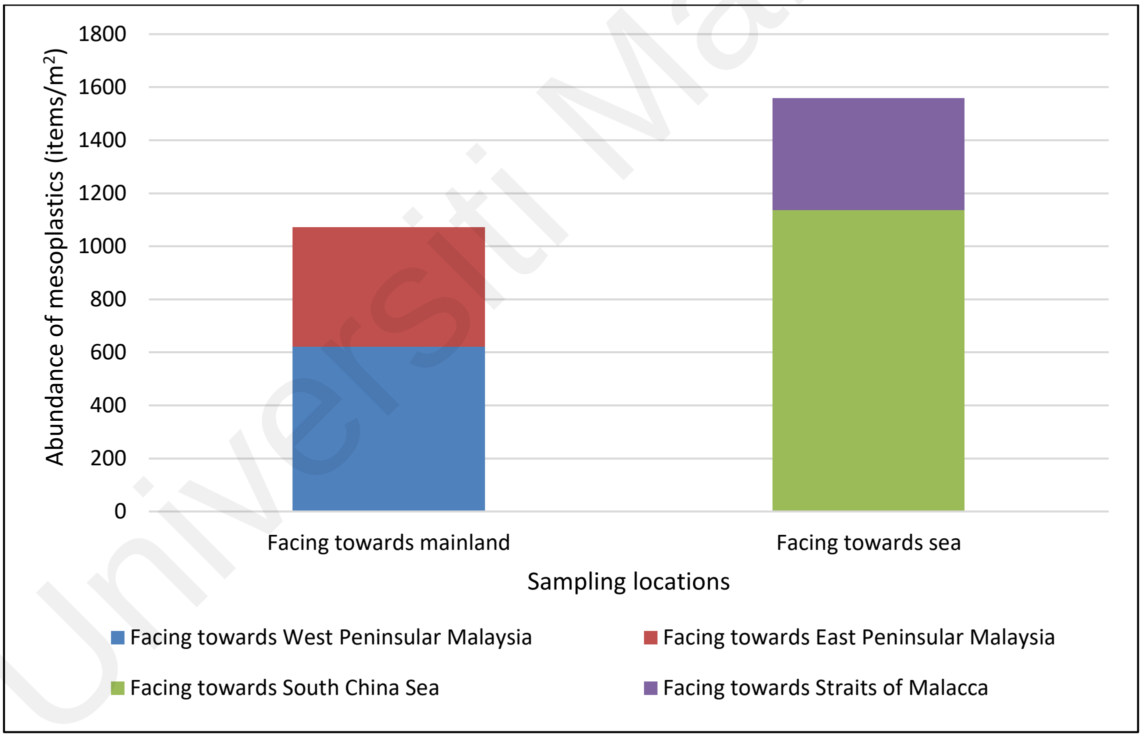

Figure 4.28: Abundance of mesoplastics according to the location of the beaches

From the 1558 items/m^2 of mesoplastics found at beaches facing the open sea, 73% are found in islands at the South China Sea and the remaining 27% is collected from beaches at islands in the Straits of Melaka. 1073 items/m^2 are collected from beaches facing the mainland of Peninsular Malaysia. With regards to this amount, 58% of mesoplastics are from beaches facing West of Peninsular Malaysia (622 items/m^2) and 42% from beaches facing East of Peninsular Malaysia (451 items/m^2).

The number of mesoplastics collected at Pulau Perhentian, Pulau Langkawi, Pulau Besar, and Pulau Sibu are 1398 items/m^2, 701 items/m^2, 342 items/$m^{2,}$ and 190 items/m^2 respectively. Figure 4.29 shows the average number of mesoplastics collected during this study at all selected beaches. The highest numbers of mesoplastics are obtained from Pinang Seribu beach followed by Penarak beach with 1113 ± 30 items/m^2 and 601 ± 19 items/m^2, respectively.

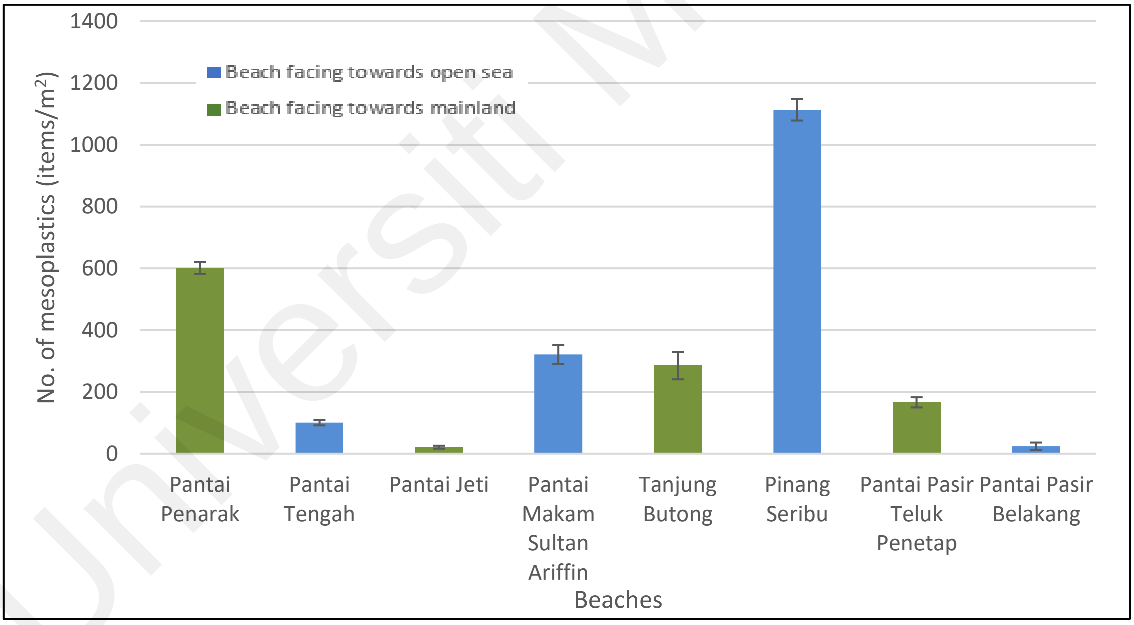

Figure 4.29: Average number of mesoplastics collected at all sampling beaches

The total number of mesoplastics collected at Sultan Ariffin Beach are 321 ± 30 items/m^2, Tanjung Butong Beach are 285 ± 44 items/m^2, Pasir Teluk Penetap Beach are 166 ± 16 items/m^2 and Tengah Beach are 100 ± 8 items/m^2. The lowest numbers of mesoplastics are collected from Pasir Belakang Beach with 24 ± 12 items/m^2 and Jeti Beach with 21 ± 5 items/m^2.

At Pulau Langkawi and Pulau Sibu, the highest mesoplastics are recorded at beaches facing towards the mainland as compared to beaches facing the open sea. This result is vice versa at Pulau Besar and Pulau Perhentian. The number of mesoplastics collected at beaches facing the open sea is more than beaches facing the mainland. From the obtained results, it can be observed that the location of beaches either facing towards the open sea (Straits of Melaka or the South China Sea) or facing towards the mainland of Peninsular Malaysia (East or West) does not influence the presence of mesoplastics at the coastal lines.

Thus, there is no significant correlation between the number of mesoplastics collected and the location of the beach. This is supported by a study conducted in Hong Kong, where no significant spatial variations in microplastic abundance were observed in the marine sediments of different coastal region (Tsang *et al*., 2017). In addition, due to population densities, hydrographical, and geological conditions, the rate of accumulation of litter in different coastal area is technically difficult to compare (Bhuyan *et al*., 2020).

The highest number of mesoplastics was collected at Pinang Seribu Beach. High accumulation of small plastic debris at this beach occurred because of its geological condition. Exposed to tides of the South China Sea and located at the top corner of the island may be the root cause of mesoplastics accumulation on the sea at this beach. The second highest number of mesoplastics was found at Penarak Beach. Besides being a fish-landing jetty, this beach is also one of the main tourist spots in Pulau Langkawi. Beach activities and the number of beach users contributed to the presence of mesoplastics on this beach extensively. Recreational activities may be the reason for the accumulation of plastics in the sand.

Intermediate levels of mesoplastics were found in Sultan Ariffin Beach, Tanjung Butong Beach, and Pasir Teluk Penetap Beach. Recreational activities at Sultan Ariffin Beach may contribute to the presence of small plastic debris on this beach. At Tanjung Butong Beach, the pebble sediment type helps in trapping mesoplastics from the seawater. As this beach is quite isolated and only accessible by boat, the number of visitors is limited. Pasir Teluk Penetap Beach is a tourist jetty for resorts at Pulau Sibu. There are always fewer beach users in this area and they only spend a very limited time here while waiting for their boat to arrive. Most of the time the boats arrive on time because it is managed by the resort located on this island to transport their own guests.

The lowest number of mesoplastics was recorded at Tengah Beach, Pasir Belakang Beach, and Jeti Beach. Tengah Beach and Pasir Belakang Beach are spotlight areas for beachgoers to perform recreational activities. Hence, the dumping of plastics waste must have occurred intentionally or unintentionally. However, a very less amount of mesoplastics are collected here because beach cleaning activities are frequently conducted. The resorts nearby these beaches take the responsibility for keeping these beaches clean. Thus, these beaches recorded the lowest number of mesoplastics collected. Besides that, the least amount of mesoplastics were found at Jeti Beach because the length of the beach from the berm to the low tide is very short. This may contribute to the movement of small plastic debris towards the sea.

4.6 Water Quality Analysis

In addition to the study on the presence of mesoplastics on the beach, the coastal water quality was also studied to identify the relationship between mesoplastic abundance and seawater quality at the sampling areas. The results were analyzed and compared with the Malaysian Marine Water Quality Standard (MMWQS). Results and findings according to studied parameters are discussed in the next sections.

4.6.1 Temperature

The temperature of seawater in the studied areas were between 24.7 ± 2.54°C – 33.1 ± 3.39°C. Figure 4.30 shows the temperature recorded at all the study sites at distances of 3 m and 6 m away from the shoreline. The temperature did not vary much and was highly dependent on the weather conditions during the sampling time. The highest temperature was observed at Pinang Seribu Beach while the lowest temperature was recorded at Sultan Ariffin Beach.

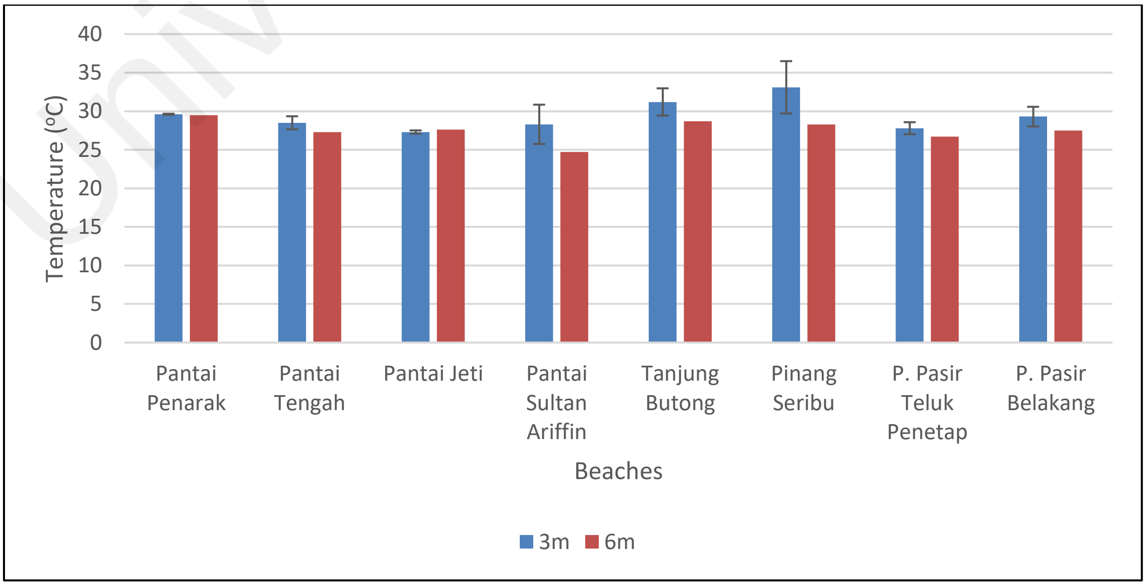

Figure 4.30: Temperature of seawater at all the sampling sites

The results can be concluded that the further the distance of sampling point from the beach, the lower the temperature recorded. This trend was observed at all the sampling sites where the temperature of samples collected at 3m away from the shoreline is much higher compared to samples at 6m from the beach except at Jeti Beach. At Jeti beach the temperature of seawater at sampling point 6m away from the shoreline 0.3ºC higher compared to the sampling point at 3m from the beach.

Moreover, the data shows that at most beaches the temperature variation at the sampling points were not more than 2ºC. Some notable degrees of variance in temperature between the sampling points were only observed at three beaches which are Sultan Ariffin Beach, Tanjung Butong Beach, and Pinang Seribu Beach with 3.6ºC, 2.5ºC, and 4.8ºC, respectively. There were no large differences found in the seawater temperature among the sampling sites.

The changes in the ambient temperature affect the temperature of surface water. The comparison of data with the weather conditions during the sampling periods shows that seawater samples collected during the sunny day recorded the highest temperature. The high temperature of seawater at Pinang Seribu Beach might be due to the first three samplings were conducted during a hot sunny day. At Sultan Ariffin Beach, the weather when the samples were taken was mostly cloudy which contribute to the low temperature of seawater.

These results show similarities with the outcome from the study conducted by Hamzah *et al*., (2011). Variations in the seawater temperature are mainly due to the prevailing weather condition during the sampling period which does not contribute to significant differences in temperature between the locations. Generally, many factors such as the weather condition, sampling time, and location impact the increase or decrease of temperature which in turn also affects the percentage of dissolved oxygen, biological activities, and other parameters. In the following section, the pH value of coastal water at all the sampling beaches will be discussed.

4.6.2 pH

The pH value at both sampling points 3 m and 6 m away from the shoreline did not show much variation. A pH value of 8.42 ± 0.59 was obtained at Tanjung Butong Beach at a 3m distance from the beach whereas a lower value of pH 6.61 ± 0.12 was recorded at Pasir Belakang Beach. At sampling points 6m away from the shoreline, the highest pH was obtained at Tanjung Butong with a pH value of 7.59 ± 0.59 while the lowest value was recorded at Sultan Ariffin Beach with a pH value of 6.53 ± 0.18. The pH range at all the sampling sites is shown in Figure 4.31. In this study, the pH level for coastal waters ranged between pH 6.5 and 8.5. Based on the MMWQS guidelines, these results are within the standard range of pH 6.5 to 9.0.

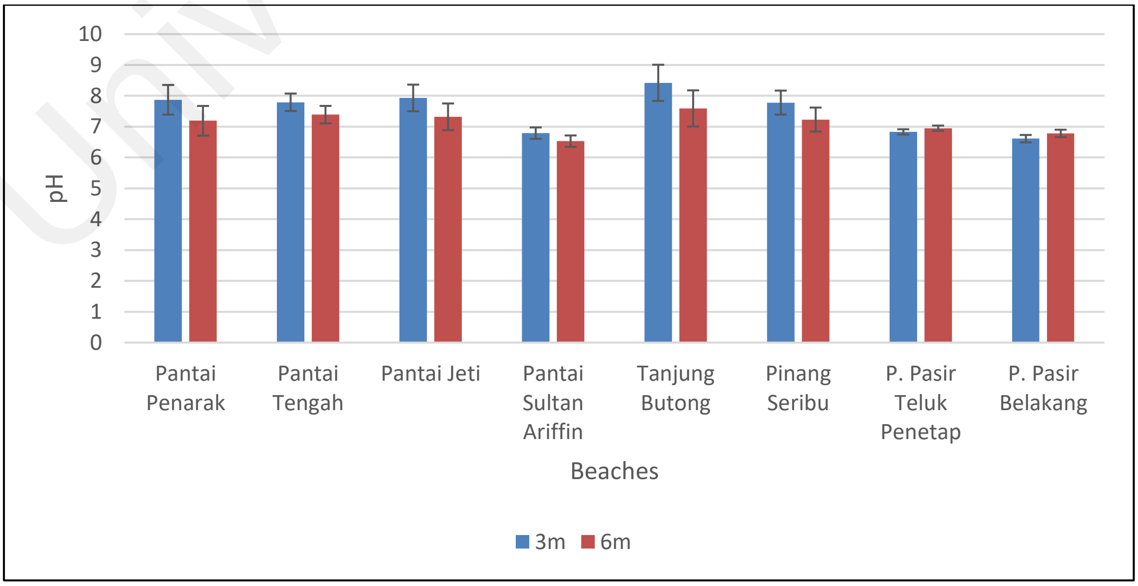

Figure 4.31: pH of seawater at all the sampling sites

Beaches such as Sultan Ariffin, Pasir Teluk Penetap, and Pasir Belakang recorded pH values less than seven for both sampling points. This is probably caused by agriculture, recreation, and industrial discharges from Pulau Besar and Pulau Sibu got into the sea. In addition, the locations of these islands in the southern part of Peninsular Malaysia along the main route for water logistics which also influences the pH of seawater in these areas. Port Klang, West Port, and Tanjung Pelepas Port are located nearby to the islands. According to the study carried out by Rahman *et al.,* (2016), shipping activities cause implications to the environmental aspects particularly water pollution. Ship collisions and emissions are two main factors that introduce plastic pollutants into the marine biodiversity and brought negative consequences to the environment.

Other than that, waste disposal could also lead to a more acidic pH level. The hotels, resorts, and restaurants located at these beaches might release wastewater into the sea. The entry of these pollutants can influence the pH value of coastal water. These discharges contain industrial and municipal wastes including animal remains and domestic waste, such as kitchen waste, detergent from washing, and fecal matter. These wastes might contain viral, bacterial, protozoan pathogens, toxic chemicals, and a variety of other organic and inorganic wastes.

Generally, the pH concentration increases as a result of the photosynthetic algae activities that consume carbon dioxide dissolved in the water. Overall, the range of pH from 6.5 to 9.0 is mainly appropriate for aquatic life. Therefore, it is very important to maintain the aquatic ecosystem within this range because high and low pH can be destructive in nature. The decomposition of organic matter in the presence of dissolved oxygen increases the carbon dioxide content of water and lowers the pH. The correlation between the pH value recorded with the dissolved oxygen level obtained will be discussed in the next section.

4.6.3 Dissolved Oxygen (DO)

The lowest DO value recorded was 3.62 ± 0.78 mg/L at Pinang Seribu Beach while the highest was 8.55 ± 0.27 mg/L at Jeti Beach for the sampling point of 3 m away from the shoreline. At the sampling point 6m away from the beach, the lowest and highest DO readings were also recorded at Pinang Seribu and Jeti beaches with 4.73 ± 0.78 mg/L and 8.83 ± 0.27 mg/L, respectively. The DO values at all sampling sites are shown in Figure 4.32. As the sampling distance increases from the shoreline, the DO value also increases. This trend can be observed at all sampling beaches.

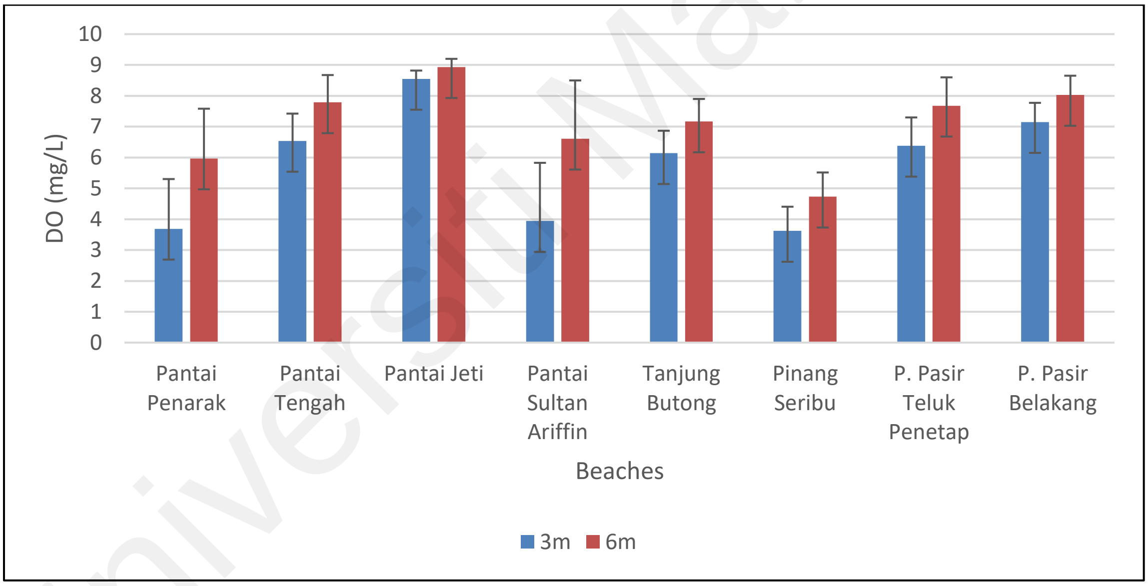

Figure 4.32: DO level of seawater at all the sampling sites

According to MMWQS, low DO indicates high pollution content. The DO level obtained in this study were between 3.62 to 8.93 mg/L which is generally higher compared to the standard at all sampling sites indicating that these systems were well oxygenated. The DO value is high because all samplings were done in the morning and afternoon. At this time photosynthesis rate of the sea algae are expected to be at the peak.

Overall, there is a slight difference in DO values of coastal water among the studied areas. The spatial differences of sampling site might lead to these results.

In addition, the DO value was high at Pasir Belakang Beach (7.15 mg/L and 8.03 mg/L) since it was a cleaner beach with better management. Besides that, the lowest value of DO recorded at Penarak Beach (3.69 mg/L and 5.97 mg/L) and Sultan Ariffin Beach (3.94 mg/L and 6.61 mg/L) may be due to the influx of floodwater from river and tourist activities such as fishing, boating, and swimming. There are many shops, restaurants, and hotels along these beaches and these sites might be affected by the wastewater coming from the locality situated near to the beach. From the obtained results, DO values at Pinang Seribu Beach and Tanjung Butong Beach were considered relatively high and potentially good for living marine life which answers why these sites are very famous for their coral reefs at Pulau Perhentian.

4.6.4 Conductivity

The average value of conductivity of coastal water at the sampling sites during the study time ranges from 44.38 ± 5.50 - 52.62 ± 5.02 mS/cm. The conductivity corresponding to each location is shown in Figure 4.33.

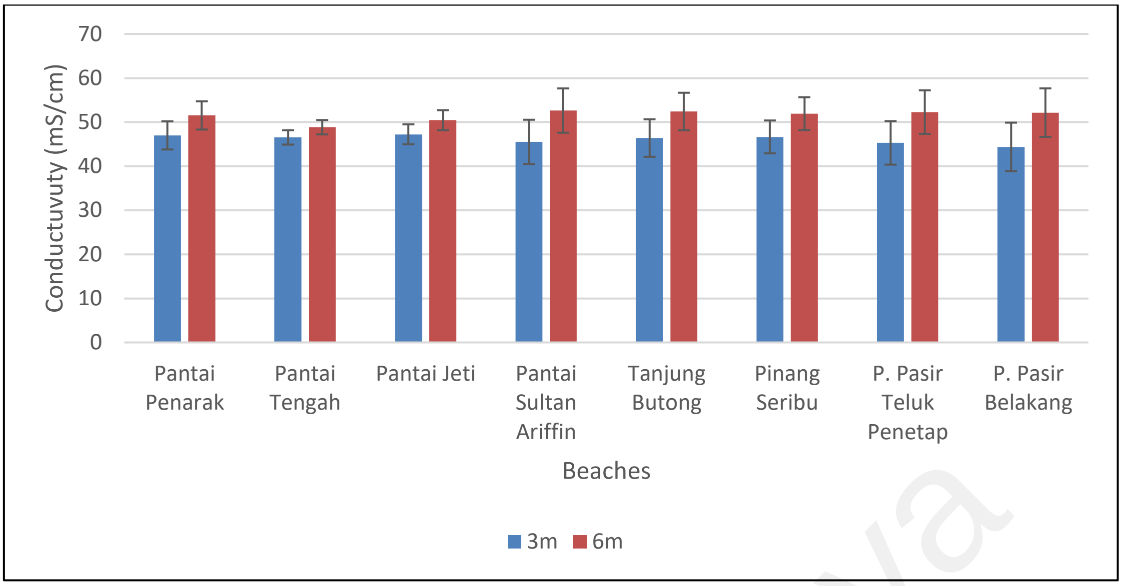

Figure 4.33: Conductivity of seawater at all the sampling sites

The minimum value of conductivity is obtained at Pasir Belakang beach at sampling point 3 m away from the shoreline while the highest conductivity was recorded at Sultan Ariffin beach at 6 m away from the seashore with 44.38 ± 5.50 and 52.62 ± 5.02 mS/cm, respectively. From the result, the trend observed is that increase in the distance of sampling point from the coastal line, the conductivity value also increases.

The seawater conductivity in our study areas is much lower compared to the research carried out by Gasim *et al.*, (2013). In his study areas, the conductivity of seawater was recorded between 46 and 231 mS/cm. In addition, the results also show seasonal variation in conductivity of the seawater with respect to different study sites. It is highly dependent on the number of dissolved solids in water. The conductivity of water is affected by the suspended impurities and also depends upon the number of ions in the water.

The findings in this study also contradict with the findings of previous studies conducted by Hernández *et al.*, (2004) and Bakan *et al.*, (2010), which concludes the weather condition during the sampling period does not affect much the seawater conductivity. The conductivity results obtained from all our study sites are within the same limit range of 40 – 50 mS/cm.

4.6.5 Salinity

The average value of coastal water salinity at all sampling sites ranges from 23.80 – 38.31 ppt. The salinity corresponding to each location is shown in Figure 4.34. The highest salinity reading of sampling points 3m away from the shoreline was recorded at Penarak Beach with 37.23 ± 1.11 ppt and the lowest value 26.40 ± 1.83 ppt was obtained at Pasir Belakang Beach. Similar results were also obtained from the water samples collected at a distance of 6m away from the shoreline. The highest value was found at Penarak Beach with an average of 38.31 ± 1.11 ppt and lowest at Pasir Belakang Beach with a reading of 23.80 ± 1.83 ppt.

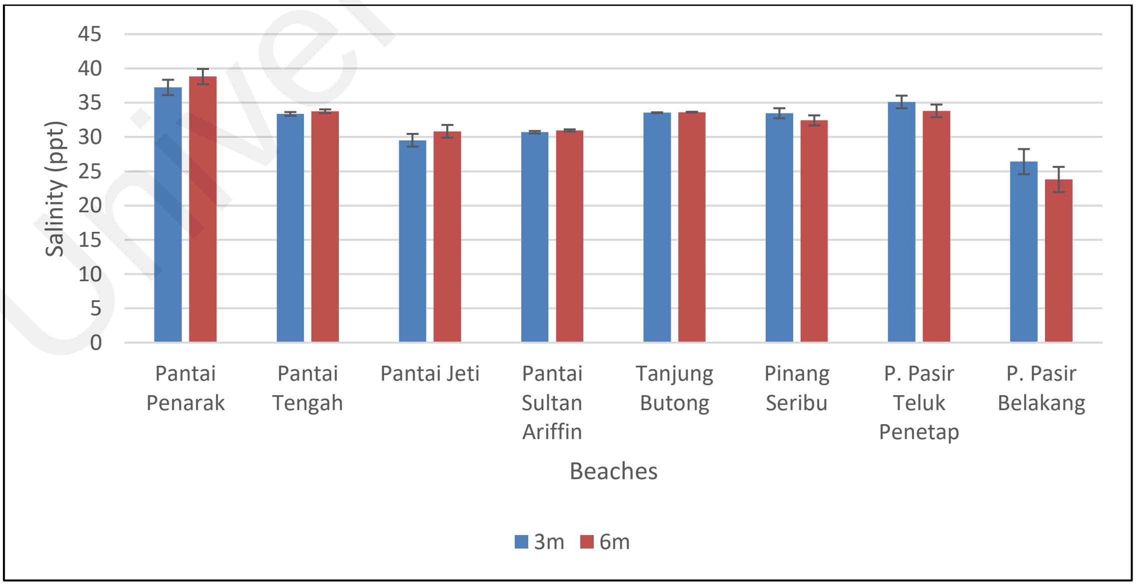

Figure 4.34: Salinity of seawater at all the sampling sites

The salinity of the seawater can be influenced by high rainfall and by influx from rivers. Freshwater from the rivers is largely responsible for lowering the surface salinity apart from the monsoons which affect the annual salinity variation. It can be observed that beaches such as Penarak Beach, Tengah Beach, and Pasir Teluk Penetap Beach recorded higher salinity readings.

On the other hand, beaches such as Sultan Ariffin, Jeti Beach, and Pasir Belakang Beach is located near the downstream of the rivers and showed low salinity due to the mixing of freshwater and seawater. In addition, the climate during the sampling period also affects the salinity of the seawater as the freshwater influx during the rainy months. This can be observed at Sultan Arifin Beach, Tengah Beach, and Penarak Beach as it was drizzling and light rainy season during the sampling periods.

In the month of November, coastal sites and islands at Peninsular Malaysia receive more rainwater and floodwater so it contains lesser salinity. Besides that, during sunny days, the rate of evaporation is slightly increased due to high temperature. This influences sea surface salinity.

4.6.6 Total Dissolve Solid (TDS)

The TDS at all the sampling sites were recorded and presented in Figure 4.35. The highest TDS was observed at Pinang Seribu Beach with 36824 ± 5987 g/L and the lowest at Tanjung Butong Beach with 30970 ± 1163 g/L from the sampling point 3m away from the shoreline. Similar results were obtained for the samples collected at a distance of 6m away from the beach with the highest TDS at the Pinang Seribu Beach (45291 g/L) and the lowest TDS recorded at the Tanjung Butong Beach (29324 g/L).

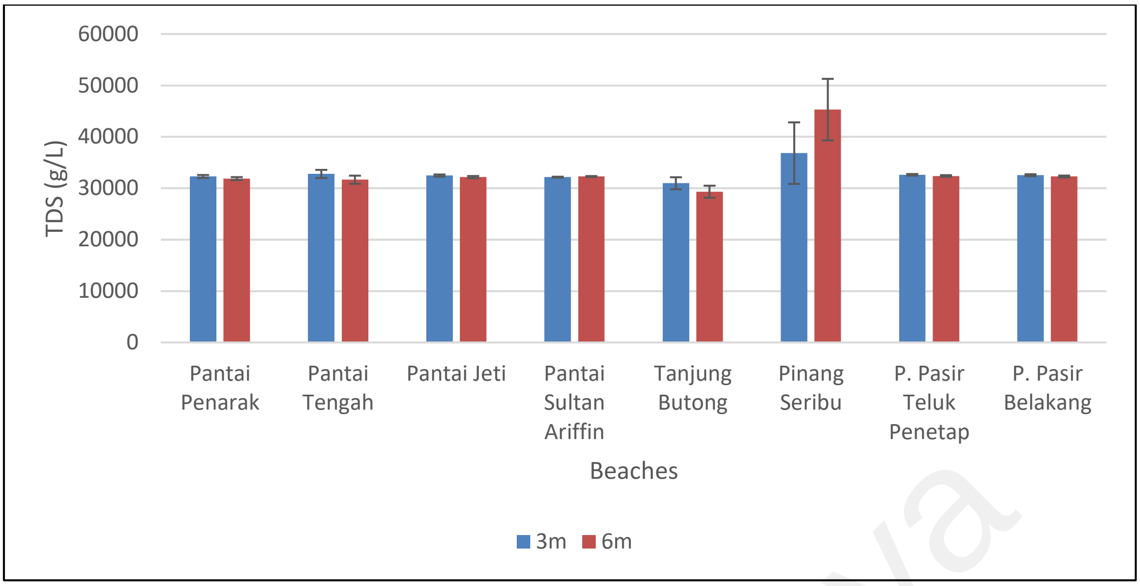

Figure 4.35: TDS of seawater at all the sampling sites

The average value of TDS of surface seawater at Pinang Seribu Beach is the highest and this might be due to the high tide monsoon at this beach in the month of November. In addition, samplings were done during the high tide and wave currents were high at that time. The TDS at other beaches (Penarak, Tengah, Jeti, Sultan Ariffin, Pasir Teluk Penetap, and Pasir Belakang) does not vary much and within the range of 31.62 g/L to 32.77 g/L. This is due to the low tide season and lesser sea wave current at these beaches during the samplings. There is no dilution due to rain or flood during the sampling periods. The turbidity of the samples collected from all beaches in this study are discussed in the next section.

4.6.7 Turbidity

Turbidity values recorded at all sampling sites in this study are between 9.26 ± 0.04 and 25.92 ± 0.93 NTU. Tanjung Butong Beach recorded the lowest turbidity of 9.26 ± 0.04 and 9.27 ± 0.93 NTU at both sampling points 3 m and 6 m away from the shoreline respectively. Similarly, the highest turbidity was at Tengah Beach with a value of 25.92 and 27.23 NTU at points 3 m and 6 m, respectively. The trend of turbidity at all sampling areas are demonstrated in Figure 4.36.

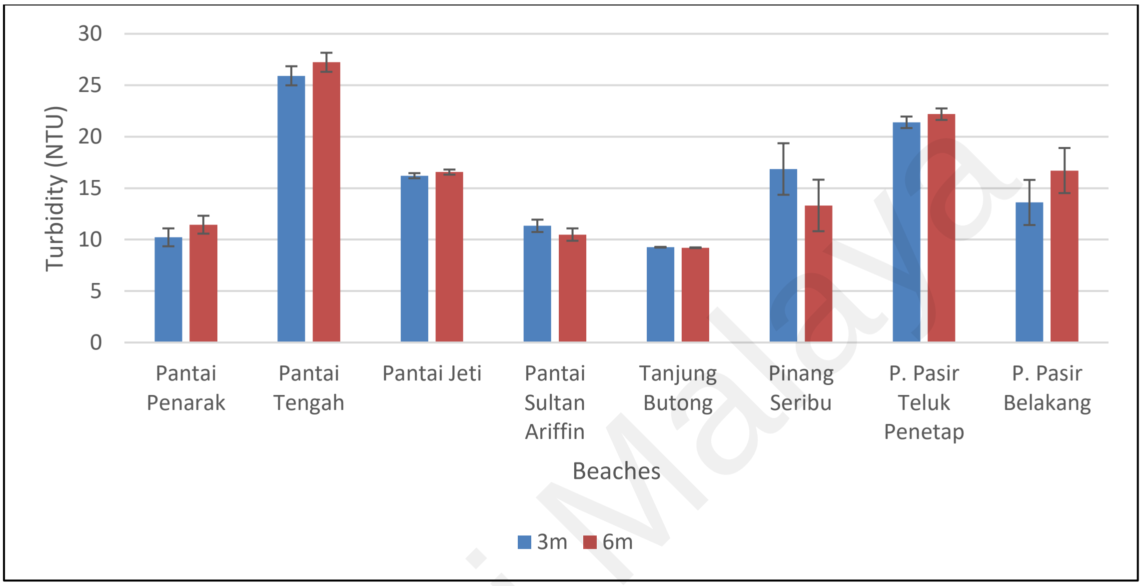

Figure 4.36: Turbidity of seawater at all the sampling sites

Besides that, other beaches such as Penarak, Jeti, Sultan Ariffin, Pinang Seribu, Pasir Teluk Penetap, and Pasir Belakang beaches recorded the turbidity values of 10.22, 16.21, 11,34, 16.56, 21.40, and 13.61 NTU, respectively, for the sampling point 3m away from the beach. For coastal water collected at sampling point 6m away, the turbidity values recorded were 11.45, 16.56, 10.49, 13.32, 22.19, and 16.71 NTU, respectively.

Furthermore, turbidity concentrations in this study were higher than 15 NTU at most of the beaches. According to the DOE's guideline, a concentration below 30 NTU is still permissible for domestic use. However, the water body at all the study sites clears most of the time and suitable for water recreational activities as the standard turbidity is 25 NTU. This statement is also supported by the study conducted by Gasim *et al*., (2013) at the northern beaches of Penang. The next section discusses the total suspended solid level in the coastal water samples.

4.6.8 Total Suspended Solid (TSS)

TSS values of seawater samples collected at all sampling sites are ranged between a minimum of 6.77 ± 1.50 mg/L at Pasir Teluk Penetap Beach and a maximum of 51.64 ± 4.51 mg/L at Penarak Beach at sampling point 3m from the coastal line. Similar results were obtained for the sampling point 6m away from the shoreline with highest at Penarak Beach (45.25 ± 4.12 mg/L) and lowest at Pasir Teluk Penetap Beach (8.90 ± 6.13 mg/L). The result is shown in Figure 4.37.

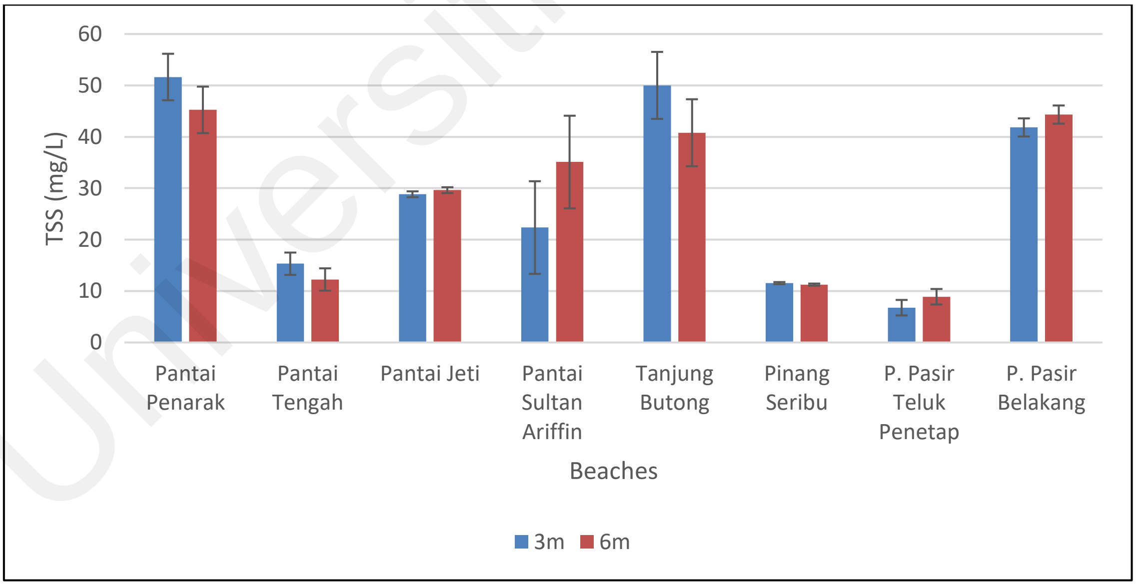

Figure 4.37: TSS of seawater at all the sampling sites

Usually, soil erosion is considered the source of suspended solids that comes from the nearby anthropogenic activities. The high TSS recorded at Penarak Beach is mostly due to the use of the shoreline for fishing activities which stimulates the erosion of coastal banks. Furthermore, Tengah Beach in Pulau Langkawi recorded a TSS value of 15.32 ± 2.17 mg/L and 12.25 ± 8.18 mg/L at sampling points 3m and 6m away from the shoreline respectively. The development and commercialization of this beach attract a high number of tourists which directly contributes to high discarded particle debris through many water-based activities such as boating, picnicking, and swimming. This high TSS also will increase the seawater temperature resulting in lower DO.

Besides that, the most turbid water was recorded at Tanjung Butong Beach (50.01 ± 6.51 mg/L) and Pasir Belakang Beach (44.33 ± 1.76 mg/L). This might be due to the rainy season during the sample collection timeframe. Besides that, the changes in the monsoon also affect the turbidity level at this beach. The high and low tide might also affect the TSS concentrations of the seawater.

In addition, the anthropogenic activities in coastal areas also contribute to the increase in TSS concentration. As TSS readings are associated with intensive land development, suspended solids usually consist of mud, refined waste minerals, fine sand particles, silt, and clay. A high TSS reading could disturb the ecosystem for aquatic life by preventing sunlight from penetrating further into the water surface. The excess level of solid particles in the aquatic environment caused various stresses, such as increasing oxygen demand, lowering the nitrification rate, and promoting the propagation of pathogens.

At Jeti Beach and Sultan Ariffin Beach, the highest TSS value is recorded which was 28.83 ± 0.56 mg/L and 35.10 ± 9.00 mg/L, respectively. Referring to the study conducted by Lee *et al*., (2009), high TSS was observed at stations along the Straits of Melaka, and this is often attributed to land clearing activities for construction projects, mining, agricultural and forest industries, and dredging operations.

The lowest TSS value was recorded at Pasir Teluk Penetap Beach with 6.77 ± 1.37 mg/L and 8.90 ± 6.13 mg/L at both sampling points, 3m and 6m from the shoreline. The sampling was conducted during the high tide. Thus, there was a reduction in water movement which could disturb the bottom sediments. This led to low TSS concentration. The next section discusses the chemical oxygen demand level at all beaches studied in this research.

4.6.9 Ammonium

The ammonium level at all the sampling sites ranged from 36.16 ± 4.43 µg/L to 84.63 ± 2.32 µg/L. The data obtained at all sampling beaches are represented in Figure 4.38.

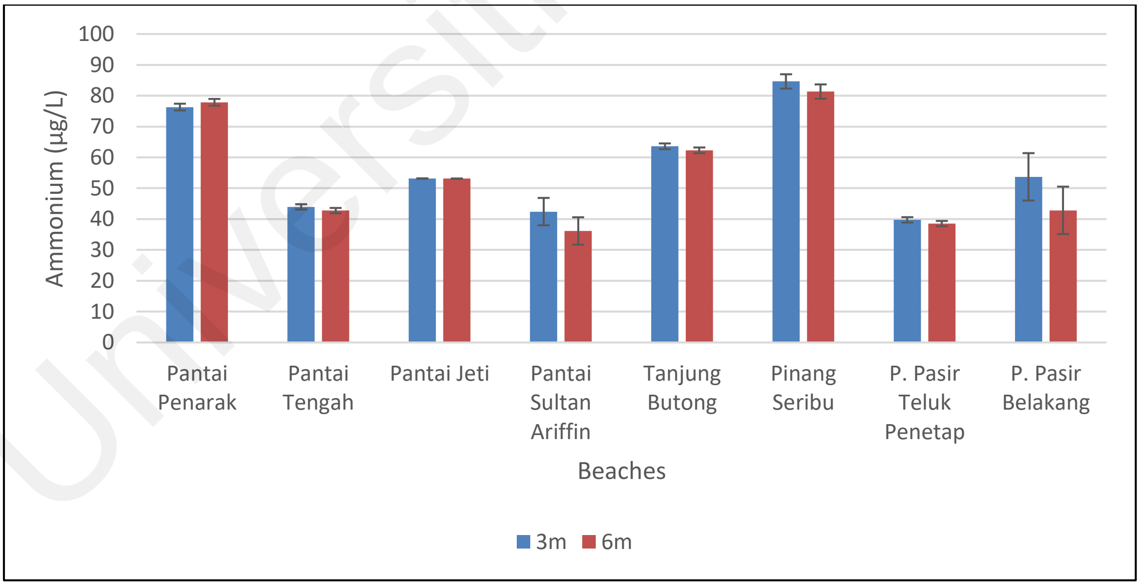

Figure 4.38: Ammonium level of seawater at all the sampling sites

The highest values were recorded at Pinang Seribu Beach with 84.63 ± 2.32 µg/L and 81.34 ± 2.63 µg/L, respectively at 3m and 6m away from the shoreline. Despite the location of this beach which is isolated from anthropogenic activities, the seawater still recorded high ammonium levels. At Sultan Ariffin and Pasir Teluk Penetap beaches the lowest ammonium values were recorded with 36.16 ± 4.43 µg/L at point 6m and 39.76 ± 3.35 µg/L at point 3 m, respectively. The high amount of ammonium in water can lead to algal bloom which creates an unfavorable condition for bacterial growth due to inadequate oxygen. As a result, the number of bacteria in this coastal habitat tends to be lower.

The next highest ammonium level was recorded at Penarak and Tanjung Butong beaches. The values recorded at Penarak Beach were 76.32 ± 1.08 µg/L at sampling 3m away from the shoreline and 77.86 ± 8.89 µg/L at sampling point 6m away while at Tanjung Butong Beach the values recorded were 63.60 ± 0.92 µg/L and 62.29 ± 6.31 µg/L, respectively. The high value of ammonium at these beaches might be due to large tidal oscillation and shallow coastal water.

4.6.10 Nitrate

The nitrate (NO_3) concentrations at all study sites were ranged from 0.01 to 0.12 mg/L. The nitrate concentration in the seawaters was recorded the highest at Penarak Beach with the reading of 0.12 ± 0.007 mg/L and 0.11 ± 0.014 mg/L at sampling points, 3m and 6m away, respectively from the shoreline. Jeti and Pasir Belakang beaches recorded similar lowest nitrate values with 0.02 ± 0.007 mg/L and 0.01 ± 0.014 mg/L at distance 3 m and 6 m, respectively. The nitrate value at all sampling sites is shown in Figure 4.39.

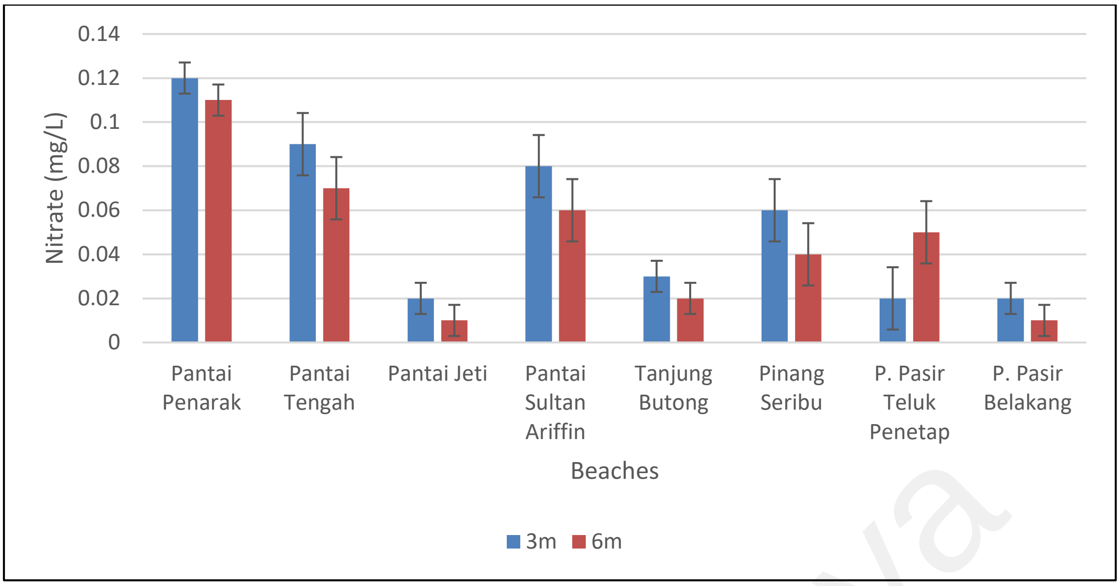

Figure 4.39: Nitrate level of seawater at all the sampling sites

The nitrate values for Jeti, Pasir Belakang, Pasir Teluk Penetap, and Tanjung Butong beaches were within the maximum permissible limit set by MMWQS which is 0.06 mg/L and falls under the class II, seawater quality standard suitable for fisheries including mariculture. On the other hand, beaches such as Penarak, Tengah, Sultan Ariffin, and Pinang Seribu recorded nitrate values between 0.06 to 0.12 mg/L. Nitrate value more than 0.06 mg/L falls under class III which indicates that the water quality standards are similar to industry, commercial activities, and coastal settlement.

The possible reason for high nitrate content in the coastal waters is due to the tourist activities and fisherman residential areas. The organic and inorganic wastes that are discharged from residential areas are high in nitrogen and phosphorous, which causes water to become nitrate and phosphate-rich after bacterial decomposition.

4.6.11 Phosphate

The highest value of phosphate was recorded at Tengah Beach with 0.58 ± 0.01 µg/L and 0.56 ± 0.04 µg/L for the samples collected at point 3 m and 6 m away from the beach, respectively. Meanwhile, the lowest value of phosphate was recorded from samples collected at Jeti Beach with the phosphate concentration of 0.06 ± 0.007 µg/L at 3 m sampling point and 0.07 ± 0.001 µg/L at sampling point 6 m away from the shoreline. The phosphate contents in all the samples collected are shown in Figure 4.40.

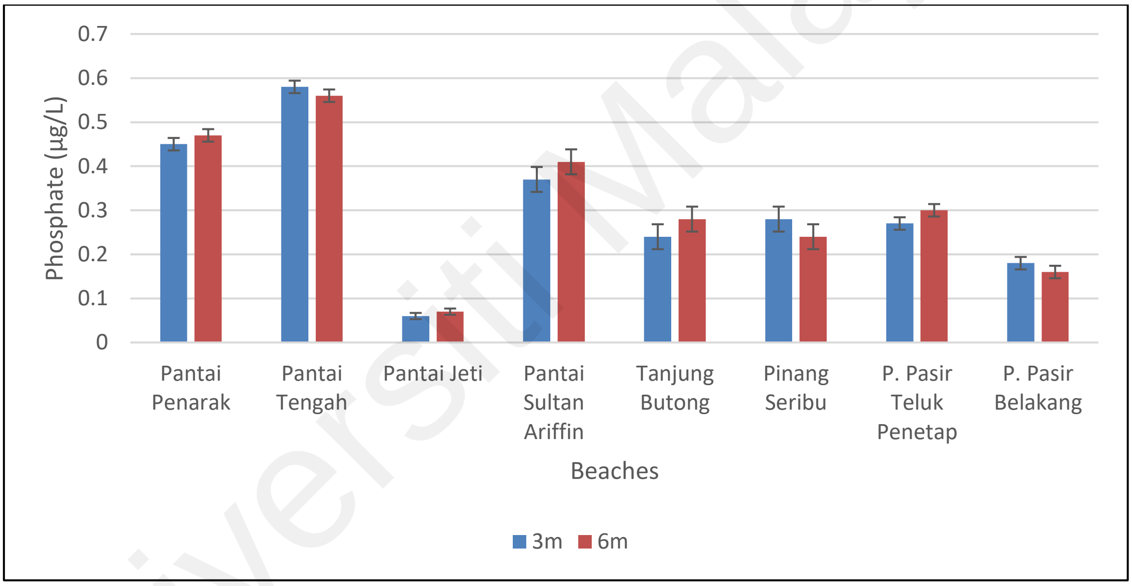

Figure 4.40: Phosphate level of seawater at all the sampling sites

The major pollution sources at beaches in this study are mainly from tourism-based activities, fishing, shipping, small industries, and urbanization along with the coastal environment. This is proven by the results obtained from samples collected at Tengah, Penarak, and Sultan Ariffin beaches. Tengah Beach recorded a phosphate concentration of 0.58 ± 0.04 µg/L. This beach is very popular for recreational activities and many anthropogenic activities were carried out here. There are high possibilities for waste products from these activities to be discarded into the waters.

In addition, phosphate concentration in the seawater samples at Penarak Beach was 0.47 ± 0.02 μg/L. This beach is famous for fishing activities which are more likely to contribute to high phosphate levels in the seawater. The main sources for this were the discharges from the fisherman village situated next to the beach where improperly treated sewage serves as the source of phosphate in this coastal environment. Besides that, many restaurants are in operation along this beach tends to have a high potential to release their wastewaters into the sea.

4.6.12 Biochemical Oxygen Demand (BOD)

BOD of the seawater at all sampling sites in this study are represented in Figure 4.41. The BOD values ranged between 1.79 ± 0.75 mg/L and 5.62 ± 0.74 mg/L.

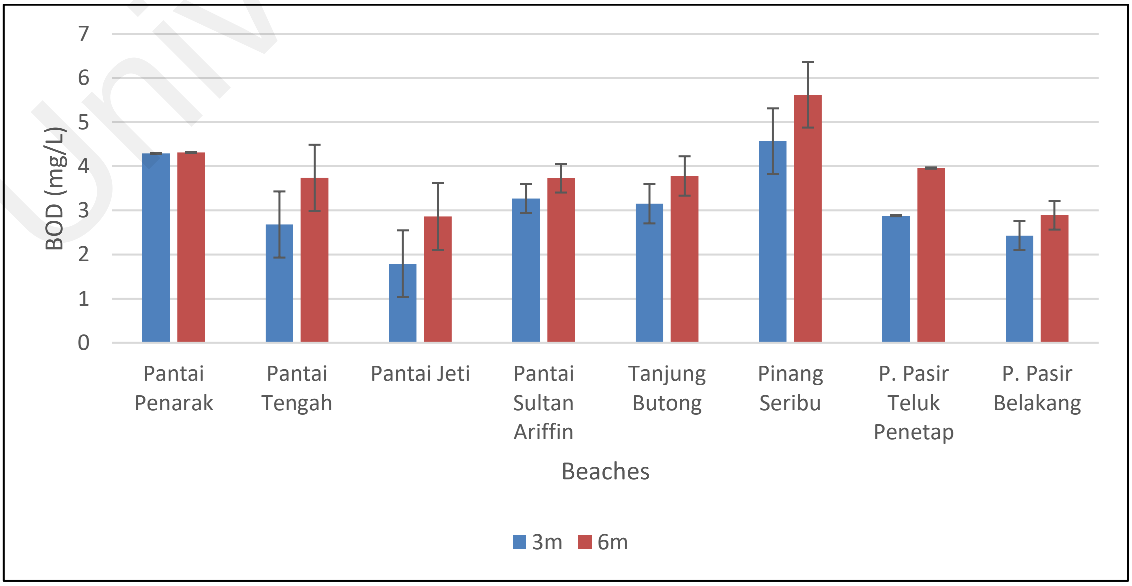

Figure 4.41: BOD level of seawater al all the sampling sites

The highest BOD was recorded at Pinang Seribu Beach for both samples collected from points 3 m and 6 m away from the coastline with 4.57 ± 0.46 mg/L and 5.62 ± 0.24 mg/L, respectively. High BOD values were recorded at this beach due to the high tendency of oxygen demanding substances disposed and accumulated here by the action of the wave. The location of this beach is on the northern corner of Pulau Perhentian which is facing towards the open sea, highly exposed to debris deposition by heavy transit of logistic ships.

Penarak beach also recorded a high value of BOD with 4.29 ± 0.01 mg/L and 4.31 ± 0.04 mg/L at both sampling points, 3 m and 6 m from the shoreline respectively. The high BOD in the seawater at this beach is mainly due to active fishing activities conducted here. A high BOD indicates that the seawater is polluted. The organic matter accumulated at this beach contributes to the high BOD of the coastal water.

Sultan Arifin and Tanjung Butong beaches recorded BOD values between 3.15 ± 0.45 mg/L and 3.78 ± 0.77 mg/L. The moderate level of BOD at these beaches indicates good seawater quality. This shows that recreational activity at Sultan Ariffin beach does not drastically affect the seawater quality. Furthermore, the seawater BOD level at Tanjung Butong beach is suitable for the coral reefs and other aquatic organisms to grow. The lowest BOD was recorded at Jeti Beach. Both 3 m and 6 m sampling points recorded BOD reading of 1.79 ± 0.75 mg/L and 2.86 ± 0.66 mg/L, respectively. The value of BOD will depend on the amount and nature of organic matter and the activity of bacteria species present in the seawater. Less amount of organic matter and bacterial activity observed at this beach compared to other sampling sites in this study shows that this beach is well preserved and less polluted.

In addition, the BOD concentration is directly associated with DO concentration. Individual values of BOD for each sampling location were plotted against values of DO and there was a significant correlation (R = 0.8688), indicating that the variation on BOD can be influenced by the variation of DO. The correlations are shown in Figure 4.42.

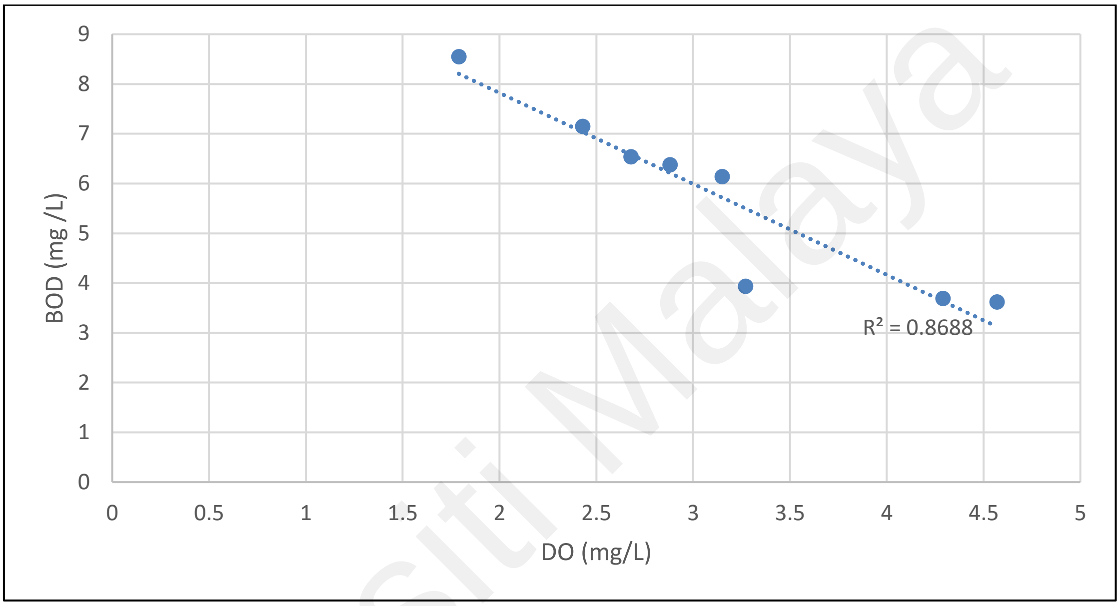

Figure 4.42: Correlation between the BOD and DO in the seawater

In general, there is a decrease in DO levels when BOD levels are high. This is because the demand for oxygen by the bacteria is high and they are consuming oxygen from the dissolved oxygen in the water. If there are no organic wastes in the water, there will be fewer bacteria to decompose them, so the BOD will appear to be lower and the DO will tend to be higher.

4.6.13 Silicate

Silicate is dissolved silicon that is present in the seawater. The value of silicate at all sampling sites are between 8.02 ± 0.12 µg/L to 14.62 ± 1.98 µg/L. For the sampling point 3 m away from the shoreline, the highest silicate is observed at Penarak Beach (12.35 ± 0.49 µg/L) and the lowest at Jeti Beach (8.02 ± 0.20 µg/L). The highest and lowest value of phosphate for the sampling point 6m away from the beach were observed at Pinang Seribu Beach and Pasir Belakang Beach with 14.62 ± 1.69 µg/L and 8.08 ± 1.13 µg/L, respectively. Figure 4.43 shows the amount of silicate for all samples studied in this research.

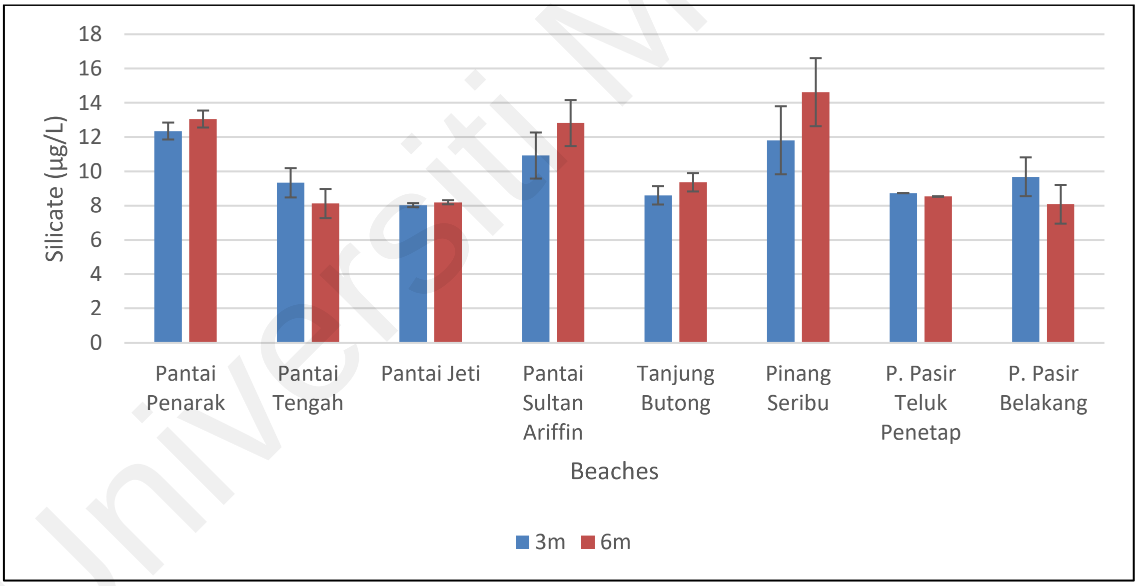

Figure 4.43: Silicate level of seawater at all the sampling sites

4.7 Mesoplastics and Seawater Quality

The presence of mesoplastics in the coastal area will have effects on its water quality. Thus, the correlation between the number of mesoplastics collected at the beach area and the coastal water quality is analyzed in this research, to determine the extent of mesoplastics debris pollution at the study area and its contamination effect on the coastal water. Mesoplastics debris affects the sea environment and has been described as one of the most pervasive pollution problems plaguing the world's oceans and waterways.

The temperature of the coastal waters is compared against the number of mesoplastics recorded at all the sampling sites, as shown in Figure 4.44. As compared to the amount of mesoplastics collected at these beaches, Pinang Seribu, Penarak, and Tanjung Butong beaches show that high number of mesoplastics at these coastal lines influences the high temperature recorded.

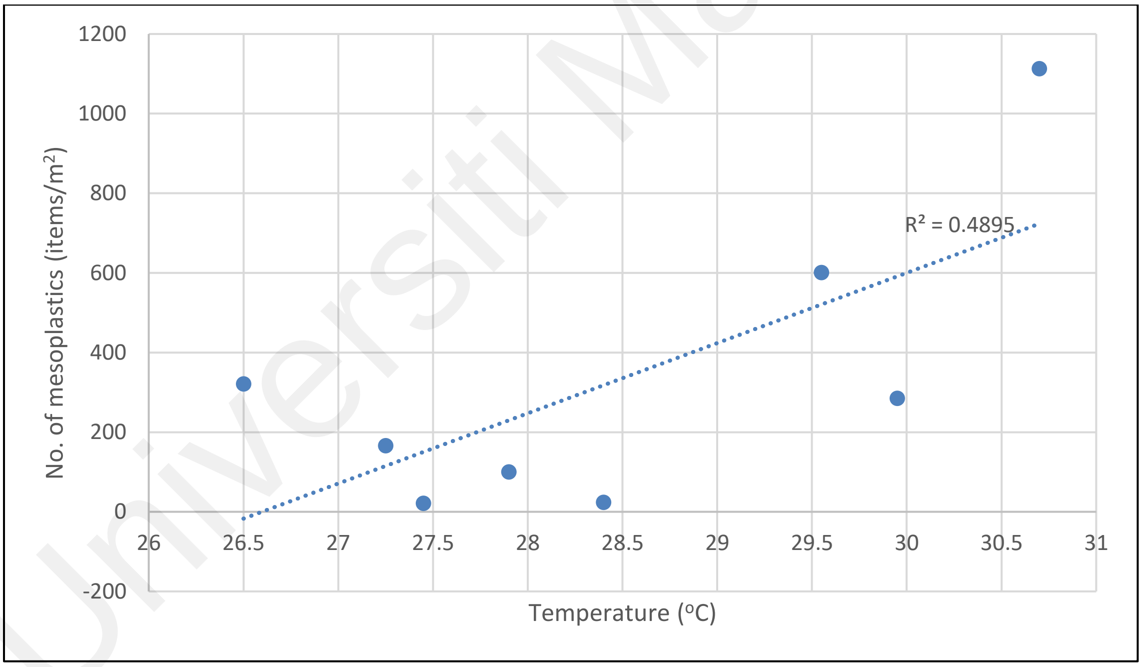

Figure 4.44: Average temperature of coastal water against number of mesoplastics

However, at Pasir Belakang beach the mesoplastics collected are the lowest but high temperature recorded. In addition, other beaches that recorded low mesoplastics debris still obtained a high temperature. Overall, the temperature at all the study sites does not show much difference. This is mainly due to the effects of weather conditions during the sampling period that influences the variation in the coastal water temperature. Thus, no clear relationship could be found between abundance of mesoplastics and seawater.

Figure 4.45 shows the correlation between the abundance of mesoplastics with the DO value recorded at all the sampling sites. From the finding, beaches with a high abundance of mesoplastics recorded a low level of DO. Pinang Seribu Beach recorded high amount of mesoplastics with low level of DO value, whereas Jeti Beach with the lowest number of mesoplastics has the highest level of DO.

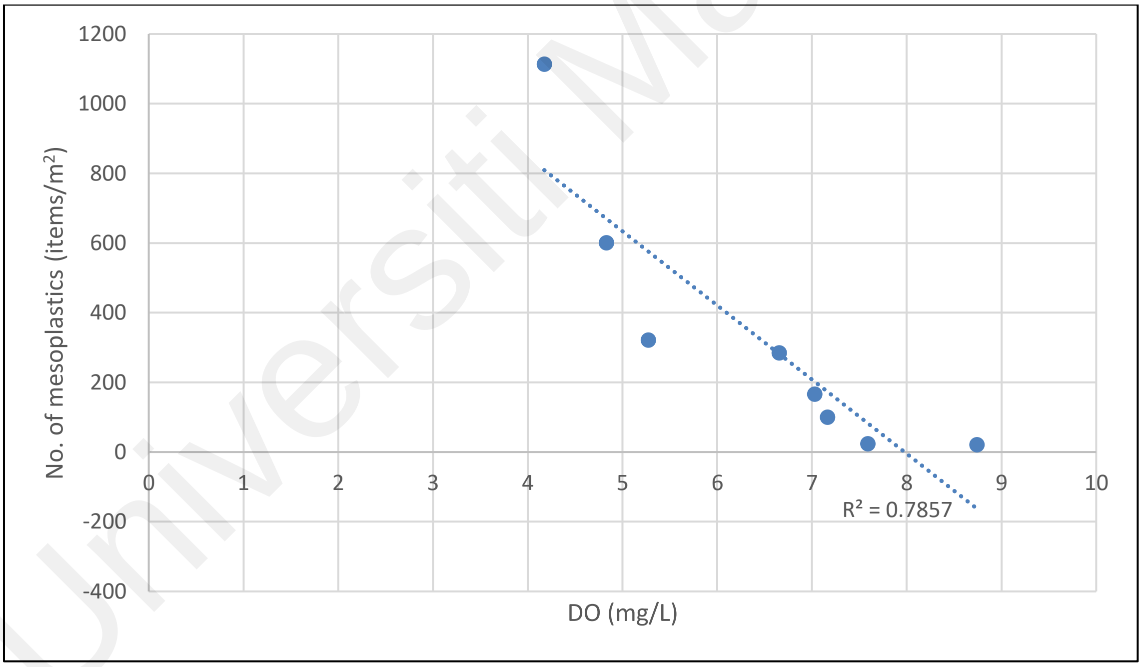

Figure 4.45: Average DO value of coastal water and the number of mesoplastics

Furthermore, the total dissolved solids (TDS) value of the coastal water was compared with the abundance of mesoplastics collected at the beaches. Figure 4.46 illustrates the findings of this research on the TDS and mesoplastics abundance. Pinang Seribu Beach obtained the highest TDS values as compared to other beaches. This beach also recorded the highest mesoplastics abundance. Thus, there are high possibilities for the mesoplastics presence in the water to affect the TDS of the coastal water. The lowest TDS value was recorded at Tanjung Butong beach, and the number of mesoplastics collected at this beach is also relatively low.

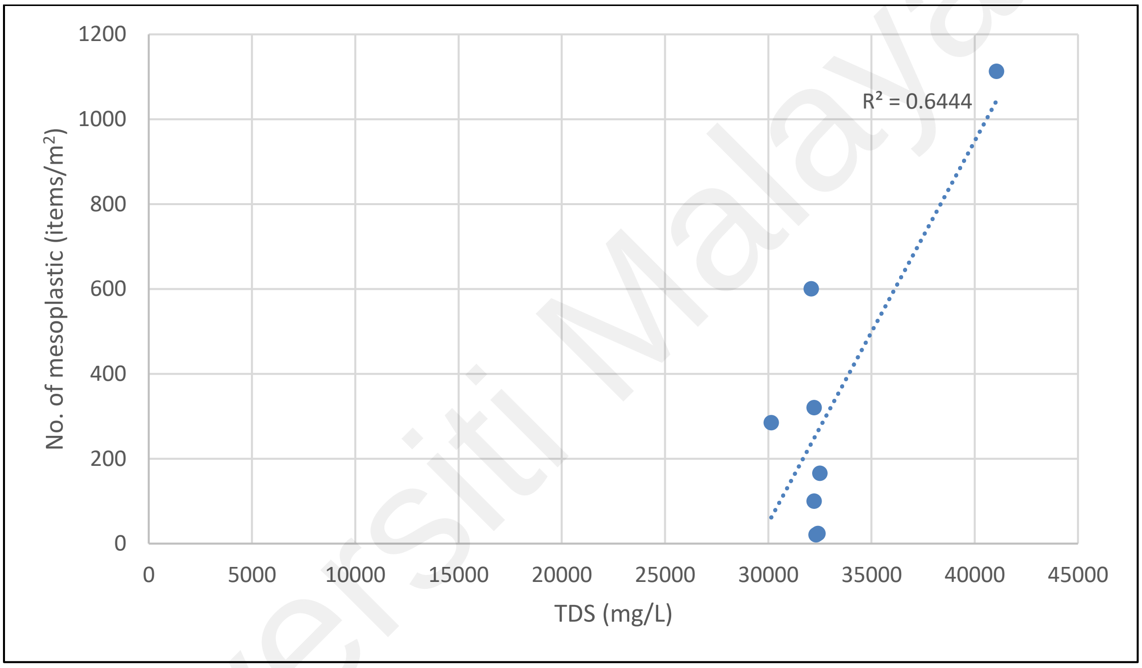

Figure 4.46: Average TDS of coastal water and the number of mesoplastics

In addition, the turbidity of coastal waters is compared with the number of mesoplastics at the beaches (Figure 4.47). The highest turbidity is at Tengah Beach while the lowest is at Tanjung Butong beach. However, these findings do not correlate with the abundance of mesoplastics, which are the highest at Pinang Seribu Beach and the lowest at Jeti Beach. This shows that the presence of mesoplastics at beaches does not remarkably influence the turbidity of the coastal water.

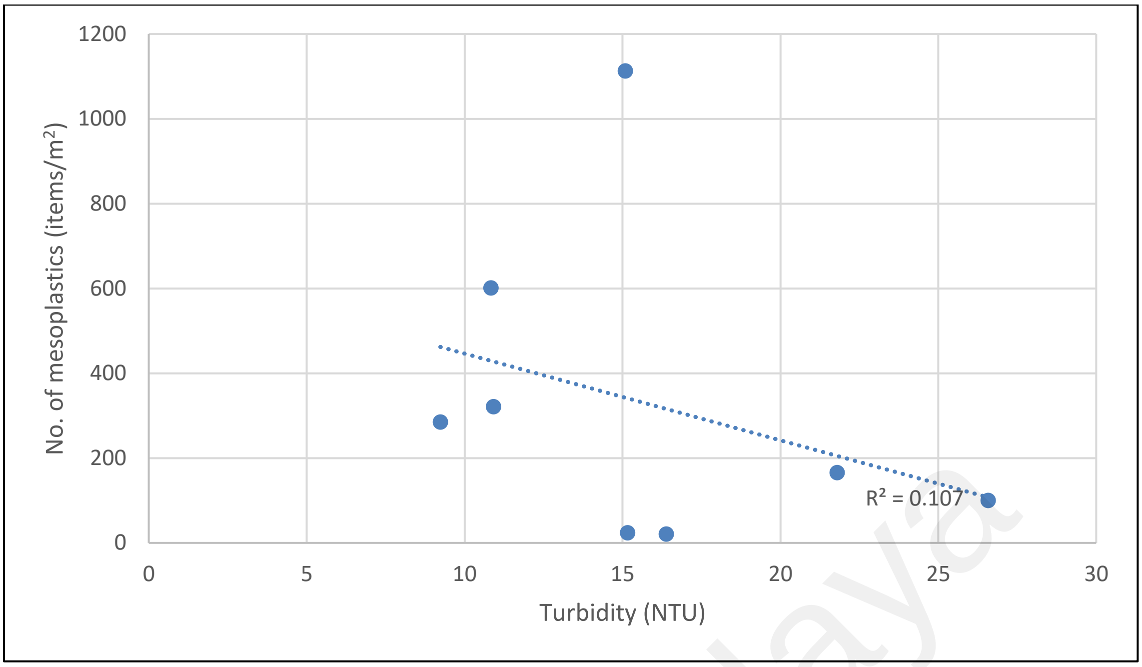

Figure 4.47: Average turbidity of coastal water and the number of mesoplastics

Other than that, salinity of the coastal water was also studied against the abundance of mesoplastics. The correlation between the salinity of the seawater with the mesoplastics found on the beach in this study were demonstrated in Figure 4.48. From the trend, the lowest number of mesoplastics were collected at Jeti Beach and the lowest salinity value was also observed at this beach. The highest salinity value was recorded at Penarak Beach which obtained second highest number of mesoplastics at the beach area. From this, the level of salinity might be affected by the presence of mesoplastics in the coastal water due to the fact that mesoplastics may have ended up here by washing off from the shoreline areas.

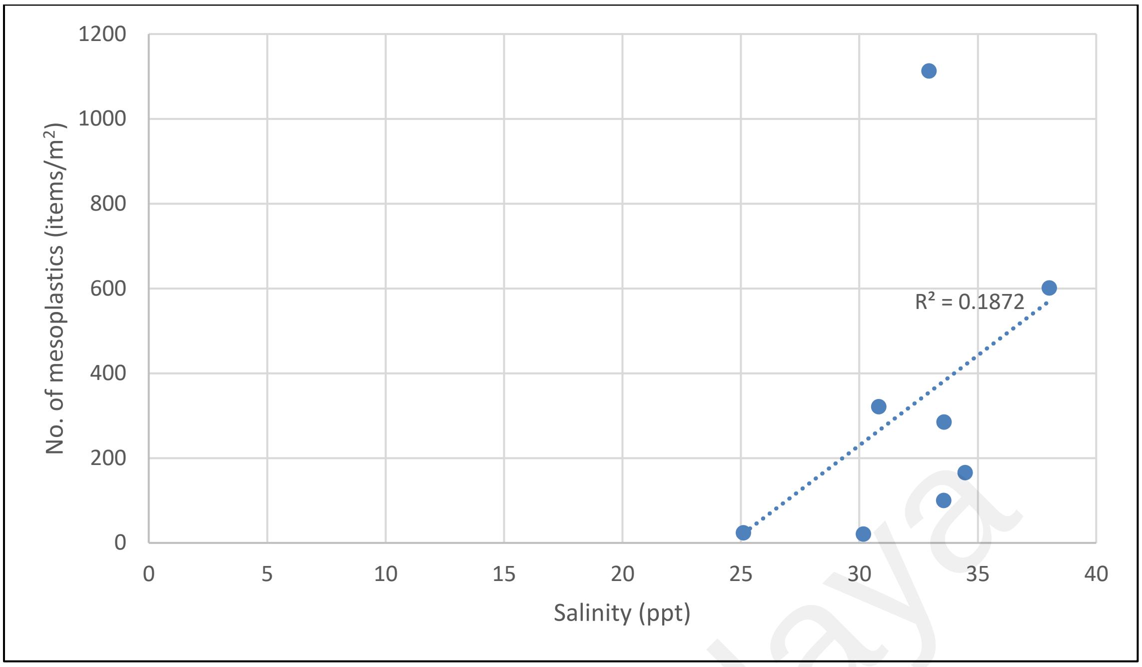

Figure 4.48: Average salinity of coastal water and the number of mesoplastics

Next, the nutrient content in the coastal water, especially phosphate, ammonium, and nitrates were compared with the abundance of mesoplastics at the beaches (Figure 4.49). A high phosphate concentration was recorded at Tengah Beach, but this beach does not contain a high number of mesoplastics. The lowest phosphate value was observed at Jeti Beach and the mesoplastics abundance was also at the lowest here. In conclusion, the trend of phosphate value at all the coastal waters studied shows that it does not depend on the number of mesoplastics present at the shoreline.

On the other hand, the nitrate concentration at the coastal water shows some relation with the abundance of mesoplastics. This can be observed at Jeti Beach where the lowest nitrate was obtained along with a low number of mesoplastics at the beach. Furthermore, Penarak beach with the second highest mesoplastics also recorded highest concentration of nitrate. Nitrates are essential plant nutrients, but excessive amounts can have serious consequences for water quality. In addition to phosphorus, excess nitrates can speed up eutrophication, causing dramatic increases in aquatic plant growth and changes in marine life.

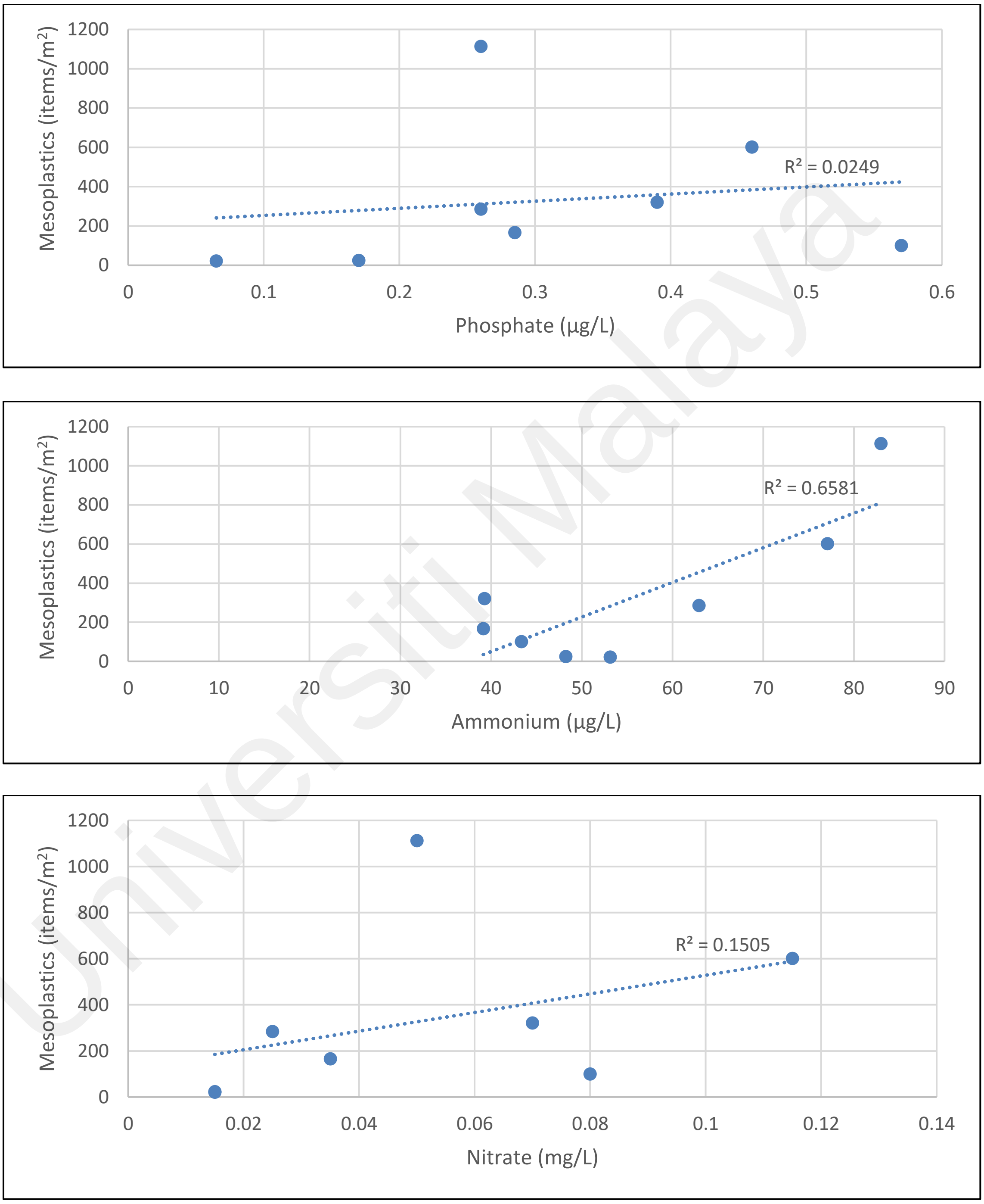

Figure 4.49: Average nutrients (A) phosphate (B) ammonium (C) nitrate of coastal water against number of mesoplastics

Furthermore, the ammonium concentration shows the highest at the beach with high number of mesoplastics. The lowest ammonium level in the coastal water was observed at Sultan Ariffin and Pasir Teluk Penetap beaches which have a moderate number of mesoplastics found in the coastal area. Comparatively, the occurrence of high level of phosphate, nitrate, and ammonium in the coastal water were noted where occurrence of mesoplastics are predominant.

4.8 Microbial Analysis

The numbers of total heterotrophic bacterial count at all sampling sites were in the range of 0.75×10^8 to 3.08×10^8 CFU/ml as shown in Figure 4.50. From bacterial count, it was found that all beaches show significant differences in bacterial abundance ($p < 0.05$). Tengah Beach (0.75×10^8 CFU/ml) recorded a lower bacterial count as compared to other seven beaches. The highest number of bacterial counts was obtained at Pasir Belakang Beach (3.08×10^8 CFU/ml).

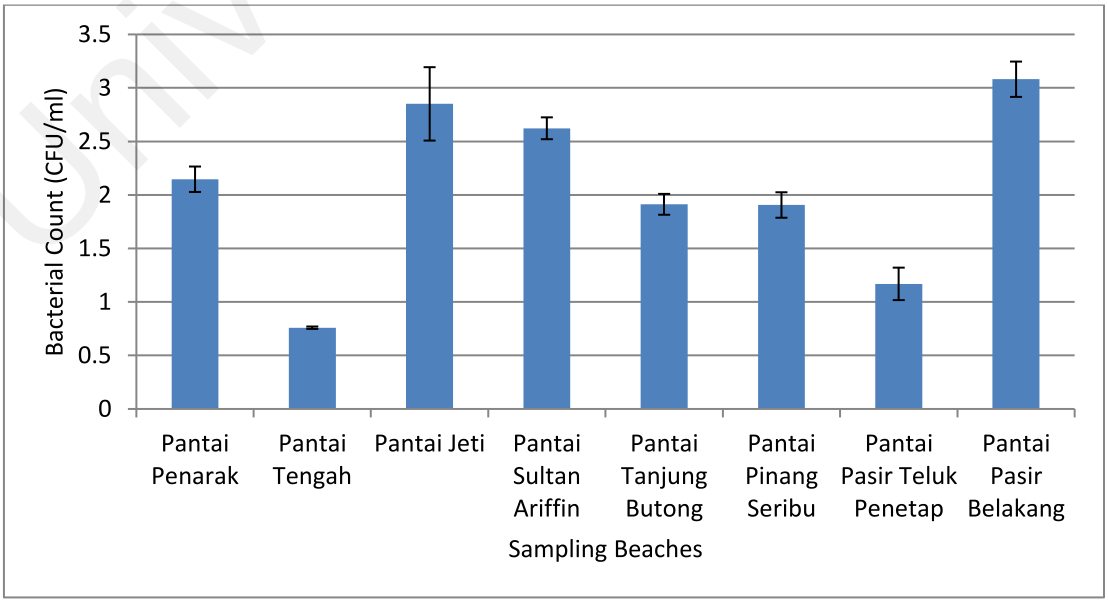

Figure 4.50: Total heterotrophic bacterial count (CFU/ml)

Results of microbiological analysis showed the presence of heterotrophic bacteria in all seawater samples. Besides that, by comparing these beaches water analysis result, it was found that beach development and commercialization has created disturbance towards seawater quality (Sultan Ariffin Beach, Pinang Seribu Beach, and Pasir Belakang Beach). The development of beaches attracts more tourists which in turn affects the water quality. Poor water quality provides an unfavorable condition for bacteria to increase its number. Thus, the low bacterial count was observed at beaches with a high number of mesoplastics such as at Tengah Beach and Pasir Teluk Penetap Beach. The relationship between mesoplastics and the coastal water quality will be further analyzed to determine their correlations in the next section.

The total coliform concentrations were ranging between a minimum of 22.64 MPN/100 mL at Sultan Ariffin Beach and a maximum of 50.84 MPN/100 mL at Tengah Beach as shown in Figure 4.51. However, the total coliform at all beaches does not exceed the 100 MPN/100 mL limit for recreational use with body contact set by the Department of Environmental Malaysia (DOE, 2006). Thus, all beaches in this study are safe for recreational use.

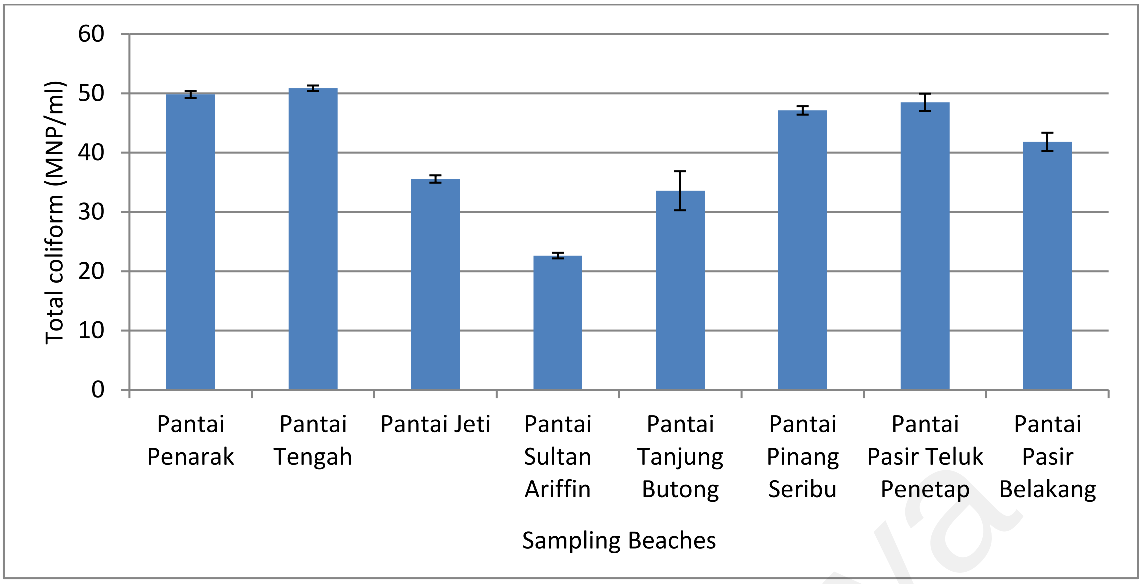

Figure 4.51: Total coliform count MNP/100 ml

The effect of distance from shoreline towards the quality of coastal water also has been investigated in this study. However, there are no significant differences in coastal water quality at 3m and 6m distance from the shoreline at all study areas. In this study, further statistical analysis will be carried out to determine the effect of mesoplastics abundance on marine bacteria by comparing bacterial counts between selected beaches. Besides that, an analysis on how marine microbes and coastal water quality are affected by the presence of mesoplastics also will be investigated in the next section.

4.9 Mesoplastics and Microbial Abundance

The correlation between the abundance of mesoplastics and the total heterotrophic bacterial counts are shown in Figure 4.52. From the results obtained, the heterotrophic bacterial count at the sampling sites is not influenced by the number of mesoplastics at the beaches. The highest total heterotrophic bacterial count was recorded at Pasir Belakang Beach with low mesoplastics. On the other hand, the lowest heterotrophic bacterial count was found at Tengah Beach which is among the lowest in mesoplastics amount recorded.

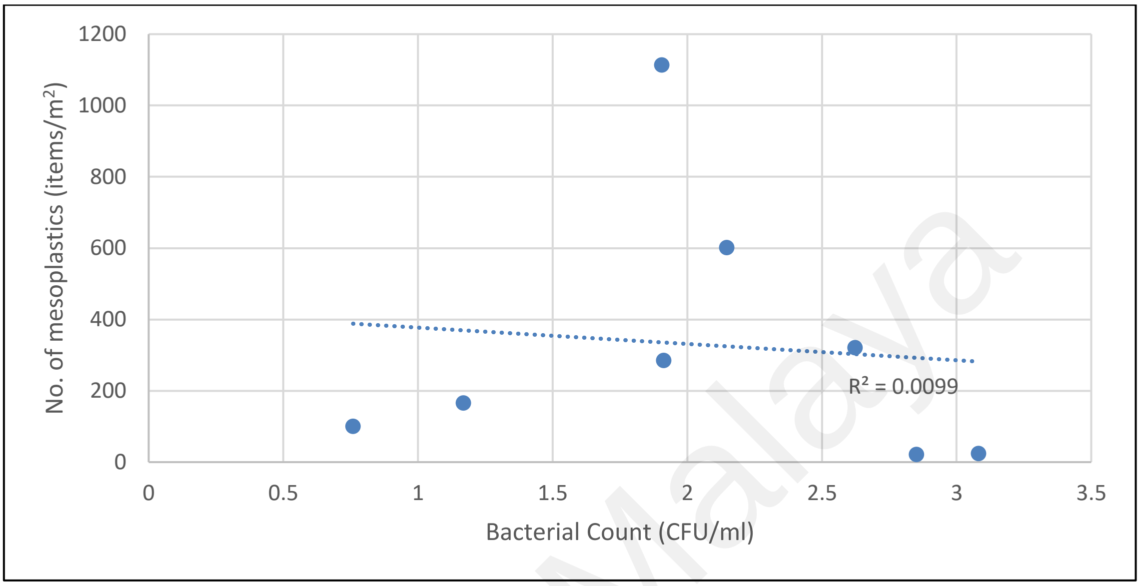

Figure 4.52: Heterotrophic bacterial count and number of mesoplastics

Similar findings were observed for the value of total coliform at all sampling areas (Figure 4.53). The abundance of mesoplastics does not show any significance in influencing the total coliform in the coastal water. However, there are high possibilities for the mesoplastics debris in the beach to stay decomposed and remain in the seawater for years. Mesoplastics use oxygen as it degrades which in turn will bring down the oxygen level in water. When oxygen levels go down, the chances of survival for marine organisms, in the long run will be impacted.

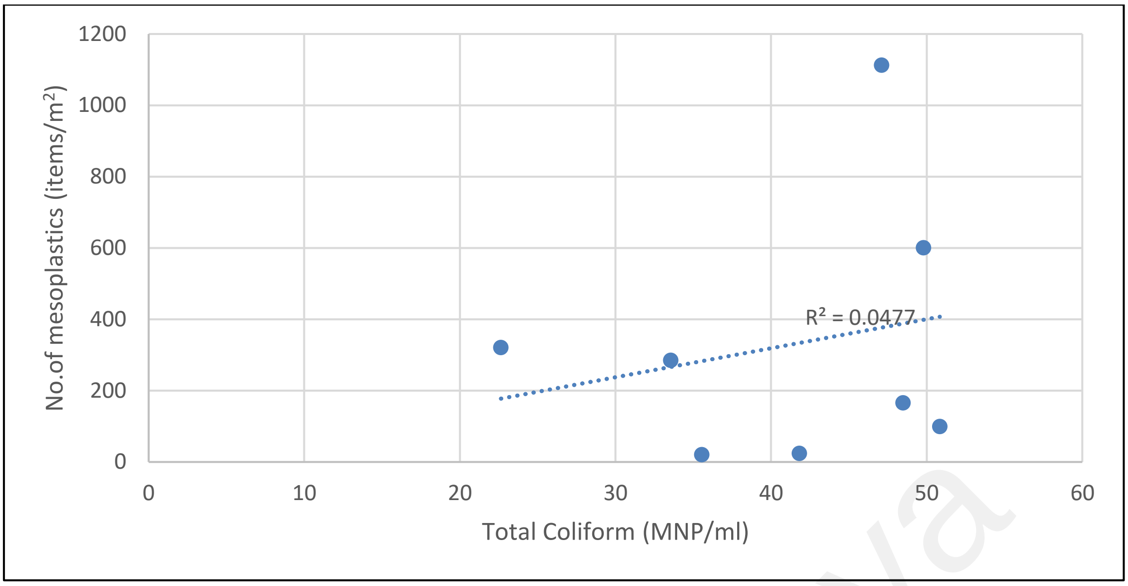

Figure 4.53: Total coliform and number of mesoplastics

Mesoplastics debris is a rapidly emerging pollutant in the marine ecosystems that may transport potential toxic chemicals into the microbial food webs. This commentary assesses our understanding of the interactions between marine organisms and mesoplastics, identifying a significant knowledge gap as a lack of microbial research into mesoplastic contamination. Microorganisms (bacteria, archaea, and picoeukaryotes) in coastal sediments represent a key category of life with reference to understanding and mitigating the potential adverse effects of mesoplastics due to their role as drivers of the global functioning of the marine biosphere and as putative mediators of the biodegradation of plastic-associated additives, contaminants, or even the plastics themselves.

CHAPTER 5: CONCLUSION

Of all the sampling sites, the quantity of mesoplastics was highest at Pinang Seribu, 1113 ± 30 items/m^2 followed by Penarak Beach, 601 ± 19 items/m^2. The lowest number of mesoplastics was recorded at Pasir Belakang and Jeti beaches with 24 ± 12 items/m^2 and 21 ± 5 items/m^2, respectively. The abundance of mesoplastics at the other four beaches ranged from 321 to 100 items/m^2.

The mesoplastics collected at all the study areas are from film, line, fragment, pellet, and foam types. The most predominant type was foam with 281 ± 53 items/m^2, followed by fragment with 194 ± 22 items/m^2. Line and film type mesoplastics were found 129 ± 15 items/m^2 and 60 ± 7 items/m^2, respectively. The least amount of pellet types was found, 9 ± 3 items/m^2. The main sources of mesoplastics found in this study are both from land- and sea-based anthropogenic activities such as recreational, picnicking, fishing, and discharges from manufacturing and ships.

The seawater quality at all the studied beaches is within the MMWQS and suitable for recreational use. The analysis shows that the most polluted seawater was recorded at Pinang Seribu Beach with low DO levels and high COD, BOD, and TDS levels. The pollution at this beach is mainly caused by the offshore plastic debris that accumulated in the sediments and coastal water. Jeti beach is the least polluted site among the other beaches, with high DO and low levels of COD, BOD, phosphate, and silicates. The presence of mesoplastics in the beach sediment affects the coastal water quality.

The highest total heterotrophic bacterial count was recorded at Pasir Belakang Beach (3.08 x 10^8 CFU/ml) with low mesoplastics while the lowest heterotrophic bacterial count was found at Tengah Beach (0.75 x 10^8 CFU/ml) which is among the beach with lowest mesoplastics recorded. Highest total coliform was recorded at Tengah Beach (50.84

MPN/100 ml) while the lowest at Sultan Ariffin Beach, 22.64 MPN/100 ml. There are high possibilities for the mesoplastic debris in the beach to stay decomposed and remain in the seawater which in turn becomes a major hazard to the aquatic ecosystem. The presence of mesoplastics in sediments on the selected beaches does not influence microorganisms in the seawater at coastal line.

This study demonstrates the level of mesoplastic pollution at beaches on Malaysian islands, which shows moderate contamination as compared with other nationwide and worldwide data, that deserves attention from the regulatory authorities such as the Department of Environment and Marine Department Malaysia. A measurable amount of mesoplastic debris (1 - 30 mm in size) was found on all the beaches. The results reflect that mesoplastic abundance and distribution vary considerably. Each beach had different sand types, beach dynamics, weather condition, wave action, and wind direction that affects the abundances of mesoplastic presence at each shoreline regardless of the functions and location of the beach.

In addition, the results of this study show that there is no correlation between mesoplastics, coastal water quality, and the abundance of microbes at the selected sites. This is the first report on mesoplastic quantification of beach sediment relating to seawater quality and microbial abundance. Thus it is necessary to establish a large scale and long-term monitoring process across the country and different marine environment, such as coastal water and sea floor.

On the other hand, to reduce or prevent plastic debris pollution, commitments and efforts such as improving solid waste management practices through the ‘reduce, reuse, recycle' (3Rs) approach, as well as supporting public awareness programmes and beach clean-up activities, are required.

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