CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 BEACH PROFILE

The typical beach profile of the sampling site is shown in Figure 4.1. Samples were collected from three belts transects, extended from the low tide (X) to the berm area (Z). Delineating the low tide line can be a problem and for standardization, the low tide mark was defined as the point where the sand was permanently wet or where sinking sands began (Velander and Mocogni, 1999).

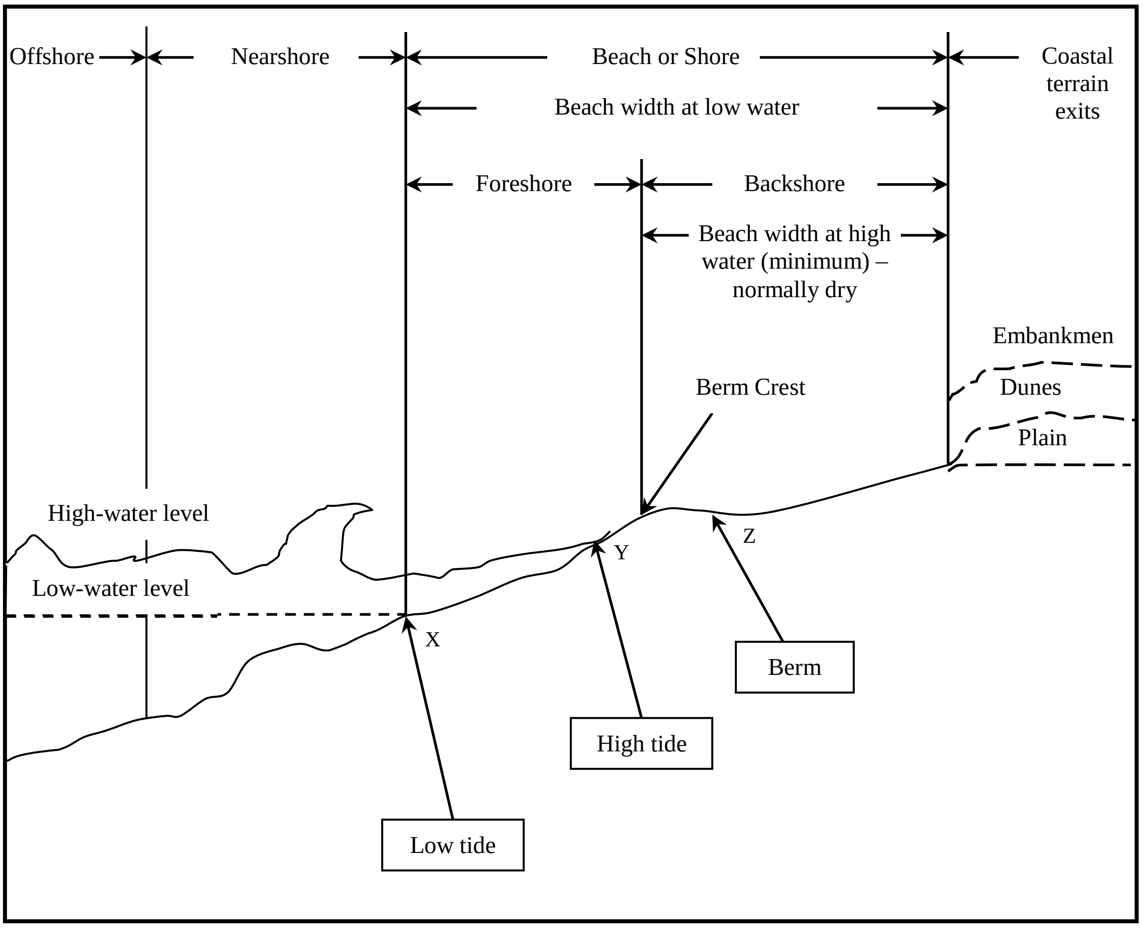

Figure 4.1: Beach profile at the sampling site.

4.2 BEACHES ALONG THE WEST COAST OF PENINSULAR MALAYSIA

West Coast of Peninsular Malaysia stretches from Perlis, followed down by Kedah, Penang, Perak, Selangor, Negeri Sembilan, Malacca and Johor. These states are fronting the narrow Straits of Malacca which is one of the busiest shipping lanes in the world and across the strait is Sumatera Island (Indonesia).

Port Dickson (PD) which is situated in the state of Negeri Sembilan in Peninsular Malaysia comprises of 57,341.21 ha^2 with 8.6% of the total state area. PD territorial division is the district administration centre. The town of PD is the main area or location for business, fishery and hotel industries. PD consists of 57.5 km of natural beach-line, which is famous as a holiday resort among both domestic and foreign tourists. Therefore, it is important that the cleanliness of the beach is well taken care. Port Dickson Municipal Council (MPPD) is the responsible authority in managing the municipal solid waste around PD including organizing beach clean-ups.

In this study, Teluk Kemang Beach and Pasir Panjang Beach in PD were selected to represent recreational and fishing beaches, respectively.

4.2.1 Teluk Kemang Beach, Port Dickson

Teluk Kemang Beach (Plate 4.1) is a well-known beach for locals and foreigners as it is located 90 km from Kuala Lumpur and 30 km from the capital city of Negeri Sembilan, Seremban. It is a 1.6 km long beach and is visited by 20,000 to 30,000 tourists every week or 50,000 to 80,000 throughout long holidays (www.portdickson.net, 2010).

Plate 4.1: Popular beach and holiday destination in Teluk Kemang.

Teluk Kemang Beach became the strategic port for various recreation activities; swimming, kayaking, waterskiing, water scooter and yachting due to its attracting sea-side view. There are also numerous seaside resorts and budget hotels along the beach, thus attracting more visitors to come to the beach. Therefore, the great number of people coming to the Teluk Kemang Beach resulted into the presence of discarded waste on the beach especially plastic debris that are found buried in the sand.

4.2.1(a) Abundance of Small Plastic Debris and Other Debris

Figure 4.2 shows the quantity of small plastic debris and other debris (plant and shell) that were buried in the Teluk Kemang Beach (items/m^2), while Figure 4.3 shows the corresponding density of these debris in the study area (g/m^2).

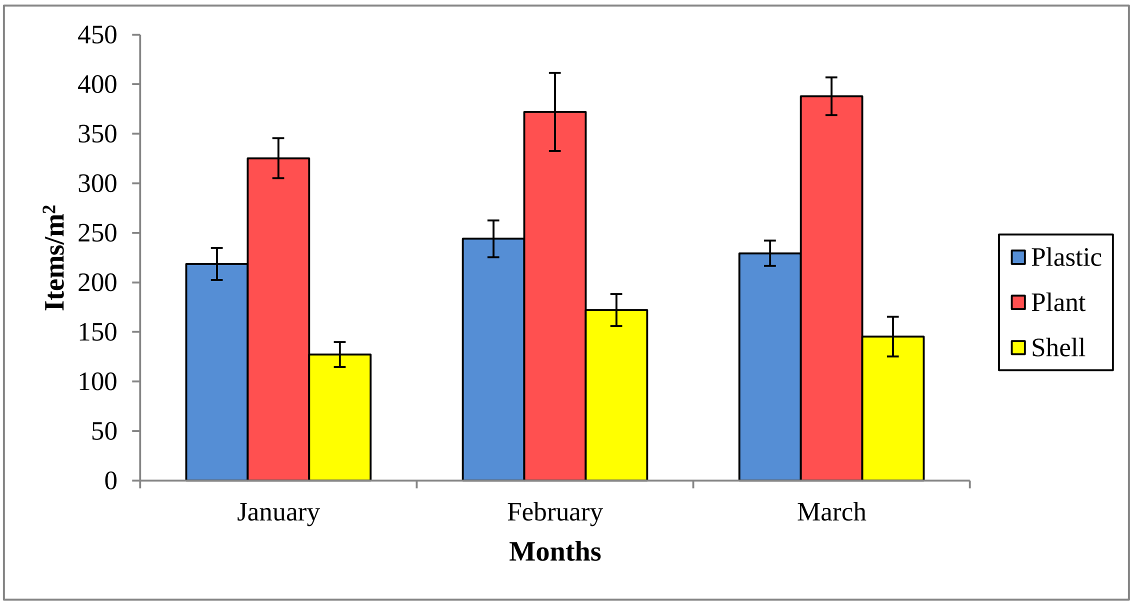

Figure 4.2: Quantity of small plastic debris and other debris at the Teluk Kemang Beach.

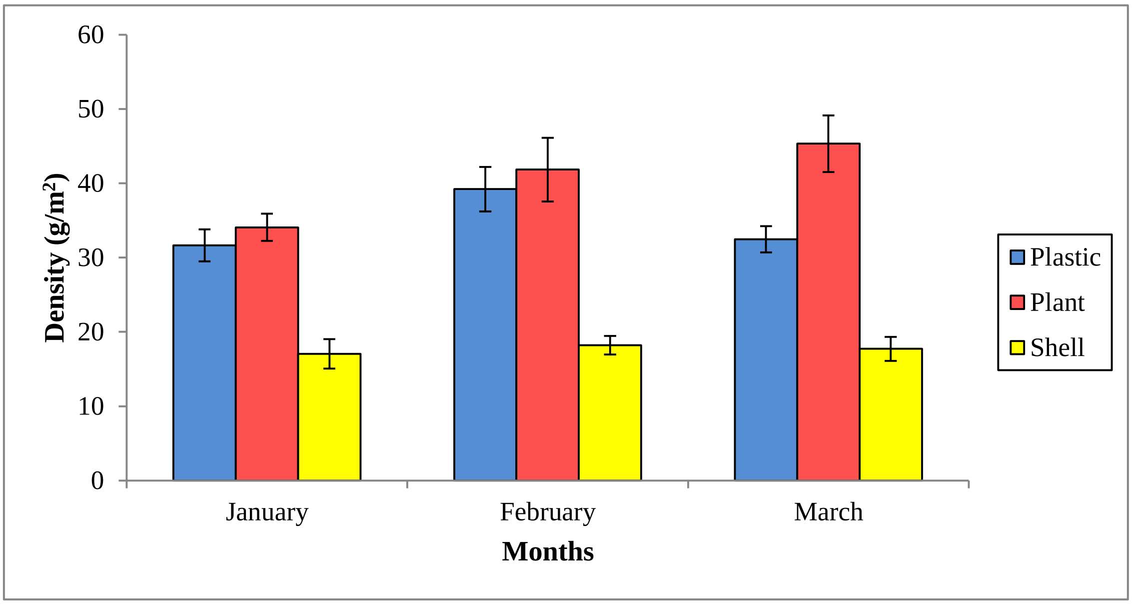

Figure 4.3: Density of small plastic debris and other debris at the Teluk Kemang Beach.

Based on the results of all sampling events, plant residues were the most abundant compared to plastic particles and shell. The quantity of plant residues ranged between 325 items/m^2 to 388 items/m^2, with corresponding density of 34.07 g/m^2 to 45.33 g/m^2. Meanwhile, the quantity of shell was between 127 items/m^2 and 172 items/m^2 at 17.06 g/m^2 – 18.22 g/m^2 density range. Abundance of plant matter was the highest in sand and may be attribute the presence of herbaceous plants and casuarina trees that are abundant along the Teluk Kemang Beach (TKB). A One-Way ANOVA statistical analysis indicated that there was no significant different ($P>0.05$) relationship between these debris and months.

The abundance of plastic was similar in all sampling events. Quantity of plastic ranged between 219 items/m^2 and 244 items/m^2 with corresponding density range of 31.65 g/m^2 to 39.21 g/m^2. The highest percentage of plastic distribution was obtained in February (35% and 38% for quantity and density, respectively) whereas the least was recorded in January [32% and 31% by quantity and density, respectively (Appendix 2)]. Recreational activities may be the reason for the accumulation of plastic in the sand. TKB is a spotlight area for beachgoers to perform recreational activities; hence dumping of plastic waste must have occurred intentionally or unintentionally. Moore (2008) and UNEP (2006) had concluded that greater amount of plastic debris was contributed by beachgoers at recreation areas.

Plastic wastes may had been transported into the sea through the drainage systems from urban development in TKB while the other plastics were disposed directly on beach. These plastics often get degraded into small pieces after certain period of time and eventually get buried within the sand itself. A similar scenario has been reported in other beaches where plastic got buried within the sand through beach – sand runoff during strong wind or rainfall (Gregory and Andrady, 2003).

4.2.1(b) Classification of Small Plastic Debris

Figure 4.4 shows the classification of small plastic debris which had been categorized into film, foam, fragment, line and pellet (items/m^2), while Figure 4.5 shows the corresponding density (g/m^2) of the debris in the study area.

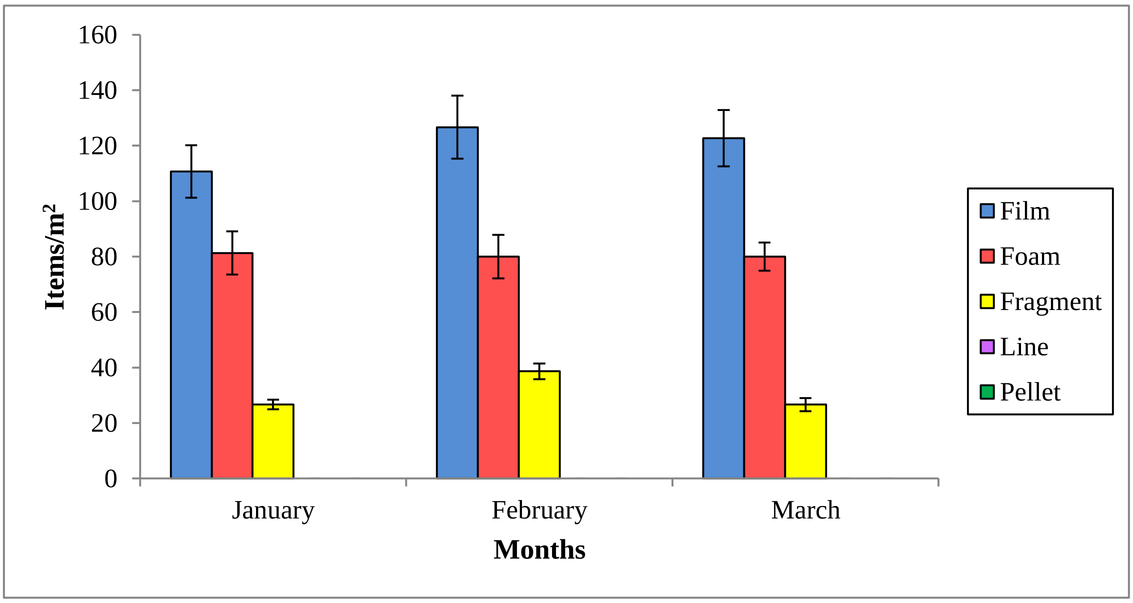

Figure 4.4: Quantity of small plastic debris according to classification at the Teluk Kemang Beach.

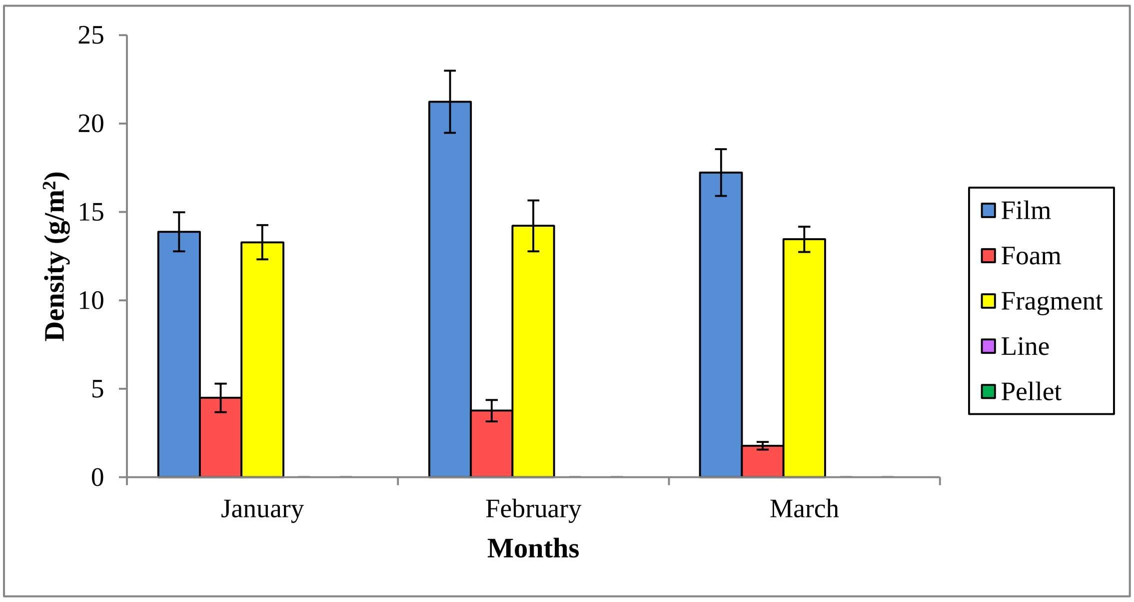

Figure 4.5: Density of small plastic debris according to classification at the Teluk Kemang Beach.

The most common types of plastics found during the sampling events were film, foam and fragment. No line and pellet were found. However, there are differences in the abundance of these three types of found plastics. In terms of quantity, the film was dominant (111 – 127 items/m^2) before foam (80 – 81 items/m^2) and fragment (27 – 39 items/m^2). As for the density, film recorded the highest (13.88 – 21.22 g/m^2) followed by fragment (13.28 – 14.21 g/m^2) and foam (1.78 – 4.49 g/m^2). This is in accordance to the lower density of foam when compared to film and fragment. Foams especially polystyrene generally are low-density packaging materials and its density is the lowest among other types of plastics (Andrady, 2003a). For both quantity and density, a One-Way ANOVA statistical analysis indicated that there was no significant different ($P>0.05$) relationship between the types of small plastics debris and months.

Recreational activity at TKB can be the major contributing factor to the trends of plastic classification on the beach surface and also in the sand. Plastic film may have originated from the confectionary and convenience plastic foods wrapping that were normally discarded casually by people at beach. These types of plastics can be disintegrated due to the degradation process whereby reduction in the mass or molecular weight of the plastic material can take place and eventually become smaller in size (Gregory and Andrady, 2003). Recreation littering is a prevalent problem where plastic fragments following degradation may persist in the sand (Ng and Obbard, 2006). Besides, foam that originated from foam packaging materials and food containers (e.g. polystyrene) that were disposed by beachgoers after picnic can also be broken into smaller pieces of foam. These processes undergone by both plastic fragments and foam were due to the fragmentation caused by weathering in the environment (Kusui and Noda, 2003). Therefore, foam plastics are also abundant in the TKB area.

4.2.1(c) Abundance of Small Plastic Debris according to Tidal Zone

Figure 4.6 shows the quantity of small plastic debris (items/m^2) according to beach tidal zone namely; low tide, high tide and berm, while Figure 4.7 shows the corresponding density (g/m^2) of the debris in the study area.

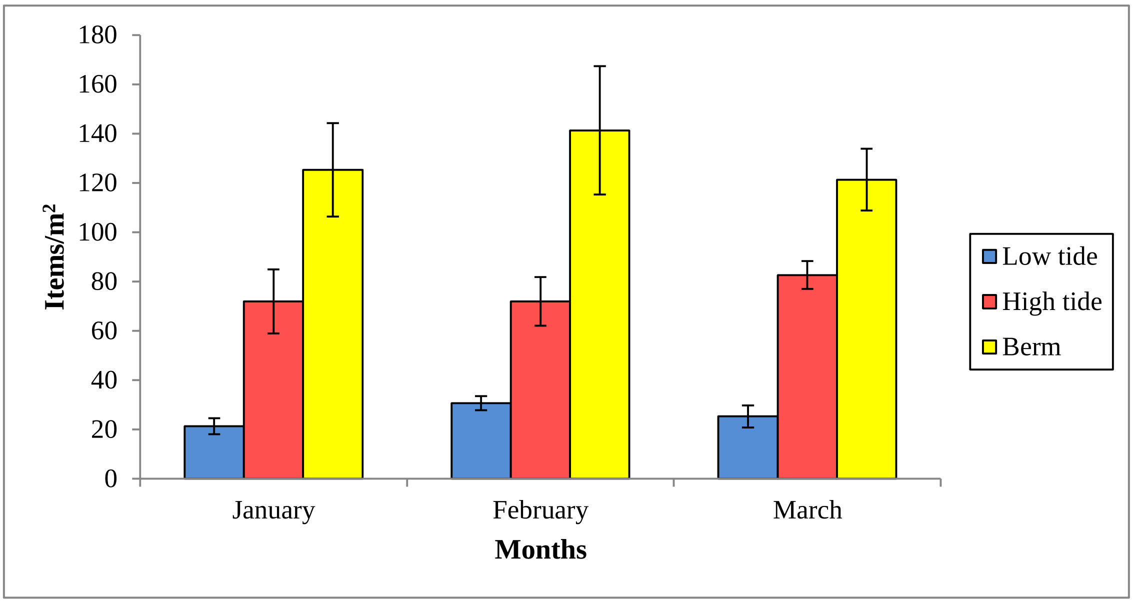

Figure 4.6: Quantity of small plastic debris according to tidal zone at the Teluk Kemang Beach.

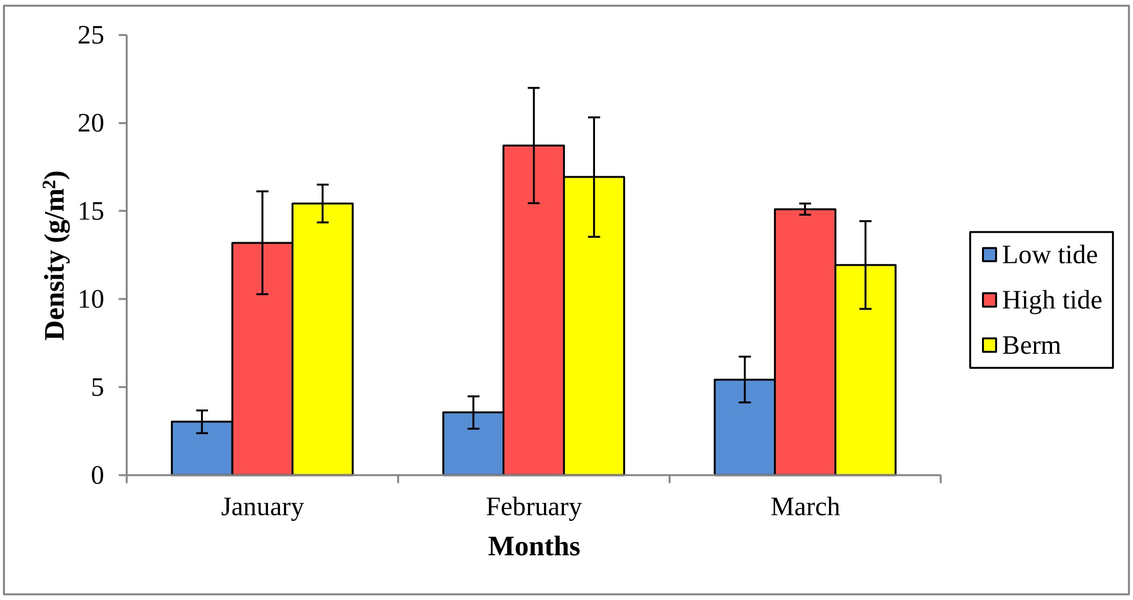

Figure 4.7: Density of small plastic debris according to tidal zone at the Teluk Kemang Beach.

The results indicate that the buried small plastic debris in TKB is the highest along the berm area (121 – 141 items/m^2), followed by the high tide area and the low tide area with 72 – 83 items/m^2 and 21 – 31 items/m^2, respectively. However, small plastic debris buried along the high tide area recorded higher density (13.20 – 18.72 g/m^2) compared to that collected from the low tide (3.03 – 3.56 g/m^2) and the berm area (11.93 – 16.93 g/m^2). There was no significant different ($P>0.05$) relationship of a One-Way ANOVA statistical analysis between the abundance of small plastic debris at different tidal zones with months.

Samples collected from the berm area contain more plastic components compared to the foreshore regions (high tide and low tide). This was probably due to the lightweight debris (e.g styrofoam) that can be easily transported landward with the aid of winds before being deposited at the backshore region or the berm. This phenomenon was also reported of the Cliffwood beach located in New Jersey, USA and Cape Town beaches in South Africa (Ryan *et al.*, 2009; Thornton and Jackson, 1998). Berm area has the most abundant foam plastic as it was categorized as the lightweight debris. Frequent visits to the TKB and use of the berm might have also contributed to the distribution of foam in the area.

As for the density, plastics obtained from the high tide area were recorded higher compared to the foreshore regions. This could have resulted from the domination of heavier plastics fragment from bottles, lighters or food containers. It is a common situation where the heavier debris are usually deposited at the strong wave area (Thornton and Jackson, 1998).

4.2.1(d) Abundance of Small Plastic Debris according to size

Figure 4.8 shows the quantity of small plastic debris (items/m^2) according to size at different tidal zones, while Figure 4.9 shows the corresponding density (g/m^2) of the debris in the study area.

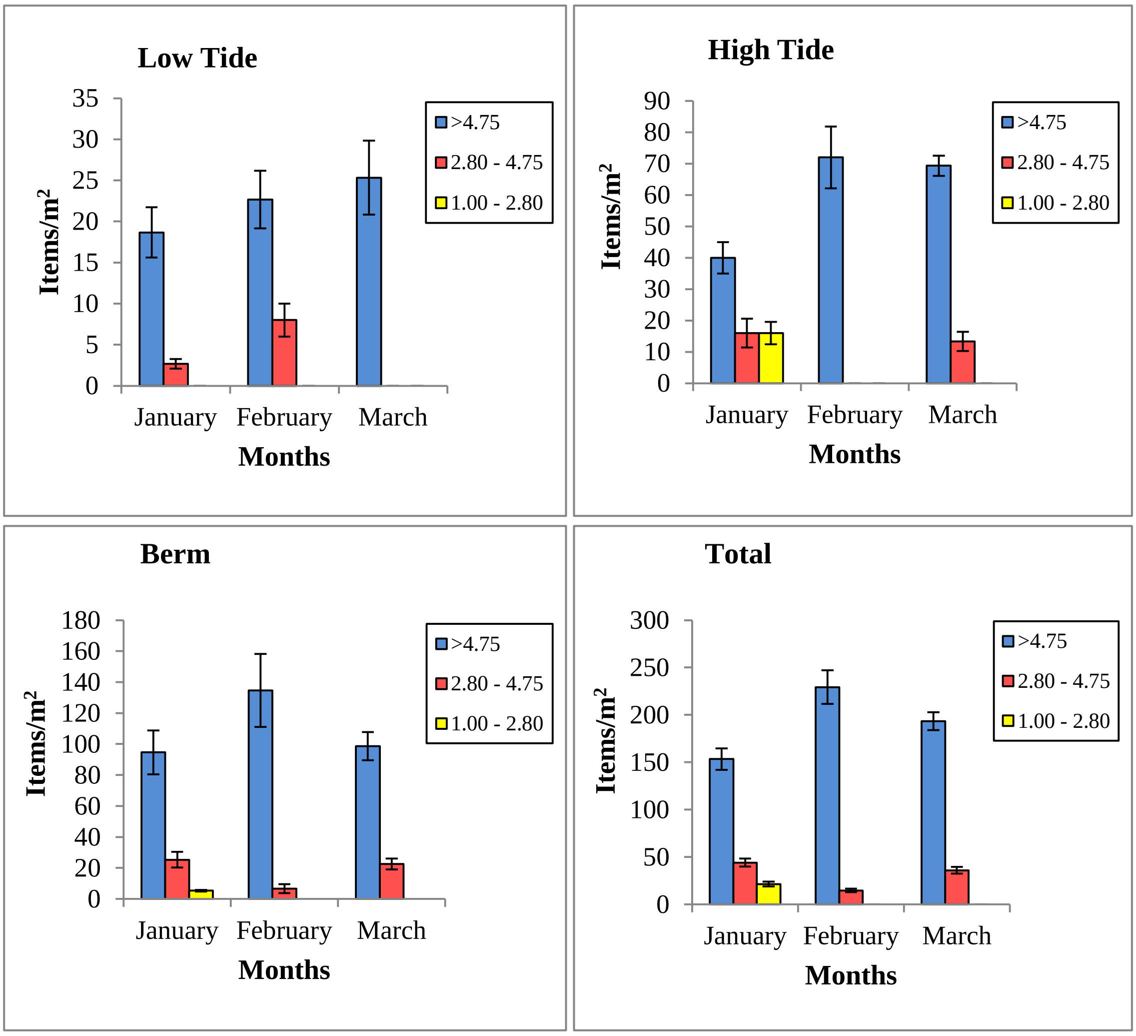

Figure 4.8: Total quantity of small plastic debris according to size range and at different tidal zone at the Teluk Kemang Beach.

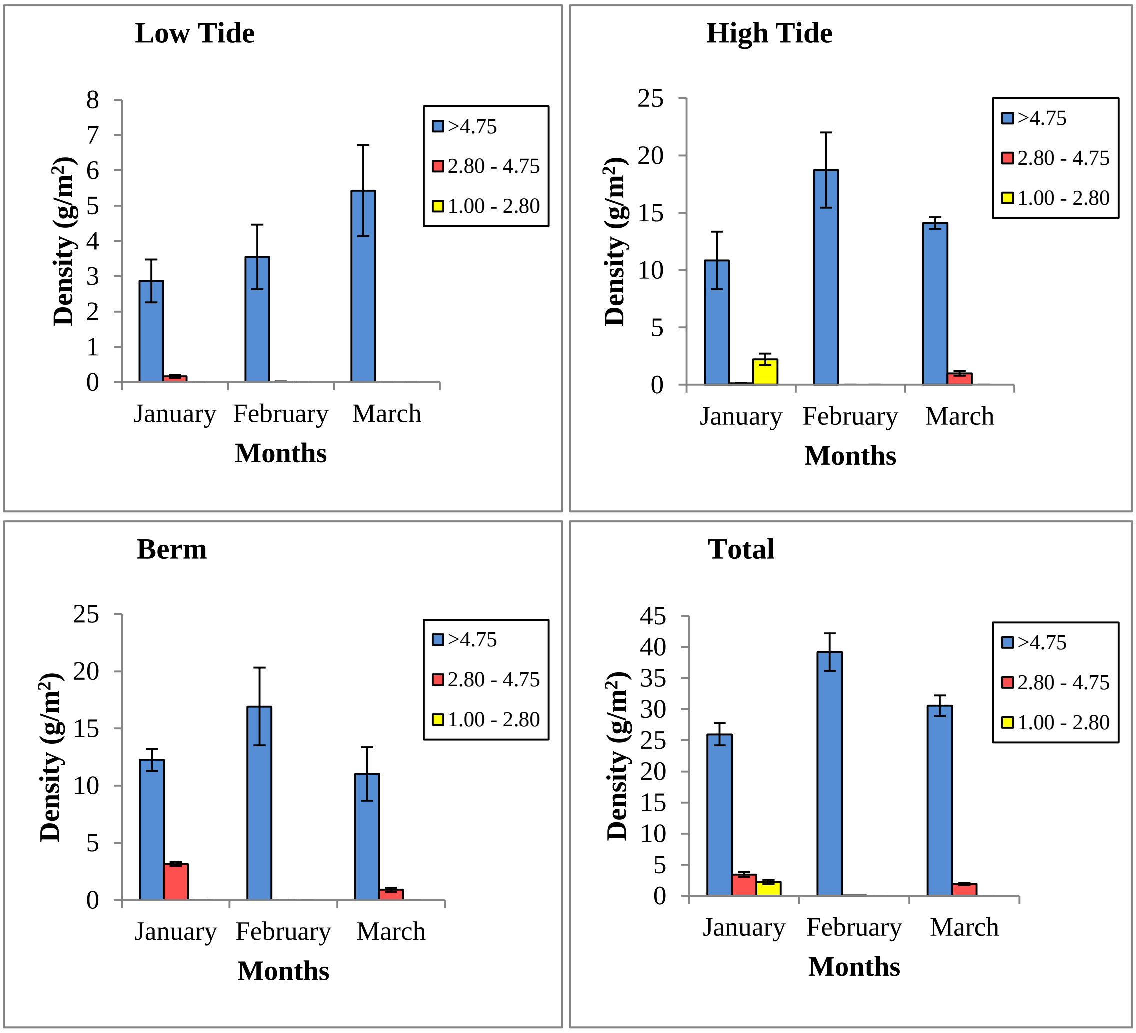

Figure 4.9: Total density of small plastic debris according to size range and at different tidal zone at the Teluk Kemang Beach.

Based on study conducted for three months, the results showed that small plastic debris which exceeded 4.75 mm was the most abundant along the berm, followed by debris which ranged from 2.80 - 4.74 mm and 1.00 - 2.80 mm. Furthermore, similar observation was recorded on the low tide and high tide shorelines.

The number of small plastic debris that exceeded 4.75 mm was the highest (192 items/m^2) with average density at 31.9 g/m^2. Sum total for debris with size range of 2.80 - 4.75 mm is 32 items/m^2 with 1.79 g/m^2 of average density. On the other hand, debris with size range 1.00 - 2.80 mm showed 7 items/m^2 and 0.74 g/m^2 in total quantity and density, respectively. From the results, it can be inferred that the existing plastics in the marine environment were broken up into smaller sizes from larger plastic products within certain duration of time. Plastic debris tends to degrade into smaller particles due to physical processes such as grinding from rocks and sands beach (Eriksson and Burton, 2003). A One-Way ANOVA statistical analysis showed that there was no significant different ($P>0.05$) relationship between the abundance of small plastic debris at different sizes with months.

The abundance of small size of plastics debris in TKB can possibly pose dangerous effect on marine organisms since the plastics in the sands can be exhumed and continuously released into the nearby marine waters by the action of sea waves or tides. Fish, as one of the most diverse group of sea organisms posses higher possibility of being in contact with plastic debris and this might have further consequences (Possatto *et al.*, 2011). For instance, it is revealed that marine fishes that ingested small plastics died and this is because such plastics were mistaken for transparent plankton (Boerger *et al.*, 2010). An experimental study conducted by Browne *et al.* (2010), demonstrated that marine organisms are highly exposed to plastic consumption as the plastics may mix with the food items, especially the plastic of smaller sizes. Thus, marine organisms especially fishes that lived near TKB coastal area are highly prone to ingest these plastic debris which can cause fatal death.

4.2.2 Pasir Panjang Beach, Port Dickson

Pasir Panjang Beach (Plate 4.2) is located about 21 km away from the PD town and it is precisely situated at the southern part of PD district, bordering Malacca. The beach site is less than 1 km long with reddish sand, filled with mangrove swamps and coarse rocky outcrops.

Plate 4.2: Pasir Panjang Beach is a site of fishing activity.

This beach area is adjacent to a predominated small, traditional fishing village. Only a few food stalls can be found near the beach area. Another attraction that can be seen nearby the beach area is the Pasir Panjang Recreational Forest Park or also known as Hutan Lipur which is known as a favourite spot for bird watching. Besides, variety of mangrove trees including the species of *Shorea glauca* and *Shorea curtisii* can be found at this area. Thus, attendances of people at the beach and nearby area might have contributed to the occurrence of plastic debris.

4.2.2(a) Abundance of Small Plastic Debris and Other Debris

Figure 4.10 shows the quantity of small plastic debris and other debris (plant and shell) collected from Pasir Panjang (items/m^2), while Figure 4.11 shows the corresponding density (g/m^2) of these debris in the study area.

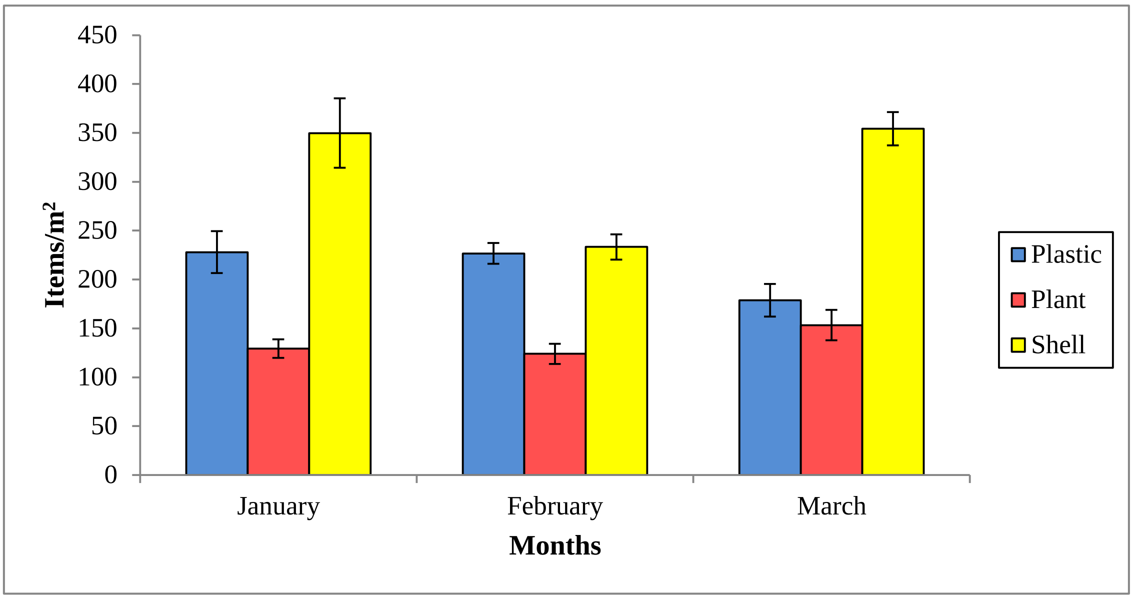

Figure 4.10: Quantity of small plastic debris and other debris at the Pasir Panjang Beach. (ANOVA: P>0.05).

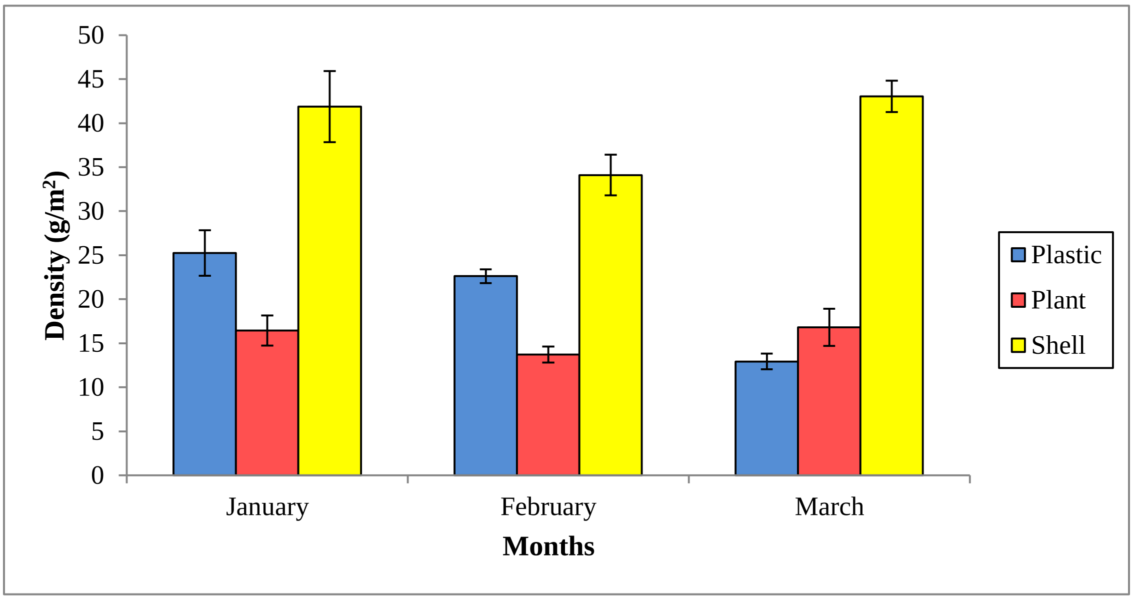

Figure 4.11: Density of small plastic debris and other debris at the Pasir Panjang Beach. (ANOVA: P>0.05).

The results for Pasir Panjang Beach (PPB) showed that shell was the main debris followed by plastic and plant residues. The quantity of buried shell ranged between 233 items/m^2 and 354 items/m^2 with corresponding density range of 34.11 g/m^2 – 43.03 g/m^2. However, the quantity of plant was between 124 items/m^2 and 153 items/m^2 while the density range was 13.72 g/m^2 to 16.81 g/m^2. Shell debris was recorded as the highest among others found in sands which may be due to the actions of sea current and wave that eventually transport the dead shell from the sublittoral zone (subtidal zone) to the surface of the intertidal zone. These actions are known as the natural deposition process that occurs along the shoreline (Garrison, 2005).

When shell was excluded from the debris, the most abundant item was plastic. The quantities of plastics collected in PPB were slightly different in all sampling events (179 items/m^2 – 228 items/m^2 and 12.93 g/m^2 – 25.24 g/m^2 in quantity and density, respectively). It is obvious that larger plastic products used in fishing activities are discarded carelessly along the beach area. The plastic debris might also appear to be remnants of offshore fishing-related activity that were thrown overboard and eventually washed ashore. Fishing activity is the foremost activity in PPB. A survey by Khordagui and Abu-Hilal (1994) along the Arabian Gulf and Gulf of Oman reported that the abundance of plastic present in the areas were related to marine-based sources, mainly fishing activity. The discarded plastic from fishery products were transported and dispersed to long distance by surface waves, winds, tides and then finally washed ashore (Abu-Hilal and Al-Najjar, 2004). These larger plastics debris may be degraded into smaller size and eventually buried in sands as found in PPB.

4.2.2(b) Classification of Small Plastic Debris

Quantity of small plastic debris (items/m^2) has been classified into film, foam, fragment, line and pellet as seen in Figure 4.12, while Figure 4.13 shows the corresponding density (g/m^2) of the debris in the study area.

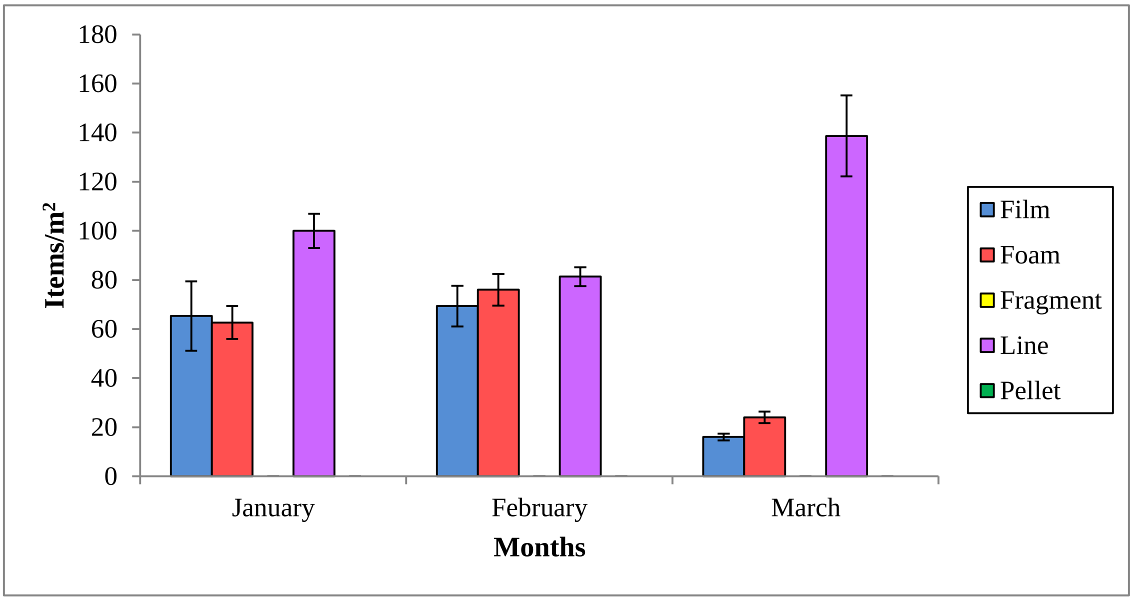

Figure 4.12: Quantity of small plastic debris according to classification at the Pasir Panjang Beach. (ANOVA: P>0.05).

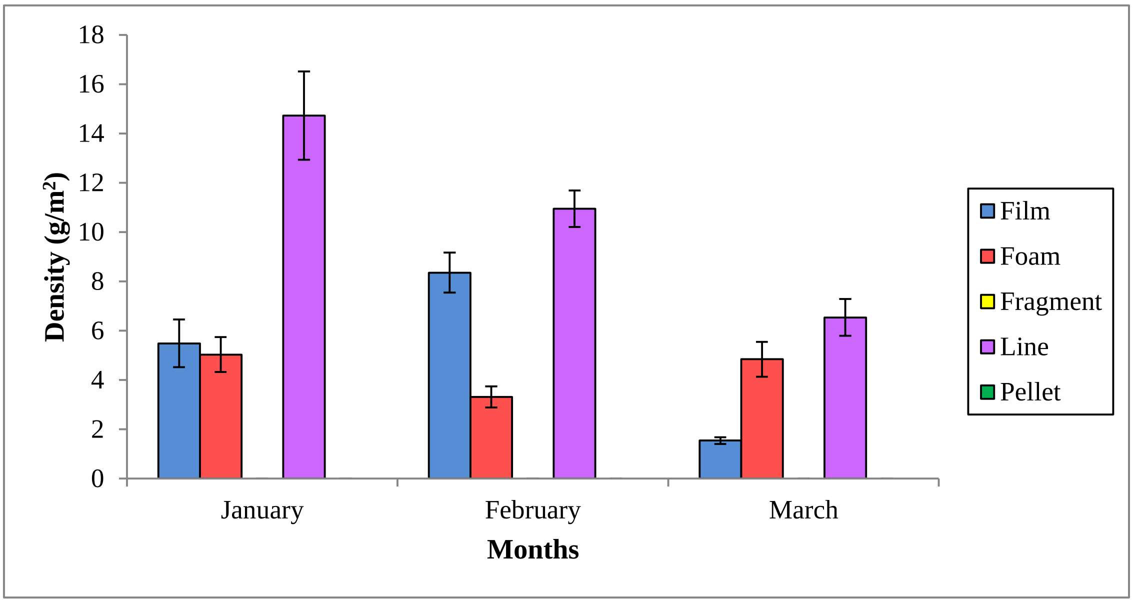

Figure 4.13: Density of small plastic debris according to classification at the Pasir Panjang Beach. (ANOVA: P>0.05).

The most dominant type of plastic found in PPB is the line plastic (81 – 139 items/m^2) with a density of 6.54 – 14.72 g/m^2. Next were the foam (24 – 76 items/m^2) and finally the film (16 – 69 items/m^2). The density recorded for foam and film were 3.31 – 5.03 g/m^2 and 1.55 – 8.35 g/m^2, respectively. No fragment and pellet plastics were found.

The source of generating high quantity of line plastics are assumed to be from the usage of fishing equipment. This includes fishing lines, nets, ropes, polyester and vinyl strapping bands which significantly contributes to the greater number of plastic debris in this study area. Besides, foam is believed to have originated from styrofoam fish crates and styrofoam bait boxes which are discarded once they are damaged. According to Henderson *et al.* (2001), abundance of derelict fishing debris had increased worldwide in seawaters and on beaches as a result of replacement from natural fibres to synthetic plastic fibres over the last three decades. The invention of various synthetic fibres used in fishing industry was because of high wet strength and low water absorption (Gregory and Andrady, 2003). Thus, more plastic lines were found in the study area.

The continuous use of plastics shall result in a negative impact especially to the marine wildlife once plastics entered marine realm. Small debris like synthetic line fibres, styrofoam and pieces of film from plastic bags are frequently mistaken as food/prey by seabirds (Morishige *et al.*, 2007). Therefore, these plastics debris should be prevented from being discarded, as in the case of PPB.

4.2.2(c) Abundance of Small Plastic Debris according to Tidal Zone

Figure 4.14 shows the quantity of small plastic debris (items/m^2) in the beach tidal zones namely; low tide, high tide and berm, while Figure 4.15 shows the corresponding density (g/m^2) of the debris in the study area.

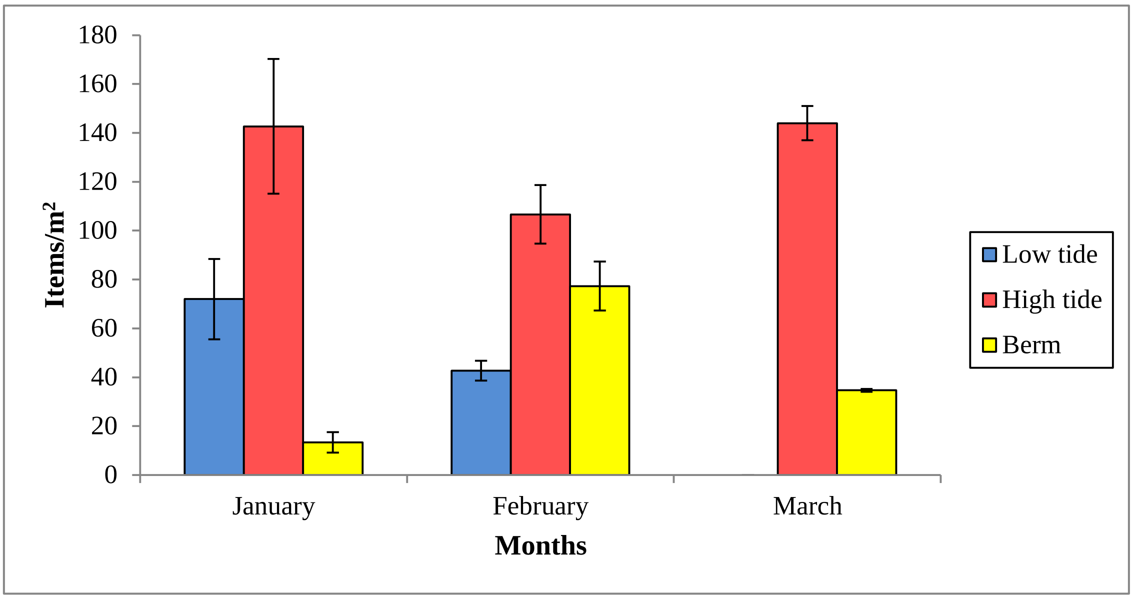

Figure 4.14: Quantity of small plastic debris according to tidal zone at the Pasir Panjang Beach. (ANOVA: P>0.05).

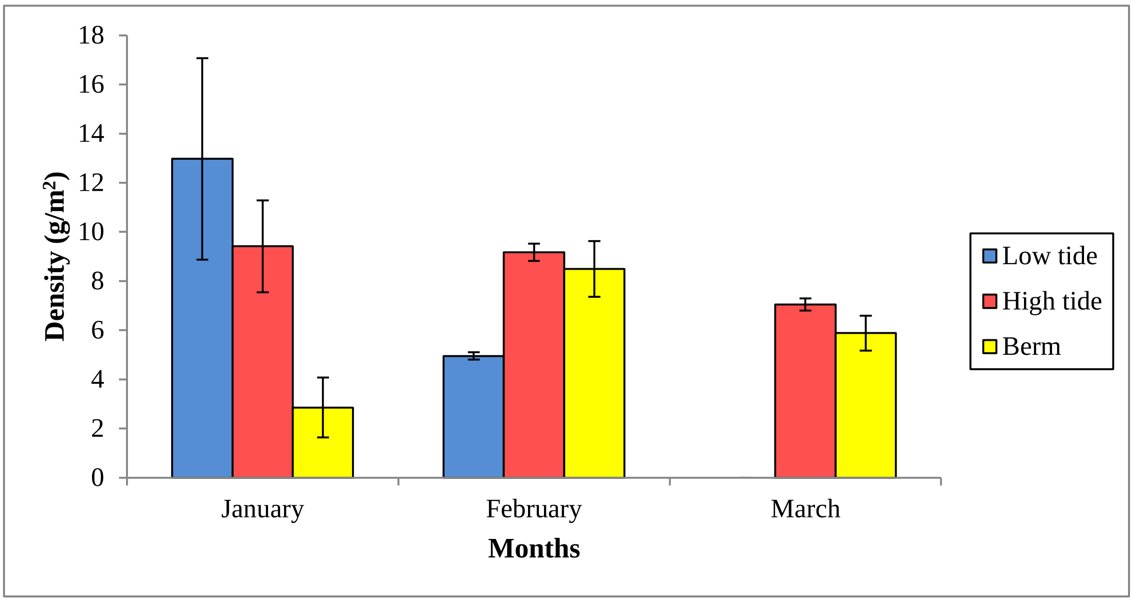

Figure 4.15: Density of small plastic debris according to tidal zone at the Pasir Panjang Beach. (ANOVA: P>0.05).

Small plastic debris buried along the high tide shoreline of PPB is the highest (107 items/m^2 to 144 items/m^2) as the density was 7.05 – 9.42 g/m^2. It was followed by berm area and the low tide area. Plastic debris collected in berm area ranged at 13 – 77 items/m^2 with density of 2.85 – 8.49 g/m^2. Meanwhile, at the low tide, 43 – 72 items/m^2 were found with density of 4.95 – 12.97 g/m^2.

High tide shoreline collections consist of greater accumulation of plastic than berm and low tide samples. Perhaps this might be due to debris that were suspended in the seawater but were left along the shoreline after every receding tide. Line and some of film plastics are the heavier debris found in PPB. Therefore, these types of plastic cannot be transported to the berm by the action of wind but directly deposited in high tide sands. Heavier debris carried by waves are commonly left stranded and trapped in the sands along the high tide shoreline of the particular beach (Thornton and Jackson, 1998).

The density of plastics at the low tide shoreline was the highest in the first sampling event at 12.97 g/m^2. But the quantity of the debris at the low tide (72 items/m^2) was much lower compared to debris at the high tide shoreline (143 item/m^2) in the study area. This result might be due to the presence of the heavy-weight debris (e.g. line) on the beach surface before being deposited in the sands. It is a common situation to find such heavier debris abundantly on the wave-dominated lower beach profile which comprise of low tide and high tide shoreline (Thornton and Jackson, 1998).

4.2.2(d) Abundance of Small Plastic Debris according to size

Figure 4.16 shows the quantity of small plastic debris (items/m^2) according to size at different tidal zones, while Figure 4.17 shows the corresponding density (g/m^2) of the debris in the study area.

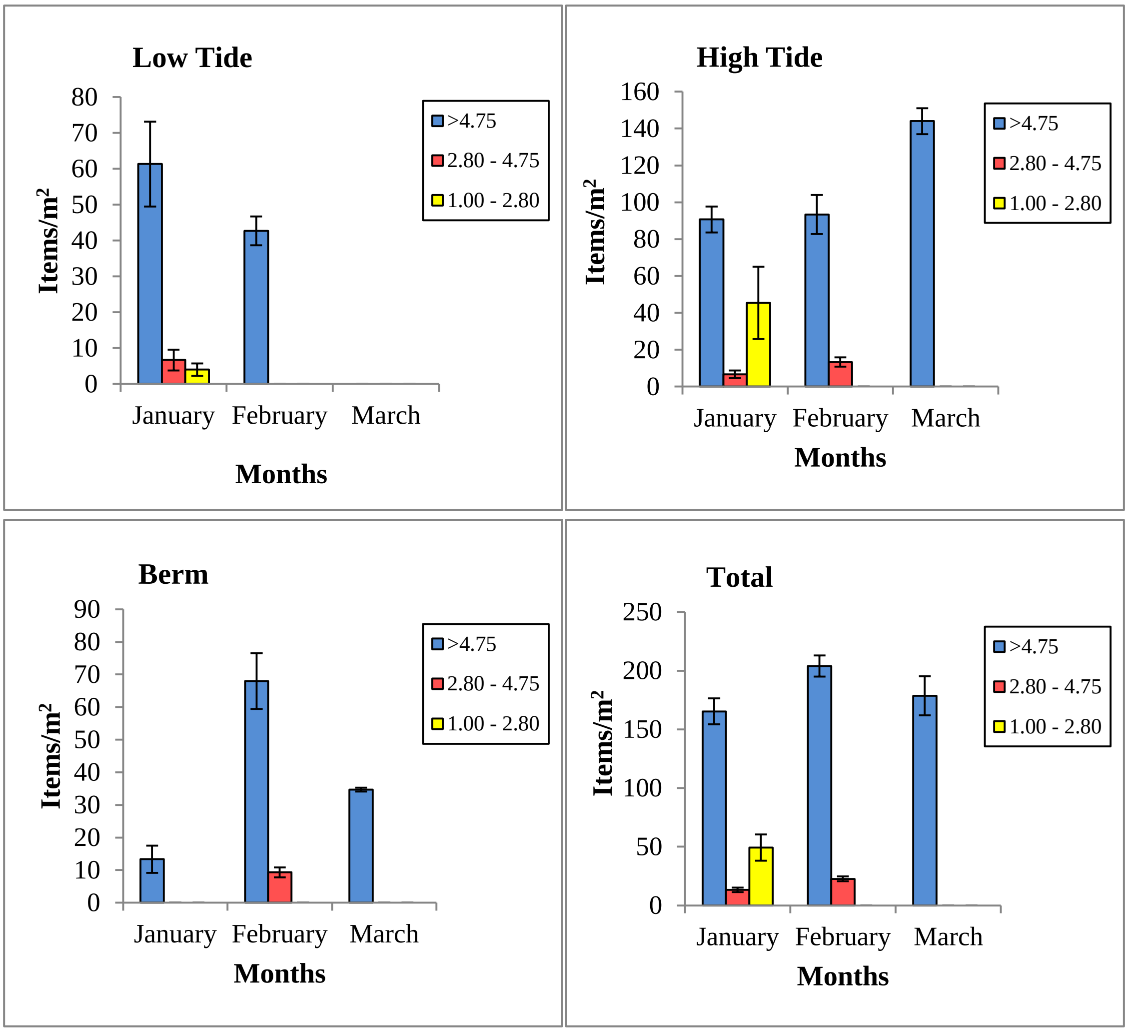

Figure 4.16: Total quantity of small plastic debris according to size range and at different tidal zone at the Pasir Panjang Beach (ANOVA: P>0.05).

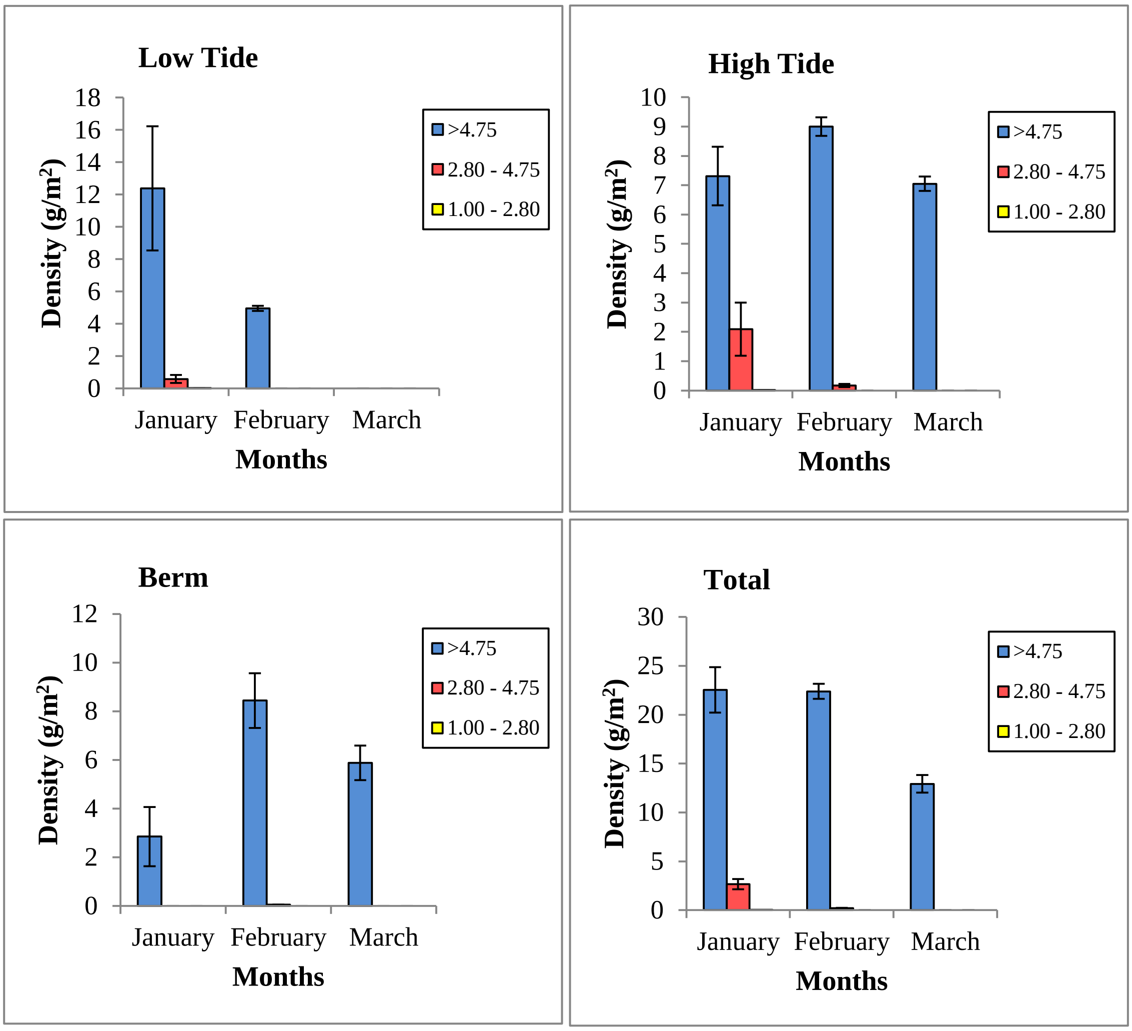

Figure 4.17: Total density of small plastic debris according to size range and at different tidal zone at the Pasir Panjang Beach (ANOVA: $P>0.05$).

In PPB, small plastic debris namely those with more than 4.75 mm was the most abundant, followed by debris which ranged at 2.80 - 4.75 mm while 1.00 - 2.80 mm was the least abundant. In overall, the total number of small plastic debris which exceeded 4.75 mm was the highest recorded (183 items/m^2) with average density of 19.29 g/m^2. Debris at 2.80 - 4.75 mm was only 12 items/m^2 with density of 0.96 g/m^2 while debris with size range 1.00 - 2.80 mm was 16 items/m^2 with density of 0.01 g/m^2.

These small plastics debris might have expected to originate from discarded sea–borne (e.g. fishery activity) plastics that are initiated to experience embrittlement while at sea and further degradation increases once the plastic reach the surface of the land. It is most likely that the smaller plastic particles are derived from the physical and chemical fragmentation of larger plastic debris in the seawater (Ng and Obbard, 2006). Environmental processes such as weathering, sunlight and wave action were reported to contribute to the complete degradation of plastics on beach before deposition (USEPA, 1992).

Unfortunately, the buried small plastic debris in the study area may be easily washed into the sea by tides current, which adds to the accumulation of plastics already present in the sea. It makes the situation worse when living marine organisms indirectly accumulate vast quantities of the chemical materials as they mistakenly ingest toxic plastic pieces that have high affinity for non-water-soluble toxic compounds (PCBs and DDT) in the seawater (Oehlmann *et al.*, 2009; Trujillo and Thurman, 2005). Positive correlation has been estimated between PCBs concentration in the fat tissue of Great Shearwater seabird (*Puffinus gravis*) and the mass of ingested small plastic debris (Ryan *et al.*, 1988). Thus, plastic debris that pollutes the PPB can lead to a serious problem as plastics could be a fatal exposure of toxic chemicals, which then potentially affects the marine organisms. These infected organisms could be the major source of toxic contamination in the marine food chain.

4.2.3 Comparison between Teluk Kemang and Pasir Panjang Beaches

TKB and PPB in Port Dickson which have different main activities were affected at different level in terms of the abundance of small plastic debris. Also, classification of plastic and their abundance according to the tidal zones were different. Beach usage is significant to determine the contamination of debris items on the shoreline area as indicated by several studies (Nagelkerken *et al.*, 2001).

TKB, which is known as recreational area, has more accumulation of small plastics which averaged at 231 items/m^2 while PPB which represents a fishing beach generates less debris averaging at 211 items/m^2. Although, MPPD is the responsible authority to ensure the cleanliness of TKB, small-buried plastic debris may not be collected during the clean-up activity since they are buried in the sand. As per the studies by Cooper and Corcoran (2010), small pieces of plastic debris still exist in Kauai beach, Hawaii even after clean-up efforts were taken regularly.

TKB was more abundant with film, foam and fragment which mainly were contributed by the beachgoers, who may intentionally or unintentionally discarded the plastic waste items. Meanwhile, common types of plastic item on PPB were line, foam and film that most likely generated from the fishing nets and ropes that had been left unattended on the beach or being washed ashore from discarded fishing items by fishing vessel.

TKB recorded the most abundant small plastic debris at the berm while in PPB it is at the high tide. Besides concentrating at the accumulation of lightweight debris at TKB, the most crucial place where the visitors spend their time at most will be the berm which eventually makes them to discard the plastic waste carelessly all around the berm area.

4.3 BEACHES ALONG THE EAST COAST OF PENINSULAR MALAYSIA

In Peninsular Malaysia, the East Coast comprises of states of Kelantan, Terengganu, Pahang and east part of Johor. These states are facing the South China Sea. It relatively has smaller population with agrarian lifestyle as compared to West Coast cities. This region is affected by North-Eastern monsoon season that occurs yearly, starting from November and ends in February. This monsoon brings strong wind, wave and particularly heavy rain accompanied by flood.

Kuala Terengganu (KT) is a district in the state of Terengganu and situated on 60,528.10 hectares of land. It is also the capital of Terengganu state. Geographically, the whole eastern part of Terengganu is overlooking the South China Sea and it has the longest coastline in Peninsular Malaysia which spans 244 km. Tourism is the major economic source of the state. Beaches and islands in KT area such as Pulau Redang, Pulau Duyung, Pulau Bidong, as well as, the beaches of Batu Buruk and Teluk Ketapang are the main tourist destinations. KT is now well known globally as the National and International level sports championships are frequently held there. Among them are the Terengganu Monsoon Cup, Sultan's Cup Endurance Ride and FEI World Endurance Championship 2008. Kuala Terengganu City Council (MBKT) serves as the body responsible for managing solid waste and maintaining cleanliness in KT, including the beaches.

In this study, Batu Burok Beach and Seberang Takir Beach in KT were selected to represent recreational and fishing beaches, respectively.

4.3.1 Batu Burok Beach, Kuala Terengganu

Batu Burok Beach (Plate 4.3) or known as the beach of the ugly stone is situated approximately 1 km away from the KT city centre.

Plate 4.3: The view of wider sandy beach of Batu Burok.

It is the most famous beach in the state and very well-known for its wider sandy appearance with the beautiful casuarina trees lining up behind the shore. Batu Burok Beach is a good place to stroll. Nevertheless, swimming is not recommended as the waves are strong here especially during the monsoon. Water-based sports are not conducted here but other recreational activities such as sepak takraw, beach soccer, volleyball, horse-riding, kite-flying and picnic are the frequent activities that can be seen at the beach. Other attractions that can be found here are night-market, food stalls, hotels and the Cultural Centre stage. The heavy recreational activities held here resulted with greater number of waste being discarded on the beach by the beach users. Thus, plastic waste can be found buried in the sand.

4.3.1(a) Abundance of Small Plastic Debris and Other Debris

Figure 4.18 shows the quantity of small plastic debris and other debris (plant and shell) buried in the Batu Burok Beach (items/m^2). Similarly, Figure 4.19 indicates the corresponding density of these debris in the study area (g/m^2).

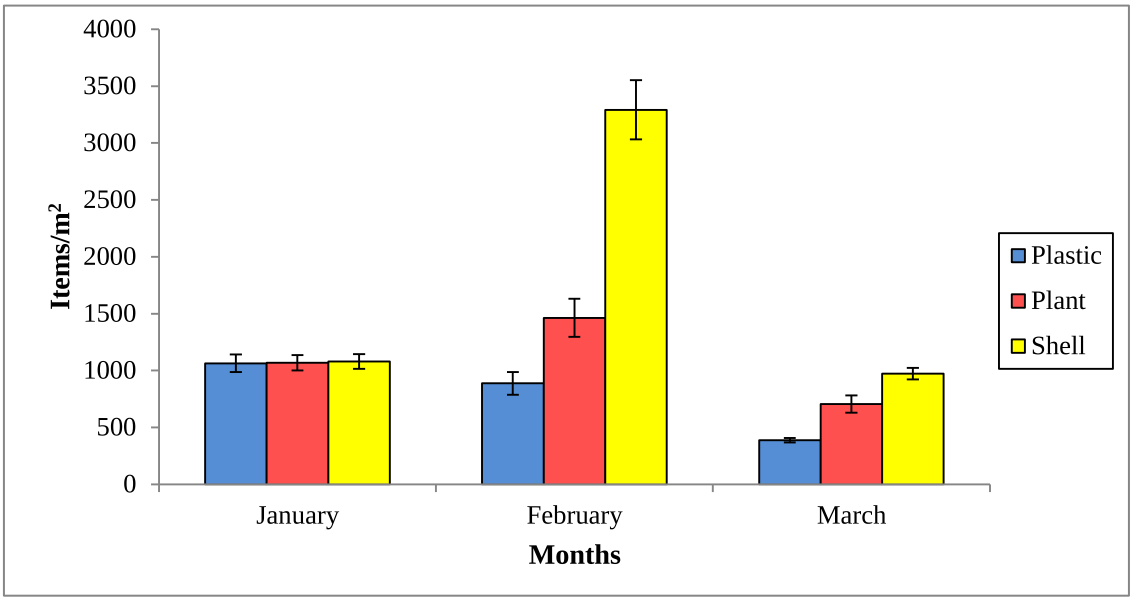

Figure 4.18: Quantity of small plastic debris and other debris at the Batu Burok Beach. (ANOVA: P>0.05).

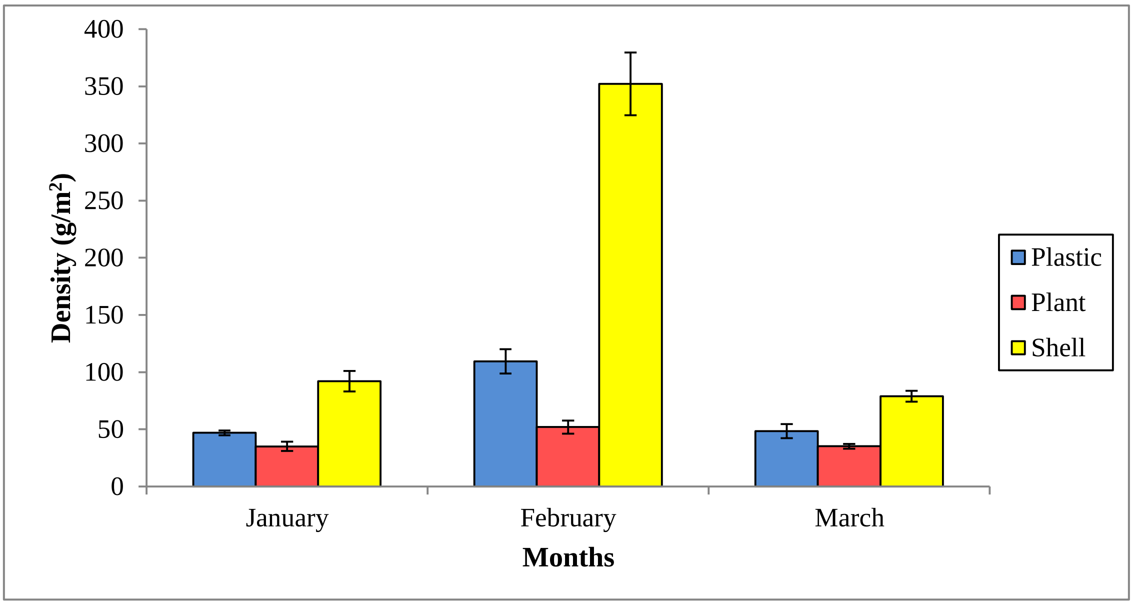

Figure 4.19: Density of small plastic debris and other debris at the Batu Burok Beach. (ANOVA: P>0.05).

Based on the results, Batu Burok Beach (BBB) was dominated by shell debris followed by plant debris and plastic particles. The quantity of shell ranged between 972 items/m^2 and 3292 items/m^2 with the density range of 78.92 – 352.08 g/m^2. Meanwhile, the quantity of plant falls within 705 items/m^2 to 1463 items/m^2 with corresponding the density at 35.06 – 51.91 g/m^2. Shell shows an outstanding dominance in February compared to other months. This may be due to the natural strong wave after the monsoon season. Waves moving towards the beach produce a current in the surf zone that pushes the water onshore. This onshore current transports sediments and dead shell in the sediment towards the shore, as well as, along the beach (Sverdrup and Armbrust, 2009).

Results also showed that the abundance of plastic varied differently in each sampling event. The quantity of plastic ranged between 388 items/m^2 and 1064 items/m^2 with the density range of 46.97 g/m^2 to 109.51 g/m^2. The highest percentage for quantity of plastic was recorded in January (45%) followed by February (38%) and the lowest was in March (17%) (Appendix 2). This scenario may have resulted because of the heavier precipitation during the monsoon months that drags the trashes from inland into the sea via drains, river or even being stranded on the beach. Besides strong waves and sea current action that usually occurs heavily during the monsoon season, may have brought in plastic debris which originated from sea-based onto the shore. Golik and Gertner (1992) revealed that the number of debris collected on Israeli beaches increased during rainy reason. However, the density showed plastic was uppermost in February (53%) but not in January (23%). This is in accordance to the lower density of plastics in January as compared to the month of February.

Moreover, the abundance of plastic debris may be due to the recreational activity in BBB. There are various studies that clearly described the relationship of recreational activities with the generation of plastic debris (Abu-Hilal and Al-Najjar, 2004; Nagelkerken, 2001; Pruter, 1987). Debrot *et al.* (1999) stated that significant source of beach debris in Curaçao, southern Caribbean resulted from recreational activities.

4.3.1(b) Classification of Small Plastic Debris

Small plastic debris were categorized into five types which are film, foam, fragment, line and pellet (items/m^2) as illustrated in Figure 4.20, while Figure 4.21 shows the corresponding density (g/m^2) of the debris in the study area.

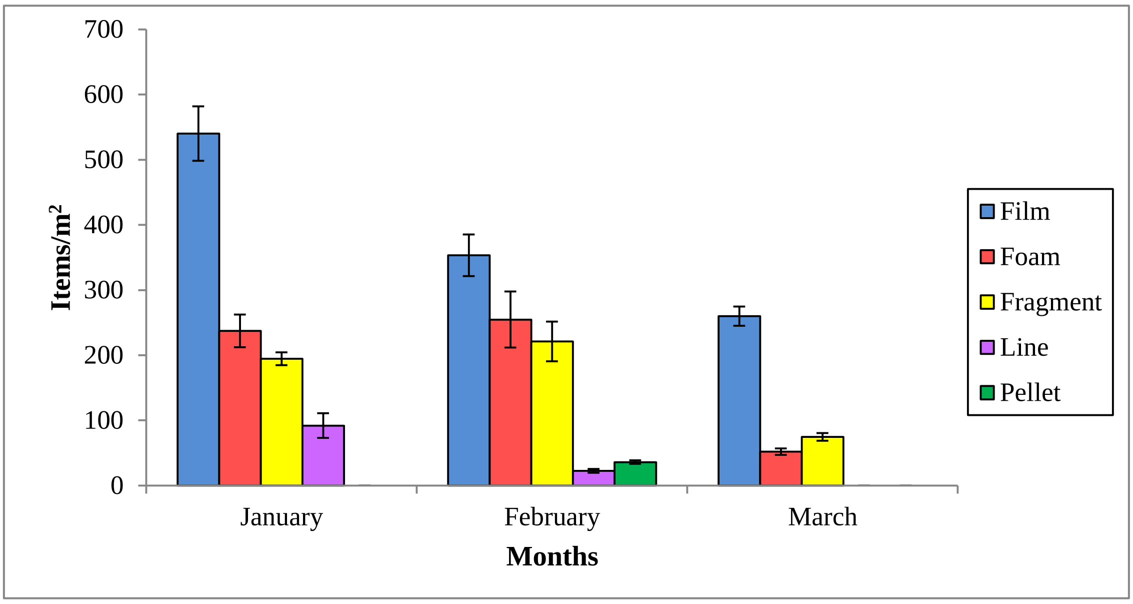

Figure 4.20: Quantity of small plastic debris according to classification at the Batu Burok Beach. (ANOVA: P<0.05).

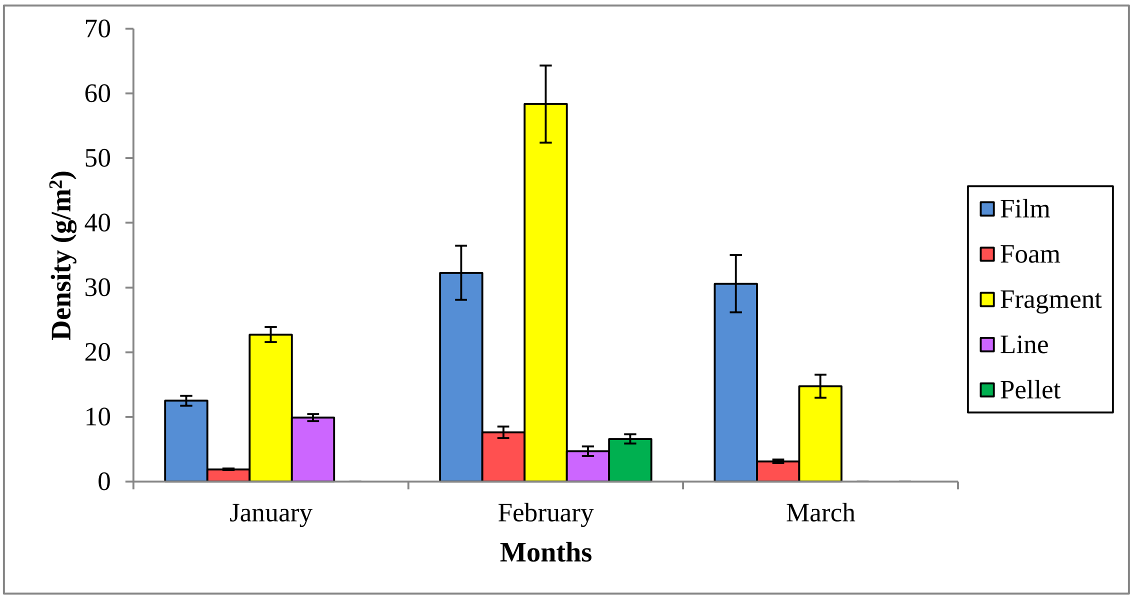

Figure 4.21: Density of small plastic debris according to classification at the Batu Burok Beach. (ANOVA: P>0.05).

Film, foam and fragment were the most common types of plastic debris found in the BBB throughout the three sampling events. The quantity of these plastics debris were 260 – 540 items/m^2 (film), 52 – 255 items/m^2 (foam) and 75 – 221 items/m^2 (fragment). While the density of these plastics debris ranged at 12.48 – 32.28 g/m^2 (film), 1.88 – 7.61 g/m^2 (foam) and 14.74 – 58.36 g/m^2 (fragment). The major reason for the abundance of film, foam and fragment might be of same reason with the TKB which is due to the recreational activity. There was a significant different ($P<0.05$) relationship in the number of items/m^2 between the types of plastic and months which is indicated by a One-Way ANOVA statistical analysis (Appendix 20). This showed that the presence of assorted plastic types ashore were different in each month and may be contributed by the occurrence of the North-Eastern monsoon.

Even though BBB is not a fishing beach, plastic line was found in this study area and assumed to have originated from both land- and sea-based sources. On the beach, small number of beachgoers often observed leisure fishing when the sea waves are calm (especially non-monsoon months). Therefore, broken fishing lines and bait are derelict on the beach which then got buried in the sands (Henderson, 2001). From the results, abundance of line were obtained in January (92 items/m^2 and 9.89 g/m^2) and February (23 items/m^2 and 4.69 g/m^2). This was possibly due to larger plastic debris that had undergone degradation process over relatively long period of time. Conversely, line from sea-based source may have originated from the use of net line, especially those discarded by fishing vessels which continued to float in the ocean until get washed ashore by the action of the sea current.

Approximately 36 items/m^2 of pellet was found in the BBB in February weighing 6.59 g/m^2. This might be due to the strong waves and sea current action from previous monsoon months which subsequently brought the pellet from the sea and washed onto the beach. Surface wind and heavier rainfall will then accumulate and keep the pellet in the sands. These pellets may originate from shipping industry which may had accidentally spilled into the sea during transportation (Derraik, 2002; Mato *et al.*, 2001). Since BBB is facing the South China Sea which is one of the busiest shipping routes, it is possible to have pellet on its beach. Once in the environment, pellets may be transported by currents to areas far away from the source (USEPA, 1992).

These two situations occurred (the presence of line and pellet) since plastic waste is world-wide problem as it is capable of originating from many sources and widely distributed by the currents to even the most remote ocean areas and beaches (Sverdrup and Armbrust, 2009; McDermid and McMullen, 2004).

4.3.1(c) Abundance of Small Plastic Debris according to Tidal Zone

Figure 4.22 shows the quantity of small plastic debris (items/m^2) according to the beach tidal zones namely; low tide, high tide and berm, while Figure 4.23 shows the corresponding density (g/m^2) of the debris in the study area.

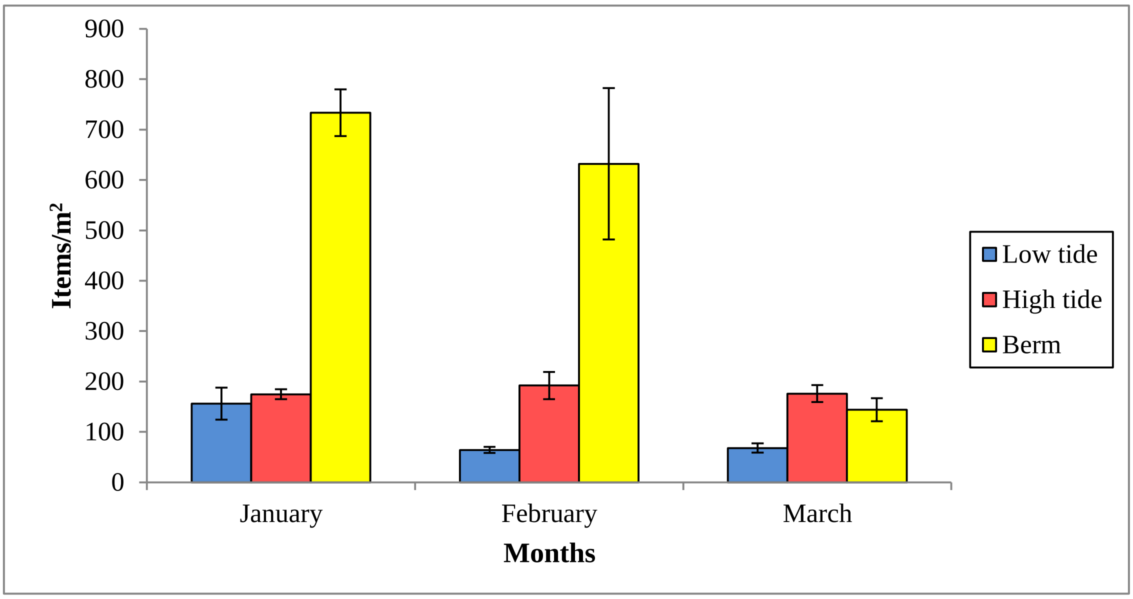

Figure 4.22: Quantity of small plastic debris according to tidal zone at the Batu Burok Beach. (ANOVA: P>0.05).

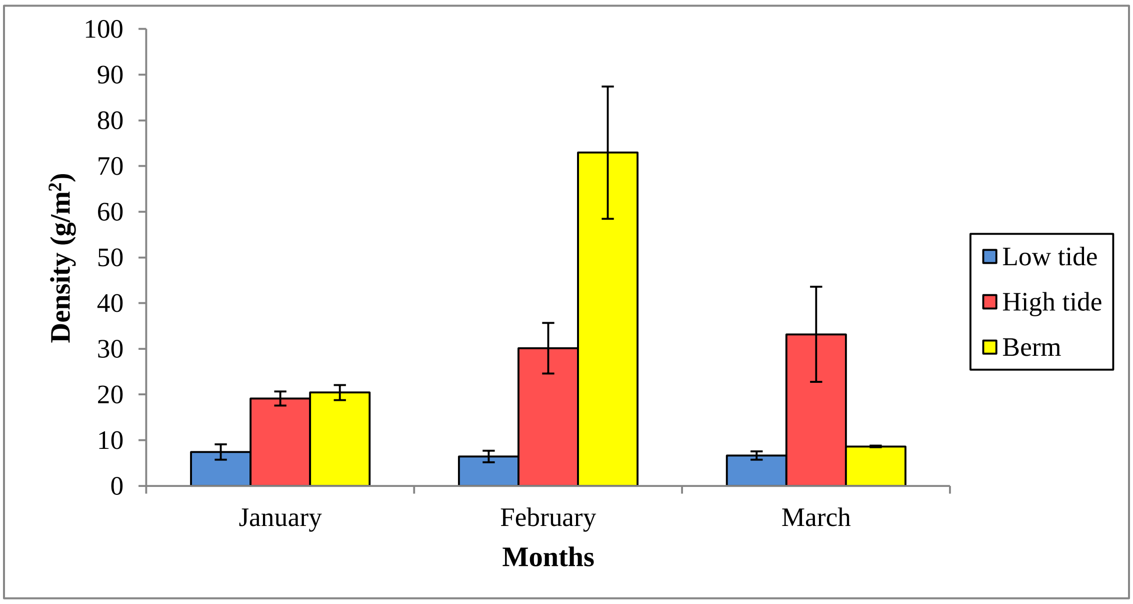

Figure 4.23: Density of small plastic debris according to tidal zone at the Batu Burok Beach. (ANOVA: P>0.05).

Small plastic debris buried along the berm area of BBB which is the highest in January (733 items/m^2 and 20.43 g/m^2) while 632 items/m^2 and 72.94 g/m^2 were recorded in February. However, the plastic abundance recorded in March was more significant along the high tide line with 176 items/m^2 and density of 33.16 g/m^2.

In January and February, plastics obtained from the berm area were higher probably due to the strong on-shore wind that blow stranded small-lighter plastics from water convergence onto berm surface before being embedded within the sands. Lower densities of film (12.48 – 32.28 g/m^2) and foam (1.88 – 7.61 g/m^2) were recorded abundantly in BBB; thus these lightweight of plastics may be moved by the winds. It can be noted that wind is one of the major contributing factor that controls the distribution of lightweighted debris. However, under special circumstances, wind transport may affect supply and demand mainly on lightweight debris just as the seawater transport on beaches (Donohue *et al.,* 2001; Ross *et al.*, 1991).

The abundance and accumulation of small plastics along the berm area might also be contributed by the beachgoers as BBB is well-known as a recreational beach. The higher quantity and density of plastic buried along the high tide shoreline in March might have originated from heavier debris such as fragments transported by wave along the high tide region. This finding had been reported by Thornton and Jackson (1998) in Cliffwood Beach, New Jersey, USA. Also, abundance of film in March suggested that film plastics were left by beachgoers along the high tide shoreline right after the monsoon season came to an end.

4.3.1(d) Abundance of Small Plastic Debris according to size

Figure 4.24 illustrates the quantity of small plastic debris (items/m^2) according to size at different tidal zones, while Figure 4.25 illustrates the corresponding density (g/m^2) of the debris in the study area.

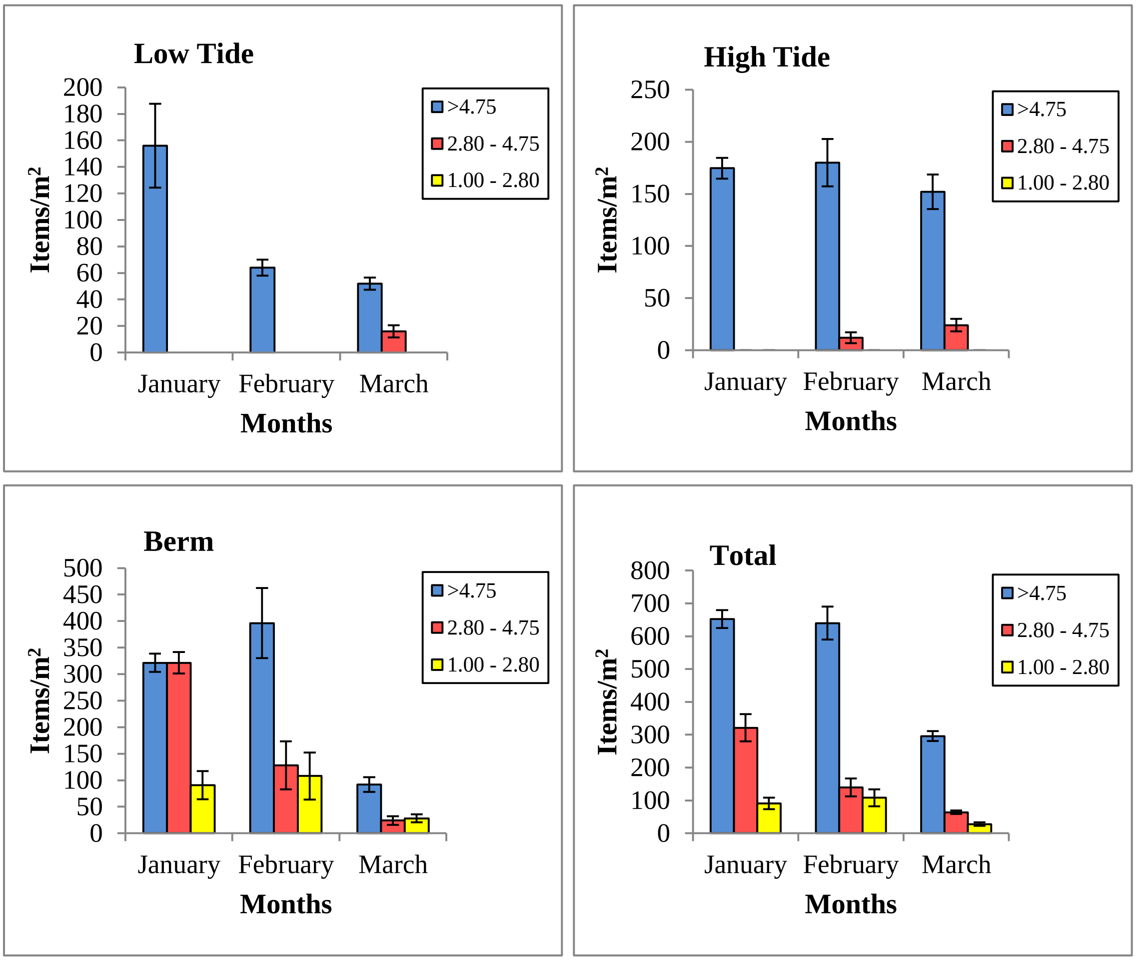

Figure 4.24: Total quantity of small plastic debris according to size range and at different tidal zone at the Batu Burok Beach (ANOVA: P>0.05).

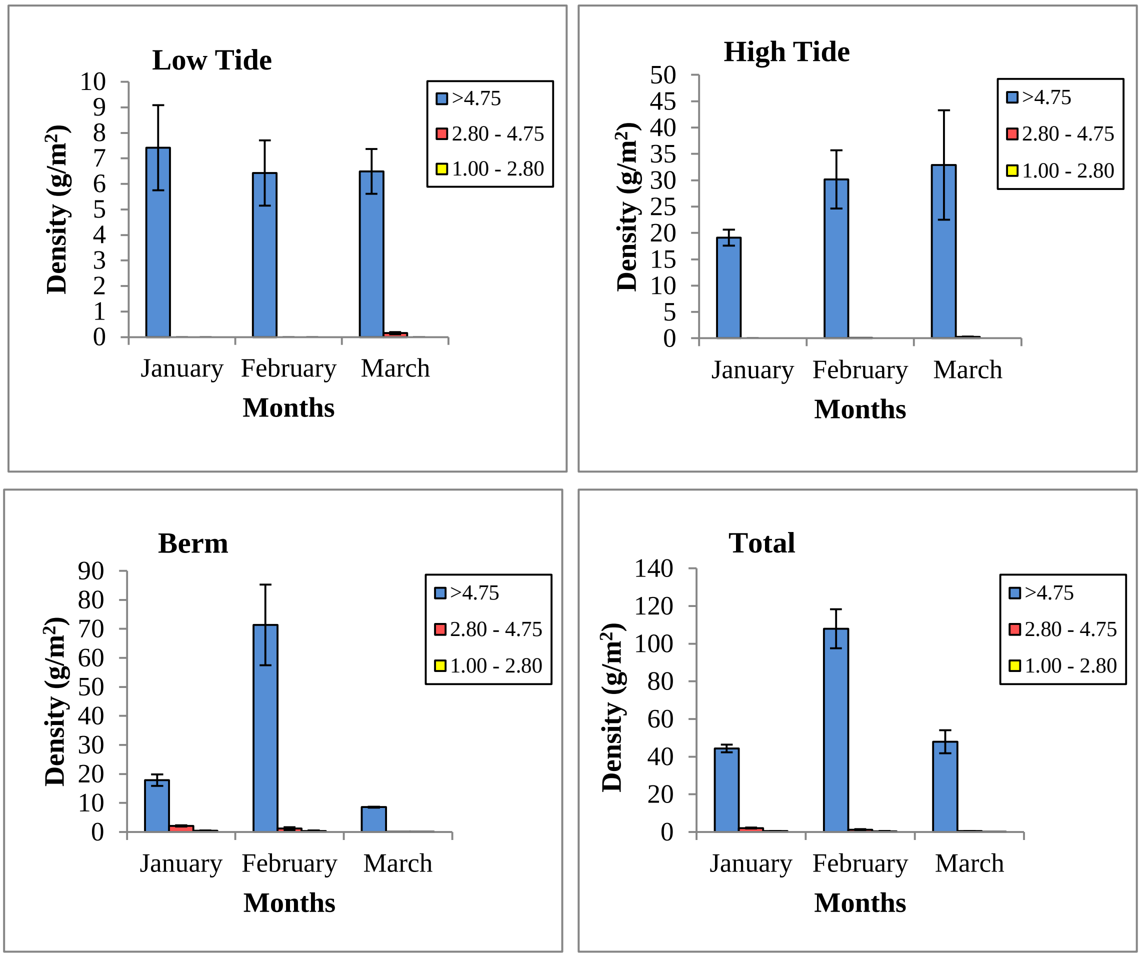

Figure 4.25: Total density of small plastic debris according to size range and at different tidal zone at the Batu Burok Beach (ANOVA: P>0.05).

The results showed that small plastic debris which exceeded 4.75 mm was the most abundant along the berm, followed by debris which ranged 2.80 - 4.74 mm and 1.00 - 2.80 mm. Meanwhile, no plastic debris ranged 1.00 - 2.80 mm was recorded along the low tide and high tide shorelines.

The total number for small plastic debris that exceeded 4.75 mm is the highest with 529 items/m^2 with density averaged at 66.78 g/m^2. Debris with size range of 2.80 - 4.75 mm were 175 items/m^2 and a density of 1.24 g/m^2 while debris with size within 1.00 - 2.80 mm recorded 76 items/m^2 and 0.28 g/m^2 in density.

Plastic debris in this study can be smaller in size due to the degradation process that caused losses in useful physical and mechanical plastic properties. The degradation of plastic occurred when it is exposed to UVB radiation of sunlight, oxygen and seawater that imply chemical changes in plastic materials which indirectly reduced the physical size of plastic (Santos *et al.*, 2009; Gregory and Andrady, 2003). Faster degradation rates of plastics debris make plastic more brittle and this is even more frequent in warm tropical seas (Ng and Obbard, 2006).

This persistent small buried plastic found in BBB may be exhumed and recycled to the surface by moving sands or wave. Many plastics float, widespread at sea or washed ashore again in ‘yo-yo-like’ episodes. Their cyclic distribution may not directly become serious aesthetic problems to human but still endangering to marine wildlife. For instance, a study conducted by Day *et al.* (1985) in Alaska had found light brown fragments and pellets sizes which are only few millimetres in the seabirds’ stomachs. This showed that seabirds may assume it to be fish eggs or larvae as these debris apparently had similar size and colour (Laist, 1987). Therefore, it is possible that marine animals habiting in the BBB ecosystem will also experience the same impact if no further action is taken to remove these persistent plastic debris once deposited in the area.

4.3.2 Seberang Takir Beach, Kuala Terengganu

Seberang Takir Beach (Plate 4.4) is located to the north of the KT city and across the Terengganu River estuary. The beach is less than 40 km from the city. There are fishing villages adjoining the beach, dotted with colourful fishing boats and surrounded by small bushes.

Plate 4.4: Visible marine debris washed ashore on the beach.

The beach and nearby villages will be flooded by shallow seawater during the early monsoon season. Instead of fishing activity, most of the villagers are involved in small business such as selling fish or prawn crackers, processing salted fish for export, batik printing and some form of cottage industry. Since the beach is also used for recreational purposes, many types of waste are found on the beach while plastic debris is trapped in the sand.

4.3.2(a) Abundance of Small Plastic Debris and Other Debris

Figure 4.26 presents the quantity of small plastic debris and other debris (plant and shell) obtained from Seberang Takir Beach (STB) (items/m^2), while Figure 4.27 presents the corresponding density (g/m^2) of these debris in the study area.

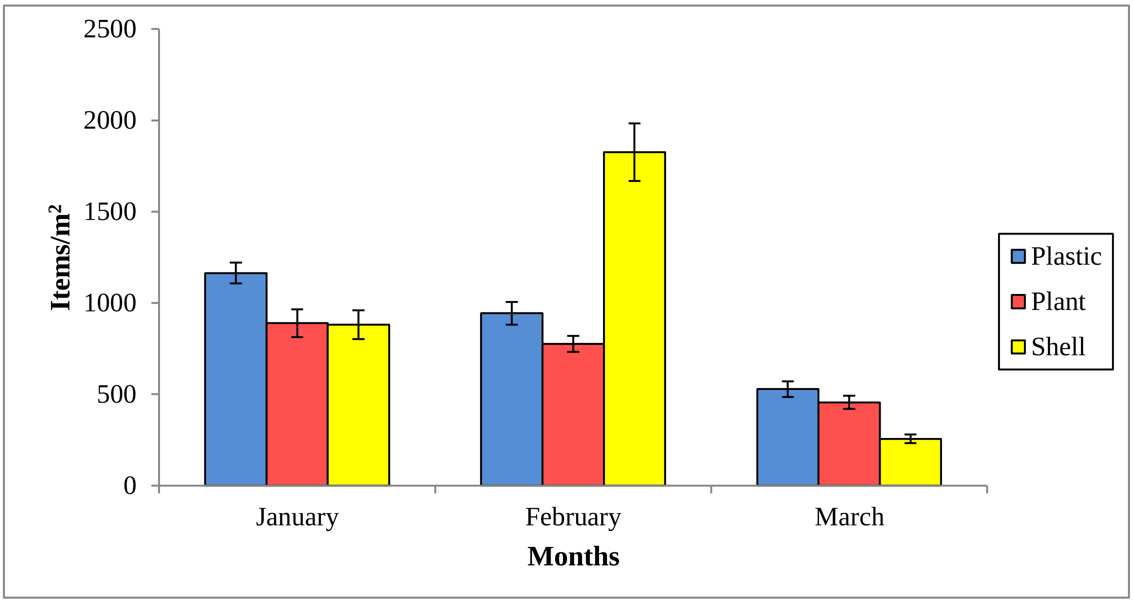

Figure 4.26: Quantity of small plastic debris and other debris at the Seberang Takir Beach. (ANOVA: P>0.05).

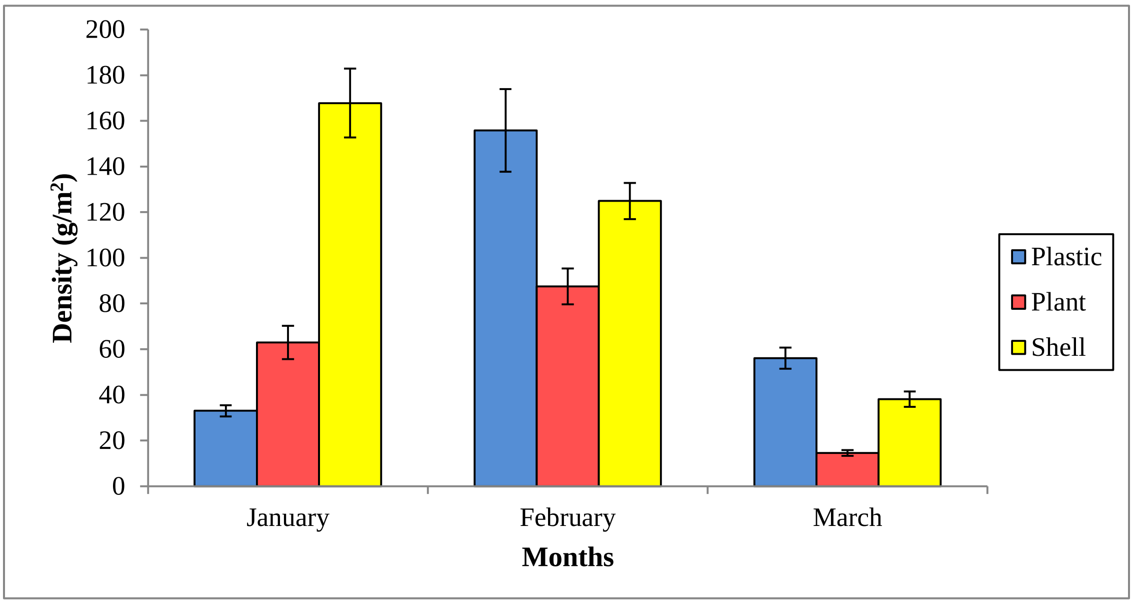

Figure 4.27: Density of small plastic debris and other debris at the Seberang Takir Beach. (ANOVA: P>0.05).

The debris collected during the sampling events in STB comprised of plastic in total range of 528 – 1164 items/m^2, plant (456 – 889 items/m^2) and shell (256 – 1825 items/m^2). The density of these debris ranged from 33 g/m^2 to 155.78 g/m^2 for plastic; 14.57 g/m^2 to 87.47 g/m^2 for plant and 38.16 g/m^2 to 167.76 g/m^2 for shell.

The quantity of plastic debris buried in STB sands from the first sampling event was recorded as the highest. Heavy rainfall and flooding during monsoon season might have resulted in the presence of plastic debris deposition in the sands. This suggests that flood brought the plastics trash from inland via storm-drains running into the sea and some of them left stranded ashore. Then, energy from the dropping rainfalls may enhance the pressure to the plastic debris on the beach surface to be buried in the sands. As mentioned by Golik and Gertner (1992), rain events contribute to the higher accumulation of beach debris as already occurred in Israeli beaches.

On the following sampling events, the debris subsequently decreased as most of the debris might be washed into the sea as the monsoon season was almost ending. Plastics can be removed from the beach and returned to the oceans with high tides or flow away during storms into the sea (Bugoni *et al.*, 2001).

The plastic in STB probably originated from the disposal of trash and discarded items from fishermen boats or vessels since fishing activity is the foremost activity in STB. Another source responsible for the occurrence of plastic debris in STB is solid waste runoff that originated from nearby fishing villages during the receding of the flood water (Liyana *et al.*, 2011).

4.3.2(b) Classification of Small Plastic Debris

Figure 4.28 shows the types of small plastic debris that are film, foam, fragment, line and pellet (items/m^2). Similarly, Figure 4.29 shows the corresponding density (g/m^2) of the debris in the study area.

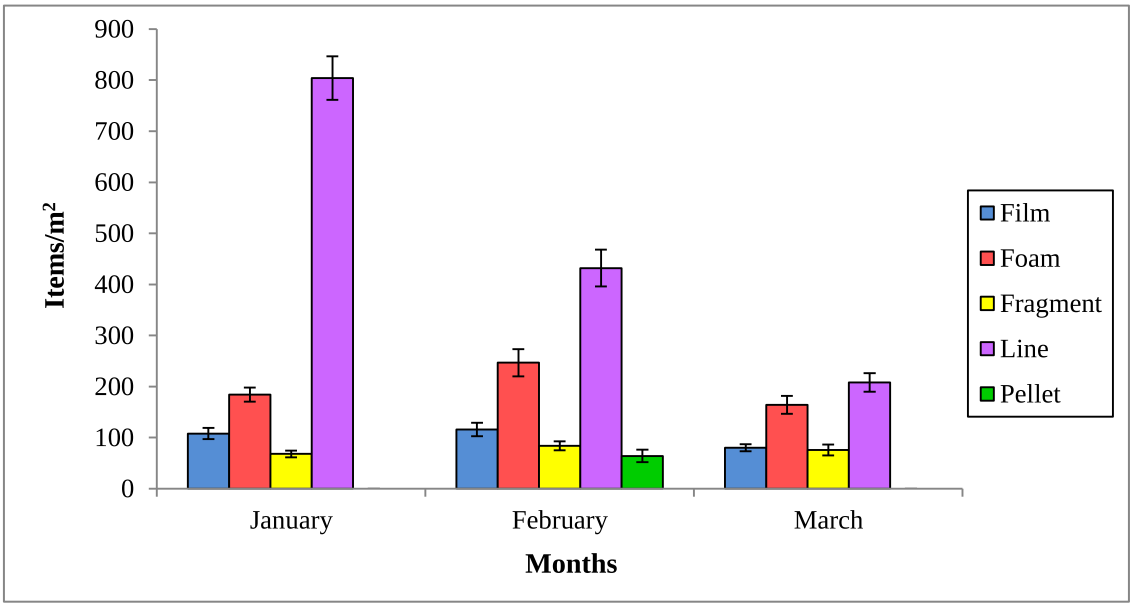

Figure 4.28: Quantity of small plastic debris according to classification at the Seberang Takir Beach. (ANOVA: P>0.05).

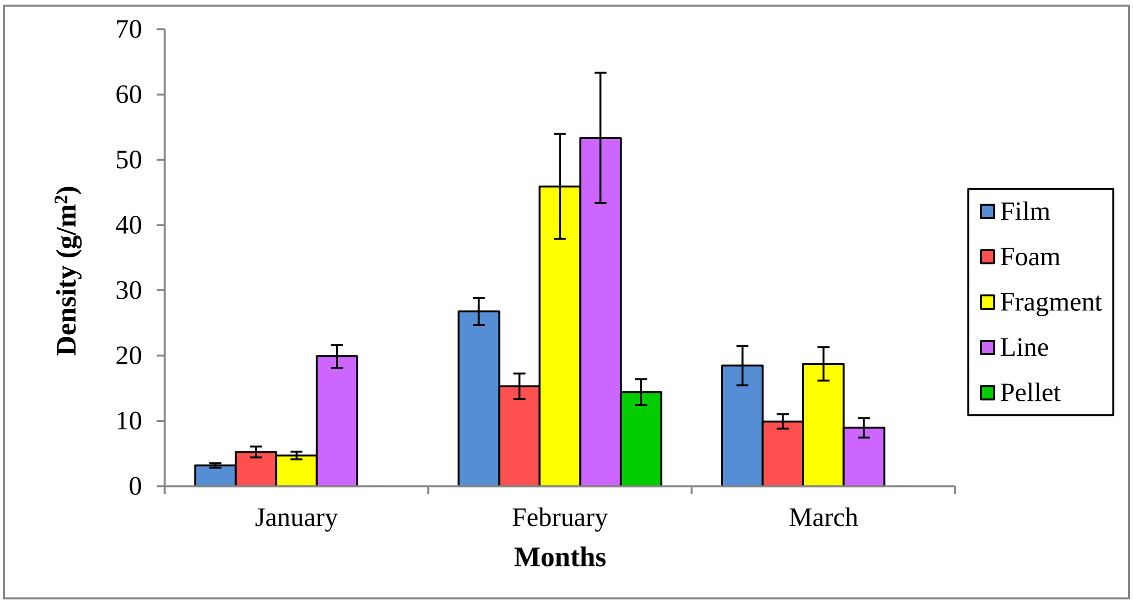

Figure 4.29: Density of small plastic debris according to classification at the Seberang Takir Beach. (ANOVA: P<0.05).

Line was dominant numerically in STB, ranged from 208 to 804 items/m^2 with the density range of 8.96 to 53.35 g/m^2. Foam was the second most abundant material (164 to 247 items/m^2) with density range of 5.25 – 15.30 g/m^2. In contrast, film (80 – 116 items/m^2) and fragment (68 – 84 items/m^2) constituted minor components of plastics collected with the densities within 3.16 to 26.78 g/m^2 and 4.71 to 45.94 g/m^2, respectively. As for the density, a One-Way ANOVA statistical analysis indicated that there was a significant different ($P<0.05$) relationship between the types of plastic and months (Appendix 24). This showed that North-Eastern monsoon may have contributed to the dissimilarity of plastic type's distribution ashore according to the different of months.

Line was the highest component of plastics found in STB as line is believed to have originated from fishing line items. This is due to the fact that STB is known as the fishing beach and increased level of line reflects the frequent beach activity. Fishery activities lead to greater abundance of derelict lines than other types due to the relative proportions of it manufacture, use and, in this particular case, discarding or loss (Browne *et al.*, 2010). Besides, varieties of plastics in this study area were considered to come from both land- and sea-based sources. Net line and styrofoam fishing crates particularly those used in fishing activity (sea-based) were thrown overboard and continued to float till washed ashore by the sea current. It was reported that some fishing gear recovered in the Northwestern Hawaii Islands beach for example were lost during active fishing operations or intentional at-sea disposal where they were then transported by currents to the beach (Donohue, 2005).

Larger plastic used for fishing container were also discarded and scattered carelessly nearby the beach area (land-based). Film and fragment may originate from fabricated items owned by fishing villagers and carried on shore during storm or via drainage systems. Similar findings has been reported that these smaller plastics debris were attributed to the breaking down of larger plastic items on the beach before being partially buried or fully smothered by sands (Santos *et al.*, 2009; Uneputty and Evans, 1997).

Plastic pellet (64 items/m^2 with 14.43 g/m^2 in density) which was found in the second sampling event might be the debris remaining after strong waves and sea current action during monsoon season. Since there is no plastic processing plants located in KT, this suggests that the disposal from ship is the major source of the pellets. As STB is fronting the wide-open sea of South China Sea and known to be the busiest shipping lane, it is possible that pellet may be transported by current from the ships towards the STB shoreline. It was reported that the pellets may find their way into the marine environment through accidental spillage during transport and handling from the ships (Takada *et al*., 2010; Karapanagioti and Klontza, 2008).

4.3.2(c) Abundance of Small Plastic Debris according to Tidal Zone

Figure 4.30 shows the quantity of small plastic debris in items/m^2 according to beach tidal zones namely; low tide, high tide and berm, while Figure 4.31 shows the graph of the corresponding density (g/m^2) of the debris in the study area.

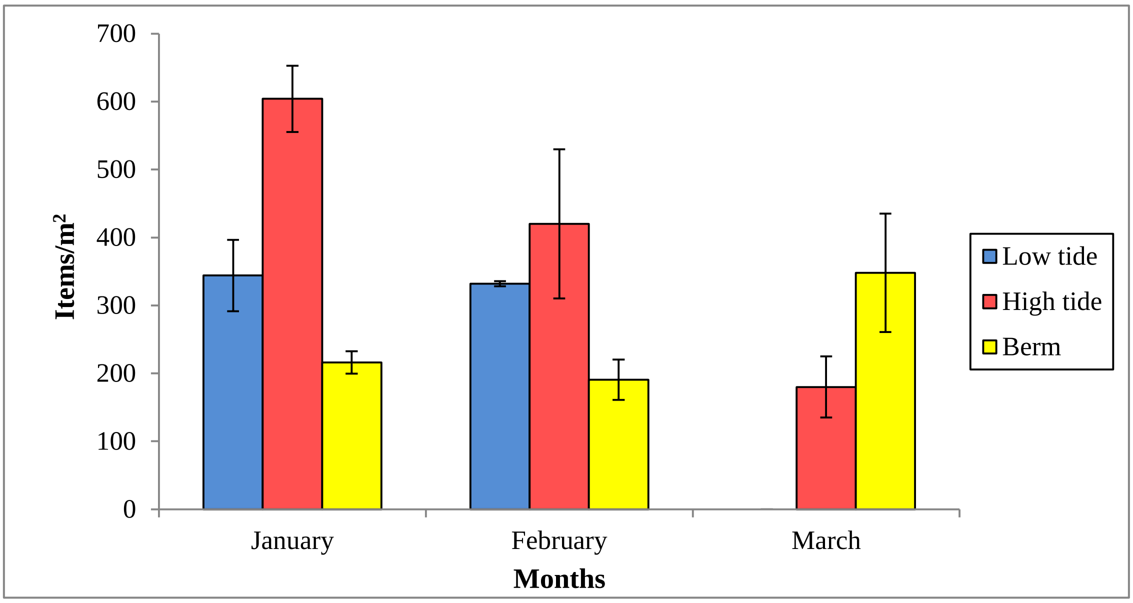

Figure 4.30: Quantity of small plastic debris according to tidal zone at the Seberang Takir Beach. (ANOVA: P>0.05).

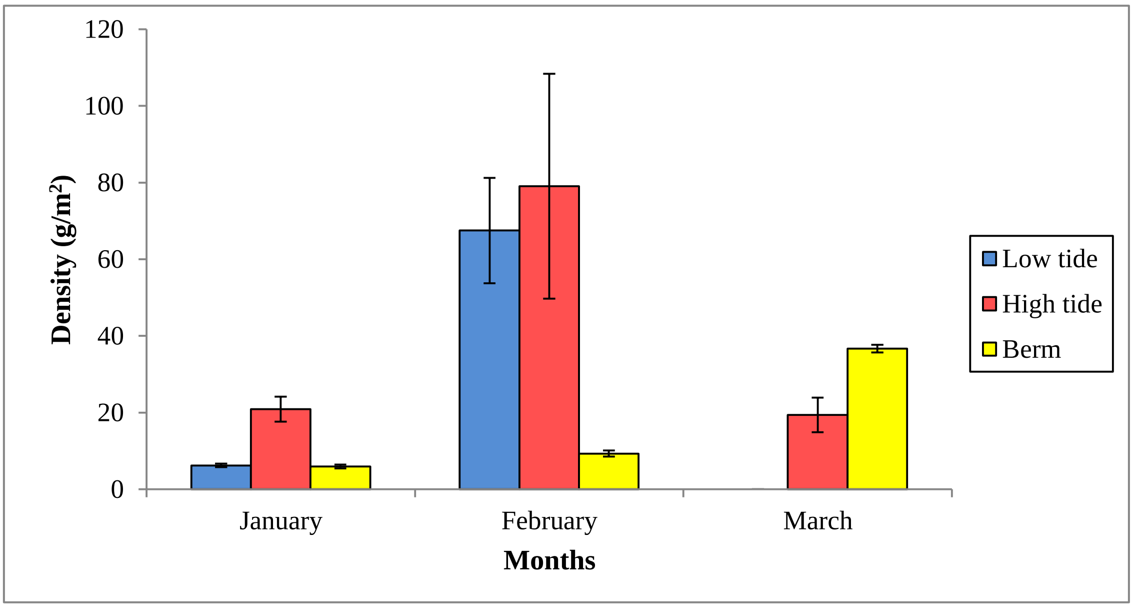

Figure 4.31: Density of small plastic debris according to tidal zone at the Seberang Takir Beach. (ANOVA: P>0.05).

The highest impact of plastic in STB was experienced at the high tide shoreline during the first sampling event (604 items/m^2) and second sampling event (420 items/m^2) with the density 20.88 g/m^2 and 79.04 g/m^2, respectively. Beaches are strongly affected by waves and sea current at the high tide shoreline. This process might bring in plastic debris and trap the debris in the STB sands. The amount and various types of plastic debris at the wrack-line of beach (high tide) were probably controlled by natural processes such as waves, current and storm activity combined with flood tides. This scenario had been previously reported (Corcoran *et al.*, 2009; Storrier *et al.*, 2007).

Plastic item was the highest at the berm in the third sampling which was 348 items/m^2 with a density of 36.68 g/m^2. Abundance of lightweight debris of foam at the berm may possibly be due to washing of foam onto beaches from water's edge and being deposited by wind. It can be noted that indirect natural exposure (wind and wave) and the characteristics of plastic debris also influence the transport of debris items in the study area. Thiel *et al.* (2003) reported that permanence of plastic debris cast ashore may vary depending on its weight and size. Consequently lightweight debris (e.g. styrofoam) may be blown away from the flotsam to the upper berm.

4.3.2(d) Abundance of Small Plastic Debris according to size

Figure 4.32 shows the quantity of small plastic debris (items/m^2) according to sizes at different tidal zones, while Figure 4.33 shows the corresponding density (g/m^2) of the debris in the study area.

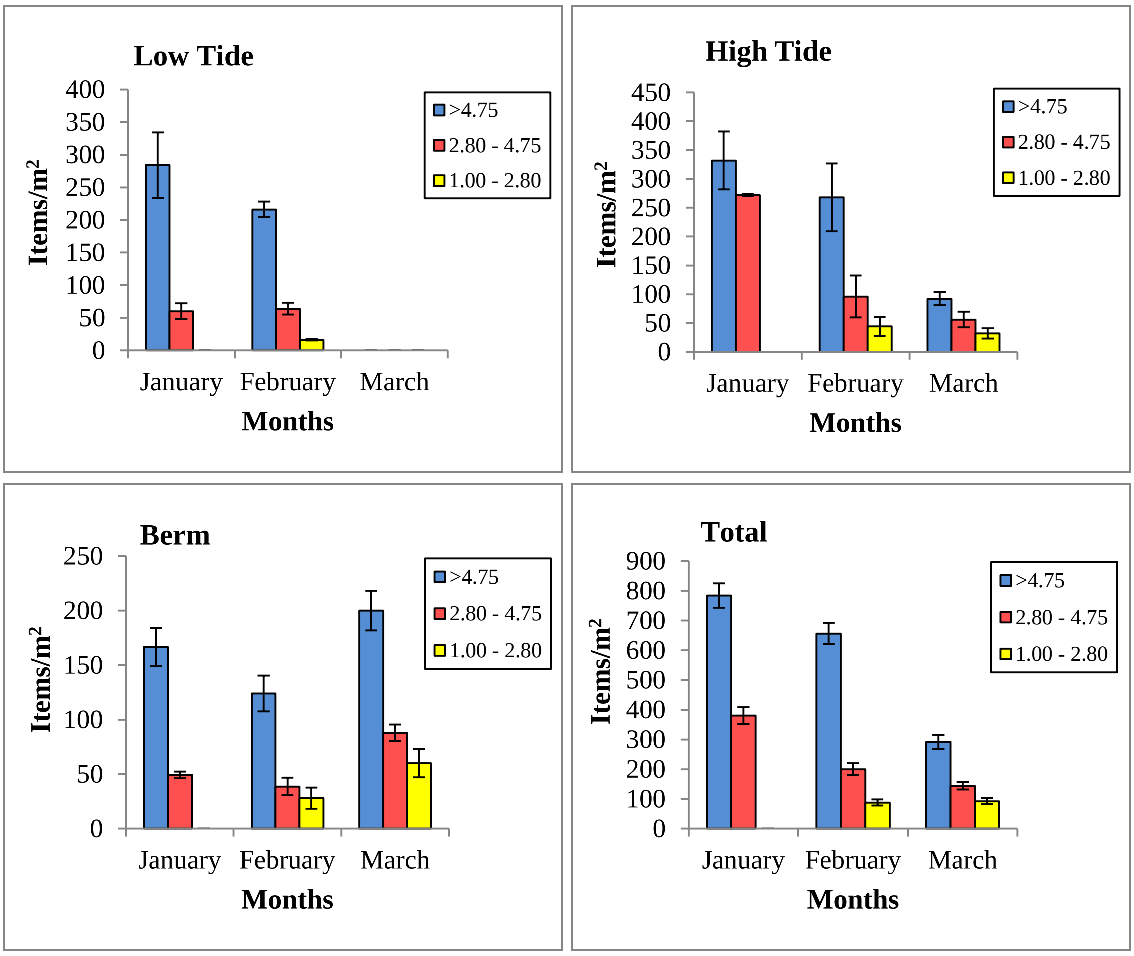

Figure 4.32: Total quantity of small plastic debris according to size range and at different tidal zone at the Seberang Takir Beach (ANOVA: P>0.05).

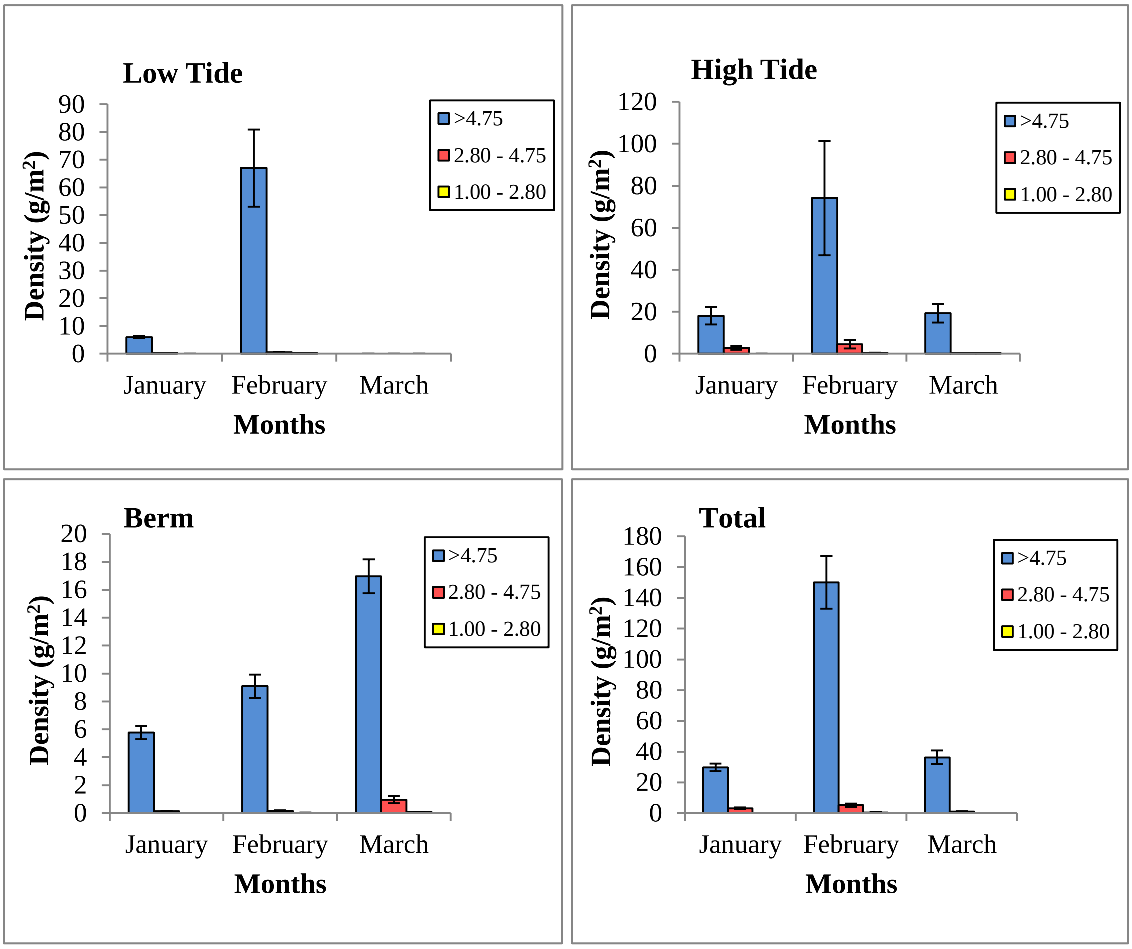

Figure 4.33: Total density of small plastic debris according to size range and at different tidal zone at the Seberang Takir Beach (ANOVA: P>0.05).

The dominant size-class of small plastic debris at the low tide, high tide and berm in STB was more than 4.75 mm, averaging at 577 items/m^2 with density averaged at 72.07 g/m^2. This is followed by debris which ranged from 2.80 - 4.75 mm (241 items/m^2) with average density of 3.14 g/m^2. The least abundant comprised of the finest debris that range from 1.00 - 2.80 mm with only 60 items/m^2 and density of 0.18 g/m^2.

The diminution of plastic debris as occurred in STB might be due to the combination of chemical weathering and mechanically eroding of plastic. The evidence of plastic degradation suggests that chemical weathering process which has been studied on Kauai beach plastic in Hawaii was developed from photothermal oxidation of solar UV radiation which may significantly reduce the mechanical strength of the plastic materials (Corcoran *et al.*, 2009; Gregory and Andrady, 2003). Additional abrasion exposure from sand grains dragging across plastic surfaces also resulted in mechanical erosion and breakages of plastic fractures (Corcoran *et al.*, 2009).

Buried plastic particles as found in STB have the potential of causing negative impact on small organisms which fed on decaying organic matter. Thompson *et al.* (2004) who had experimented on filter-feeding barnacles (*Semibalanus balanoides*), amphipods (*Orchestia gammarellus*) and sediment-ingesting lugworms in aquaria reported that these animals had ingested small plastic fragments. Debris smaller than 4.75 mm that existed in STB sands is the fraction that filter feeders are most likely to assume it as plankton. This had been seen in the southern California (Moore and Allen, 2000). Since small plastic debris have the potential of ecological risks, possible measures should be taken to reduce the amount of larger plastic that are left stranded on STB beach before it degrades into small and variable sizes that dramatically increase the possibility of being ingested as food by marine organisms.

4.3.3 Comparison between Batu Burok and Seberang Takir Beaches

STB which represents a fishing beach has greater abundance of small plastic debris averaging at 879 items/m^2 compared to BBB which represents a recreational area averaging at 780 items/m^2, since fishing activity is the foremost activity in STB. Plastic products used in fishing are discarded carelessly along the beach area. The heavy rainfall during monsoon season might also be contributing to the plastic deposition in the sands, both in STB and BBB in Kuala Terengganu. Besides, plastic wastes may also originate from the fishing villages' which were transported onto the beach by storm-drains during monsoon season. These plastics debris can be degraded into smaller sizes and eventually get buried in the sands.

Film, foam and fragment were accounted as the most abundant types of plastic debris collected in BBB. These types of plastics found abundantly as result of discarding of thin plastic bags or film plastic wrappers by beachgoers who used the BBB for recreational activity. This abundance is supported by the fact that recreational beach is one of the fastest growing usages of beaches (Garrity and Levings, 1993). On the other hand, foam, film and especially line plastics were found abundantly in STB. These types of plastic debris appeared to be the remnants of offshore fishing-related activity that were thrown overboard and eventually washed ashore. Even though MARPOL 73/78 Annex V has already prohibited illegal dumping of any plastic item into the ocean, purposeful dumping and accidental loss continues as they are ignoring the regulations. This has been reported by Henderson (2001). Also, this scenario has been reported to occur in many islands in Southern Ocean and Antarctica beach areas (Convey *et al.*, 2002; Walker *et al.*, 1997).

The highest impact of plastic debris in BBB would probably be seen at the berm while in STB it is in high tide shoreline. Berm in STB is less disturbed by beachgoers compared to those in BBB. So, berm area in STB had less plastic debris compared to the high tide shoreline where the majority of debris accumulated got transported naturally by sea waves and tidal movement.

4.4 BEACHES ALONG THE EAST MALAYSIA

East Malaysia or also known as the Malaysian Borneo is occupied by the states of Sabah, Sarawak and the Federal Territory of Labuan. It is the northern part of the Borneo Island with Kalimantan (Indonesia) and Brunei, which is separated from Peninsular Malaysia with 640 km of the South China Sea. Even though East Malaysia is less developed and less populated, the mass of its land is larger and richer in natural resources compared to the West Malaysia.

Kota Kinabalu (KK), formerly known as Jesselton, is the capital city of Sabah, as well as, the capital of the West Coast Division of Sabah. It comprises an area of 351 km^2 that make up to the smallest but the most populous district in Sabah with a density of 1,650 people/km^2. KK is the most strategic location as the major gateway into Sabah featuring plenty of tourism attraction such as Mount Kinabalu (the highest mountain on the Borneo Island), Kinabalu National Park, Tunku Abdul Rahman Marine Park and large number of fabulous beaches. KK plays a role as an important place for major industrial and trade centres of East Malaysia. KK is also the major hub for commercial and administrative activity. Kota Kinabalu City Hall (DBKK) is the authority responsible for managing solid waste collection, transporting and disposal services throughout the city including the beaches area. The responsibility fall under the Health and Urban Services Department jurisdiction.

In this study, Tanjung Aru Beach and Teluk Likas Beach which are located in KK were selected to represent recreational and fishing beaches, respectively.

4.4.1 Tanjung Aru Beach, Kota Kinabalu

Tanjung Aru Beach (Plate 4.5) is located at approximately 6 km from the centre of KK and 10 km away from the city airport. The beach stretched over 2 km in length and has very fine, white sandy beach. This place was named after the famous casuarina or locally known as Aru trees that strategically fringe the fine sands and grow along the shoreline.

Plate 4.5: The beautiful panoramic view of Tanjung Aru Beach.

Many foreign tourists enjoy jogging and strolling along the wider sandy beach or probably just to relax under the shady trees in the breezing atmosphere. There are many hawker stalls and open-air seafood restaurant along the beach which attracts more people to visit the beach area. The most special attraction here is the spectacular sunset between 6.00 and 6.15 p.m. Other recreational activities are scuba diving, windsurfing and waterskiing. Thus, the presence of debris is inevitable.

4.4.1(a) Abundance of Small Plastic Debris and Other Debris

Figure 4.34 presents the quantity of small plastic debris and other debris (plant and shell) buried in the Tanjung Aru Beach (items/m^2), while Figure 4.35 presents the corresponding density (g/m^2) of these debris in the study area.

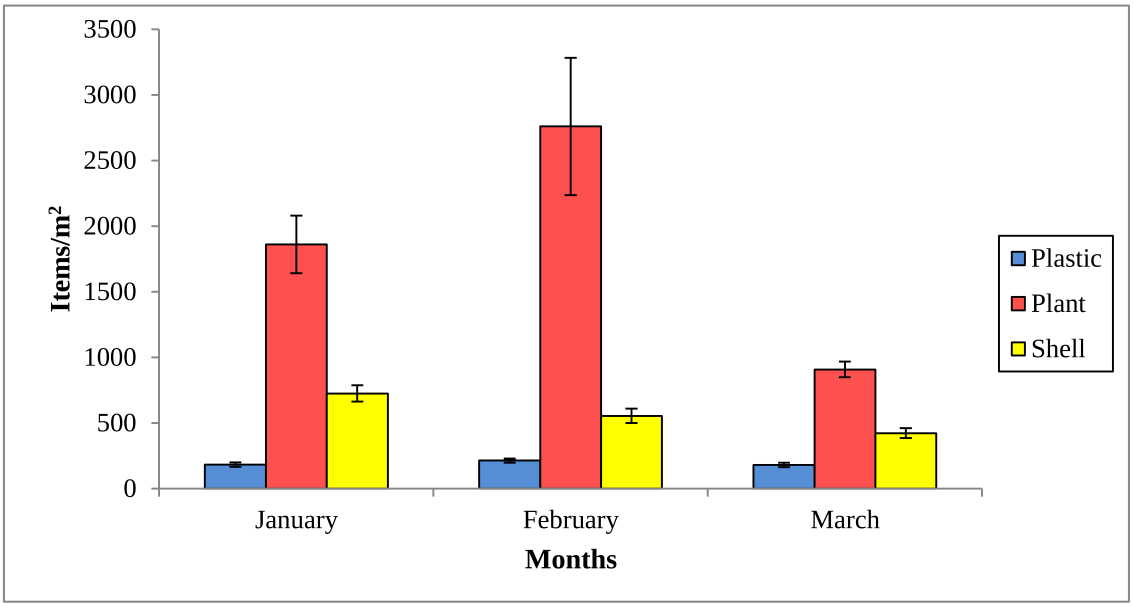

Figure 4.34: Quantity of small plastic debris and other debris at the Tanjung Aru Beach. (ANOVA: P>0.05).

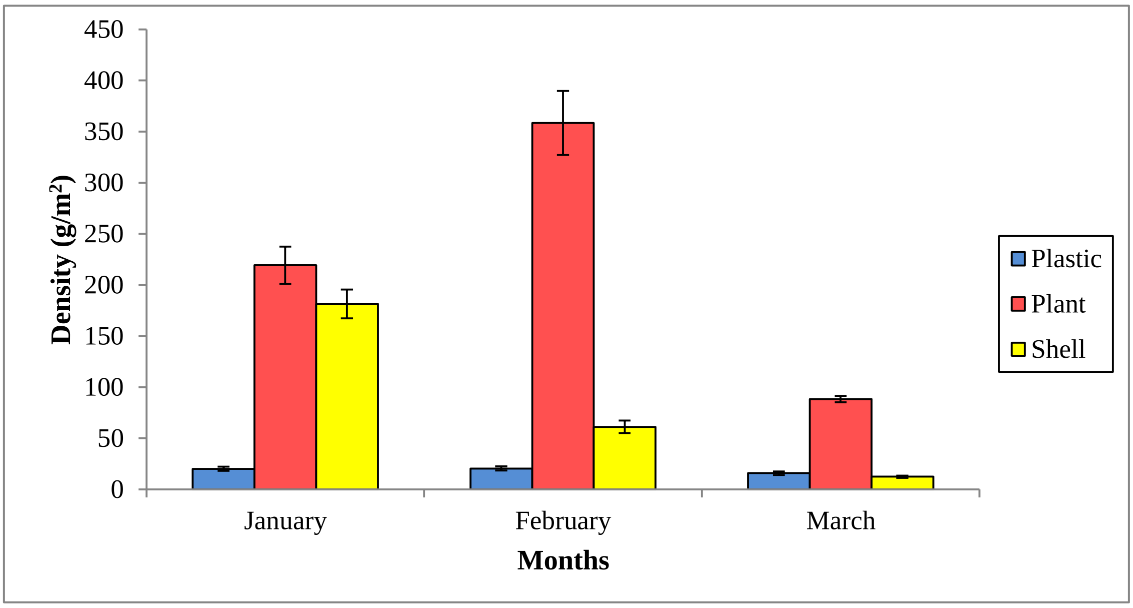

Figure 4.35: Density of small plastic debris and other debris at the Tanjung Aru Beach. (ANOVA: P>0.05).

Plant matter which was the most commonly found natural debris in Tanjung Aru Beach (TAB) ranged between 908 items/m^2 and 2760 items/m^2 with density range of 88.41 g/m^2 to 358.44 g/m^2. The quantity of shell ranged between 423 items/m^2 and 725 items/m^2 with corresponding the density that falls within 12.42 g/m^2 and 181.43 g/m^2. Anthropogenic debris which includes plastic particles was the least abundant ranging at 180 – 213 items/m^2 in quantity and 15.82 – 20.37 g/m^2 in density.

The low abundance of small plastic debris in TAB might result from the clean-up activity done regularly by the local municipality workers who collect larger plastic waste on the beach surface. The collection activity reduces the amount of plastic items which reduce the possibility of these plastic being degraded into smaller size. Beach-cleaning regimes can solve a problem of small plastic as it is a substantial proportion derived from fragmentation of larger plastic in situ (Ryan *et al.*, 2009). However, there was small plastic debris that still occurred in TAB. This might have originated from sea-borne plastics debris which had undergone fragmentation process in the sea and break down into smaller particles before reaching TAB. Clean-up operations have traditionally focused on larger items and more visible debris to the exclusion of small and finally undetectable debris (Moore, 2001a).

Littering of plastics by beachgoers is most likely the pathways that transport plastic debris to TAB. This phenomenon had also been reported in Orange County beach, California where the beach is used for a variety of recreational activities (Moore, 2001a).

4.4.1(b) Classification of Small Plastic Debris

Figure 4.36 shows the classification of small plastic debris (items/m^2) which had been categorized into film, foam, fragment, line and pellet. Also Figure 4.37 shows the corresponding density (g/m^2) of the debris in the study area.

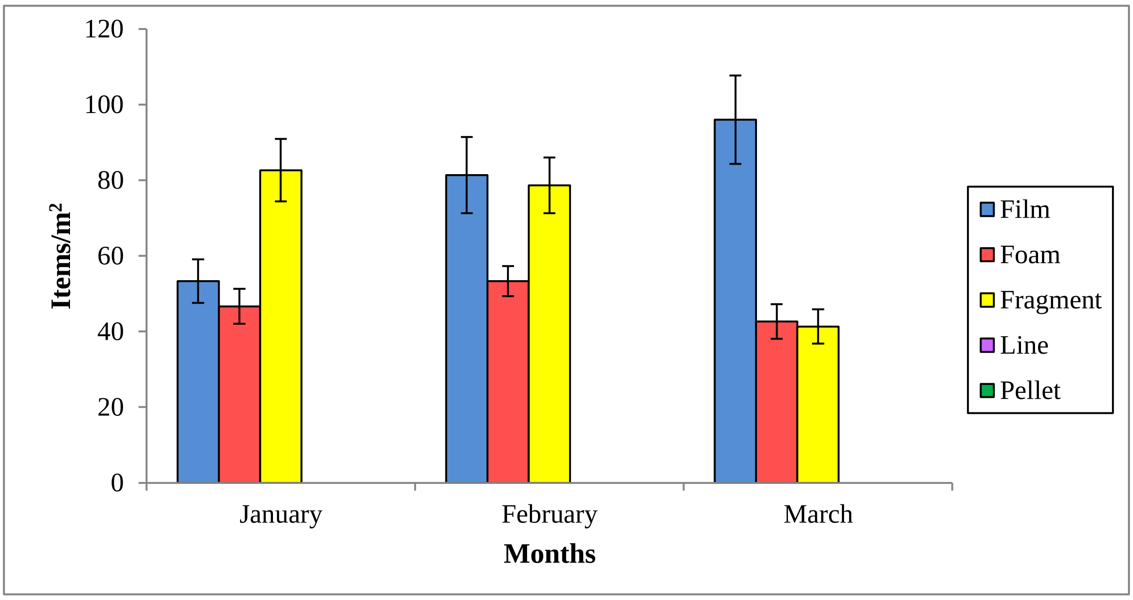

Figure 4.36: Quantity of small plastic debris according to classification at the Tanjung Aru Beach. (ANOVA: P>0.05).

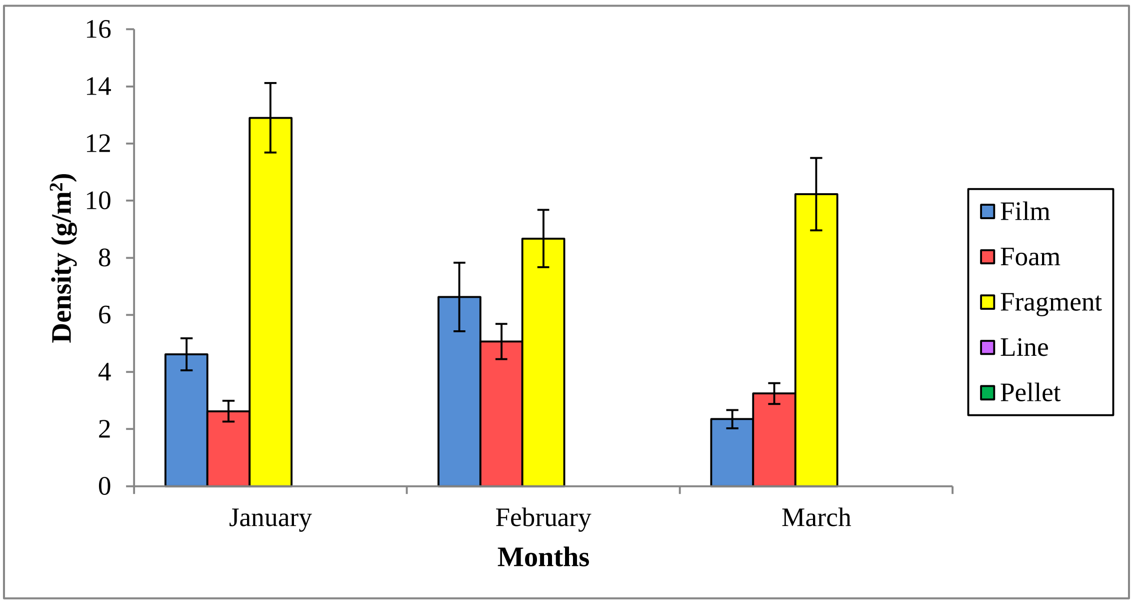

Figure 4.37: Density of small plastic debris according to classification at the Tanjung Aru Beach. (ANOVA: P>0.05).

Of the five types of small plastic, only film, foam and fragment are present in TAB. The quantity ranged at 53 – 96 items/m^2 (film), 43 – 53 items/m^2 (foam) and 41 – 83 items/m^2 (fragment). By weight, fragment was the highest (8.67 – 12.90 g/m^2), followed by film and foam at 2.35 – 6.63 g/m^2 and 2.62 – 5.07 g/m^2, respectively.

Thin plastics film such as those used as candy wrappers and sandwich bags may have been discarded by beachgoers and subsequently undergone some form of degradation. Discarded polystyrene food container also had resulted to the abundant foam pieces found in TAB. It has been reported that plastics film and foam related to fast-food operations were the most common sorts of debris found on beaches (Allsopp *et al.*, 2006). These types of plastics appeared to be sourced from shoreline and recreational activity such as general littering or beach-picnicking (UNEP, 2002).

Besides the recreational activity, plastic debris found in TAB can be attributed to land-based runoff. There are a few storm-drains located along TAB that carry solid waste, mostly plastic articles from inland especially restaurants and hotels nearby seaward. Then, because of weathering, photochemical or physical (wind, waves and sand abrasion) reactions, degradation of the stranded plastics apparently become embrittled which lead to the fragmentation. Costa *et al.* (2009) has reported similar finding. Some of the fragments are washed away to the sea by waves while some of it got buried and accumulated in the beach sands (Kusui and Noda, 2003).

4.4.1(c) Abundance of Small Plastic Debris according to Tidal Zone

Figure 4.38 illustrates the quantity of small plastic debris (items/m^2) accumulated at low tide, high tide and berm, while Figure 4.39 illustrates the corresponding density (g/m^2) of the debris in the study area.

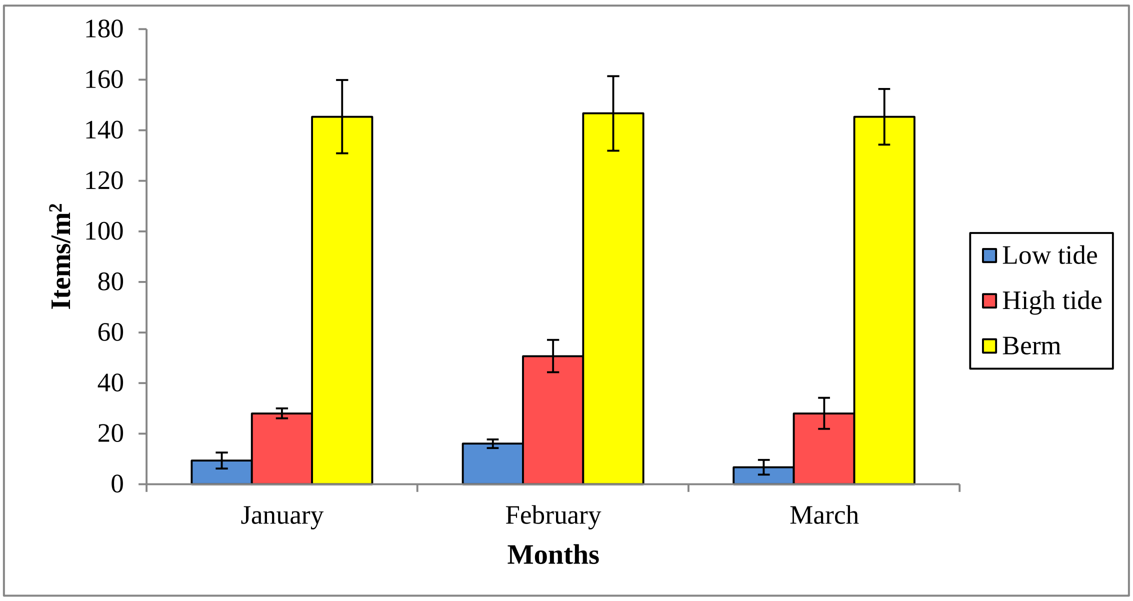

Figure 4.38: Quantity of small plastic debris according to tidal zone at the Tanjung Aru Beach. (ANOVA: P>0.05).

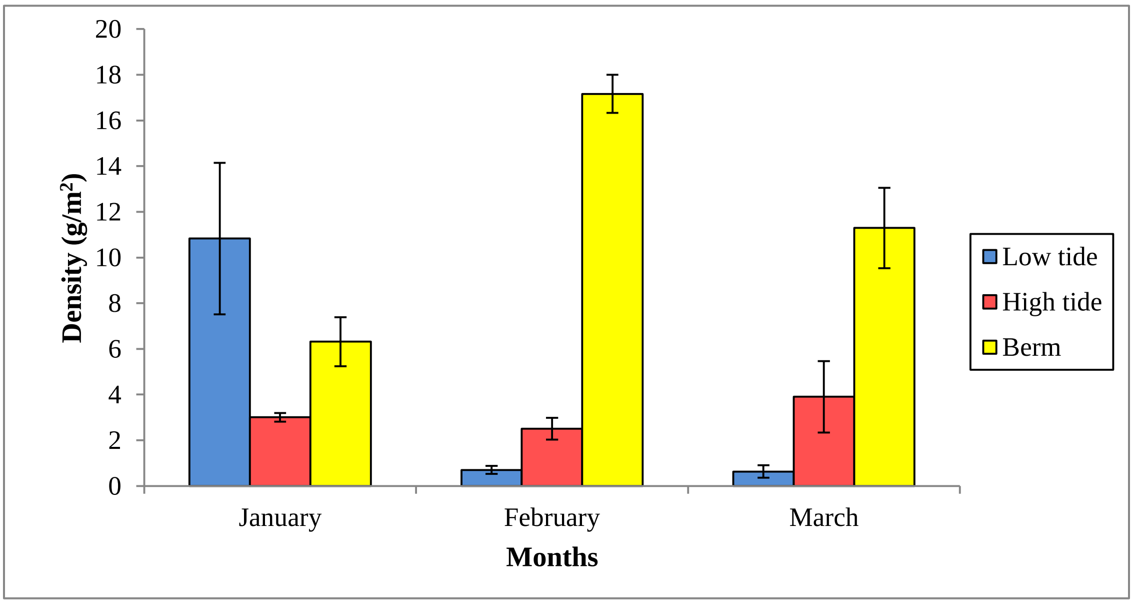

Figure 4.39: Density of small plastic debris according to tidal zone at the Tanjung Aru Beach. (ANOVA: P>0.05).

Accumulation of small plastic debris in TAB is the highest along the berm area ranging at 145 – 147 items/m^2, followed by the high tide area and the low tide area with 28 – 51 items/m^2 and 7 – 16 items/m^2, respectively. The berm is often composed of sand, making it the most favourite place for beachgoers. So, the great quantity of small plastic debris along the berm in TAB might be due to the littering of plastics by beach users. Rees and Pond (1995) also had reported similar finding in the beaches of the British Isles.

The results also indicate that the small plastic debris buried along the berm area has the highest density in the second sampling (17.16 g/m^2) and in the third sampling (11.29 g/m^2) compared to that at the high tide and low tide. However, density of plastic at the low tide was the highest in the first sampling (10.83 g/m^2) despite that small quantity of plastic items were collected. This was due to the domination of fragment (heavier debris) that were washed ashore. As expected, heavier debris get easily deposited where wave dominated (Thornton and Jackson, 1998).

At present, the results have shown that small plastic debris in TAB is much less compared to other beaches in this study survey (Appendix 2). However, the increase in numbers of beachgoers and urbanization around TAB in future will create environmental pressure on the marine habitat principally at the tidal zone. Such pressure may affect more on those areas inhabited most extensively by large number of benthic species like small crabs, chitons, bivalve molluscs and dense assemblages of burrowing shrimps (Gregory and Andrady, 2003). A study by Iribarne *et al.* (2000) revealed that burrow architecture by crab (*Chasmagnathus granulata*) enhanced the trapping of small-sized debris (mainly plastics) and indirectly bury debris in the sediments. Barnes *et al.* (2009) also reported that behaviour of hermit crabs that chose plastic debris as shelter instead of shells, has drastically increased. Therefore, the presence of plastics in the trapping burrow at the beach tidal zone may modify the characteristics of the habitat and further expose negative impact to the species. Although this buried plastic found in TAB may not directly affect the aesthetic values, it still has a negative effect on the natural life.

4.4.1(d) Abundance of Small Plastic Debris according to size

Figure 4.40 illustrates the quantity of small plastic debris (items/m^2) according to size at different tidal zones, while Figure 4.41 illustrates the corresponding density (g/m^2) of the debris in the study area.

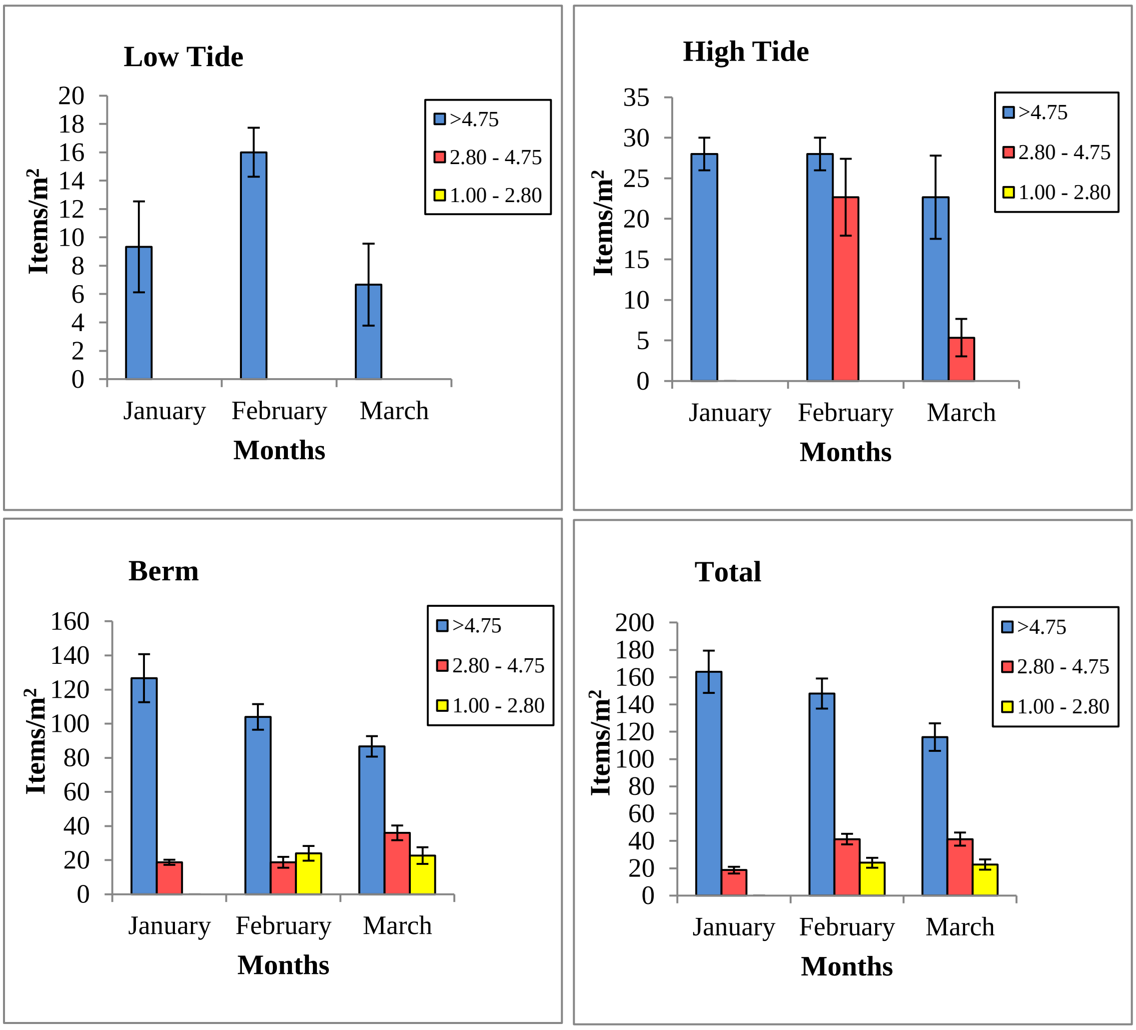

Figure 4.40: Total quantity of small plastic debris according to size range and at different tidal zone at the Tanjung Aru Beach (ANOVA: P>0.05).

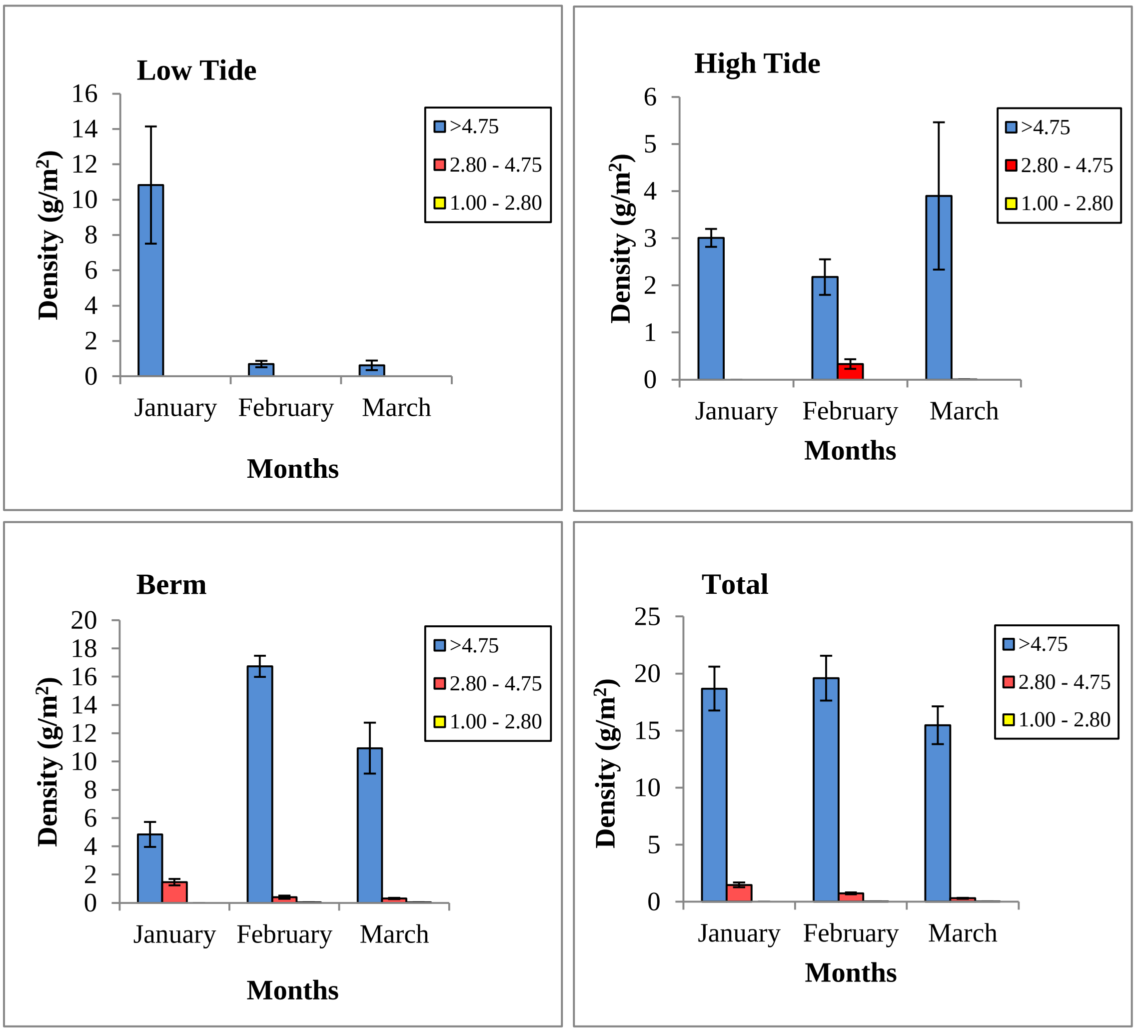

Figure 4.41: Total density of small plastic debris according to size range and at different tidal zone at the Tanjung Aru Beach (ANOVA: P>0.05).

The most abundant small plastic debris along the berm was more than 4.75 mm, followed by debris range of 2.80 - 4.74 mm and 1.00 - 2.80 mm. Meanwhile, plastic debris with range of 1.00 - 2.80 mm was absent at the low tide and high tide shorelines.

The highest number of debris collected is more than 4.75 mm (143 items/m^2) with density averaged at 17.92 g/m^2. Debris with size range from 2.80 - 4.75 mm totalled to 34 items/m^2 with average density of 0.84 g/m^2 while debris with size range 1.00 - 2.80 mm recorded 16 items/m^2 and 0.02 g/m^2 in quantity and density, respectively.

Degradation process is believed to make larger plastic items more brittle to fragment into small plastic debris in TAB. Therefore, this increases the quantity of plastic fragment at various sizes and shapes. Degradation may also reduce the density or molecular mass of plastics. It has been reported that degradation arise due to the weathering, prolonged mechanical abrasion and photochemical breakdown by UV in sunlight which significantly altered or modified the particle-density with exposure (Barnes *et al.*, 2009; Corcoron *et al.*, 2009). The UVB radiations also cause polymers in plastics to brittle proportionally with the hydrolytic properties of seawater and the oxidative properties of the atmosphere (Moore, 2008). This embrittlement makes plastic component get weaker and eventually break into smaller pieces.

The buried plastic debris can impact and disturb the biota of living organisms in the beach sands. There were marked differences of biota in sediment which were smothered by litter and that of litter-free areas in Ambon Bay, Eastern Indonesia (Uneputty and Evans, 1997). The cover of litter eliminates light caused low densities of some macrofauna (nereid and spionid polychaetes) and diatoms whereas meiofauna and some of macrofauna (decapod crustacean and oligochates) were abundant on litter covered area (Uneputty and Evans, 1997). It is not possible yet to estimate the impacts on the sand ecosystems in TAB, but it may be significant.

4.4.2 Teluk Likas Beach, Kota Kinabalu

Teluk Likas Beach (Plate 4.6) is a bay near Likas River. It is situated north of downtown KK which is about 20 km from the city centre. The beach is quite narrow and has very fine, light brownish sand.

Plate 4.6: View of Teluk Likas Beach.

Across the beach is an island occupied by local villagers who live on floating houses. Also, traditional Malay villages consisting of shanty towns and loosely arranged village plots along and around the beach. A small number of the villagers still utilized the traditional fishing method of casting-net close to the beach. There is a port known as Kota Kinabalu port, a few kilometres away from the beach area where ships are loaded with or unloaded of cargos. Locals usually spend their leisure time at the beach while eating at the food stalls along the beach. Due to the presence of anthropogenic activities, this beach also has issues of discarded debris as a result of the recreational and fishing activities taking place.

4.4.2(a) Abundance of Small Plastic Debris

Figure 4.42 shows the quantity of small plastic debris and other debris (plant and shell) collected from Teluk Likas Beach (items/m^2), while Figure 4.43 shows the corresponding density (g/m^2) of these debris in the study area.

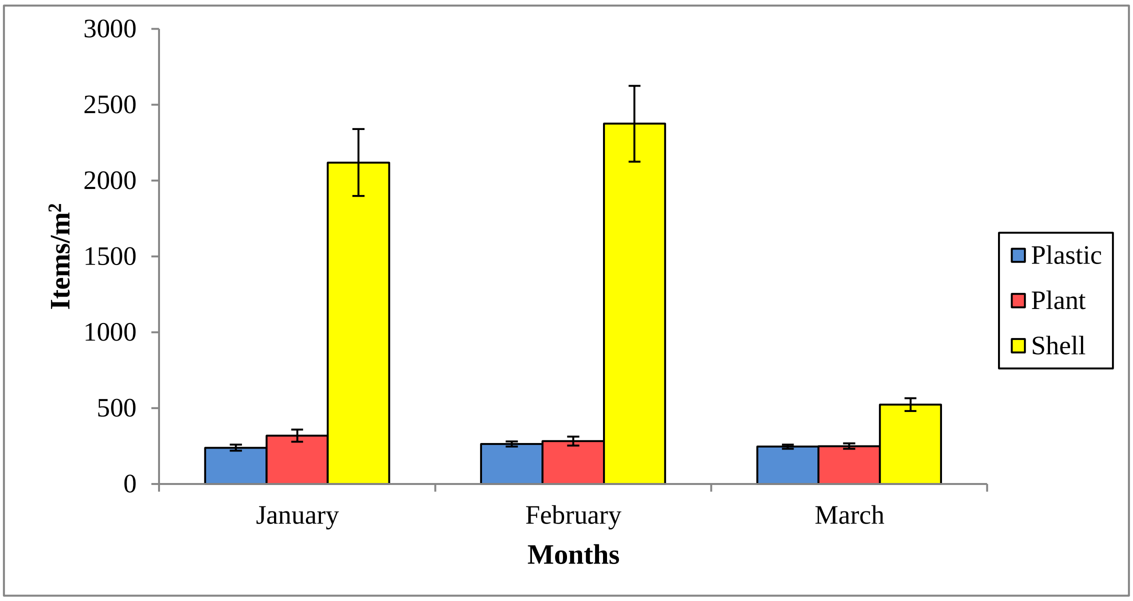

Figure 4.42: Quantity of small plastic debris and other debris at the Teluk Likas Beach. (ANOVA: P>0.05).

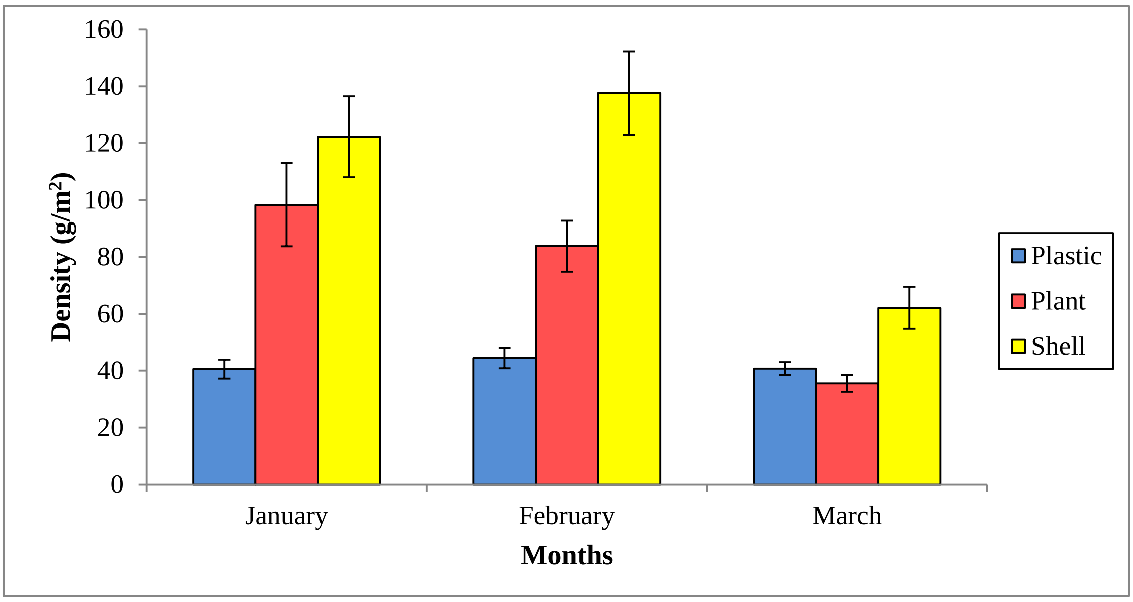

Figure 4.43: Density of small plastic debris and other debris at the Teluk Likas Beach. (ANOVA: P>0.05).

Shell was the most prevalent debris buried in Teluk Likas Beach (TLB) which is found in all sampling events. This is followed by plant debris and plastic particles. The quantity of shell ranged between 523 items/m^2 and 2375 items/m^2 with the density range of 62.11 – 137.59 g/m^2. The quantity of plant ranged from 249 items/m^2 to 319 items/m^2 with corresponding the density from 35.53 – 98.32 g/m^2. Shell debris was the highest in sands as a result of being washed off by the action of waves as shells are carried onshore. Other than that, other materials ranging from boulders to a very fine silt accompanied with plant matters and large quantity of plastic are also available on the beach. Garrison (2005) had reported similar scenario in Niihau beach, one of the Hawaiian islands.

Results indicated that the abundance of plastic is almost similar in all sampling events. The quantity of plastic ranged between 239 items/m^2 and 263 items/m^2 with the density from 40.54 g/m^2 to 44.43 g/m^2. The presence of plastic debris in TLB might possibly be due transport of plastic waste from waterborne sources to the beach. Plastic found in this study may have been generated from the four sources namely; fishing activities, river runoff, waste disposal by islanders, or waste disposal by passing ships at Kota Kinabalu port. It has been reported that marine debris, mostly plastics is known to be derived from onshore sources but high concentrations of plastic debris are found near busy shipping lanes and high fishing activity areas (Clark, 2001).

4.4.2(b) Classification of Small Plastic Debris

Figure 4.44 shows the classification of small plastic debris (items/m^2), while Figure 4.45 shows the corresponding density (g/m^2) of the debris in the study area.

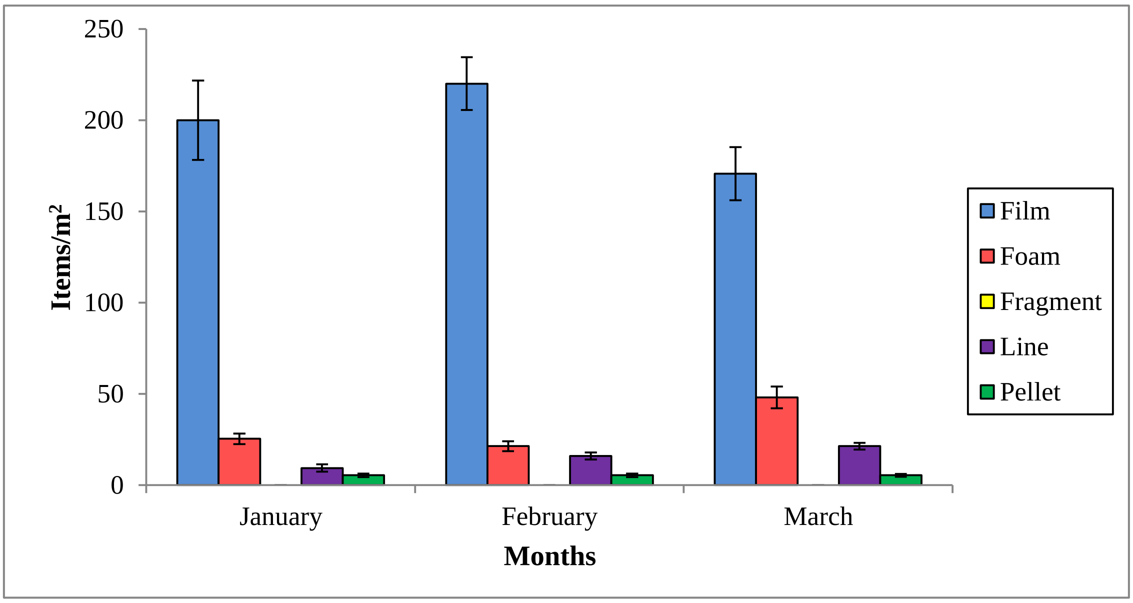

Figure 4.44: Quantity of small plastic debris according to classification at the Teluk Likas Beach. (ANOVA: P>0.05).

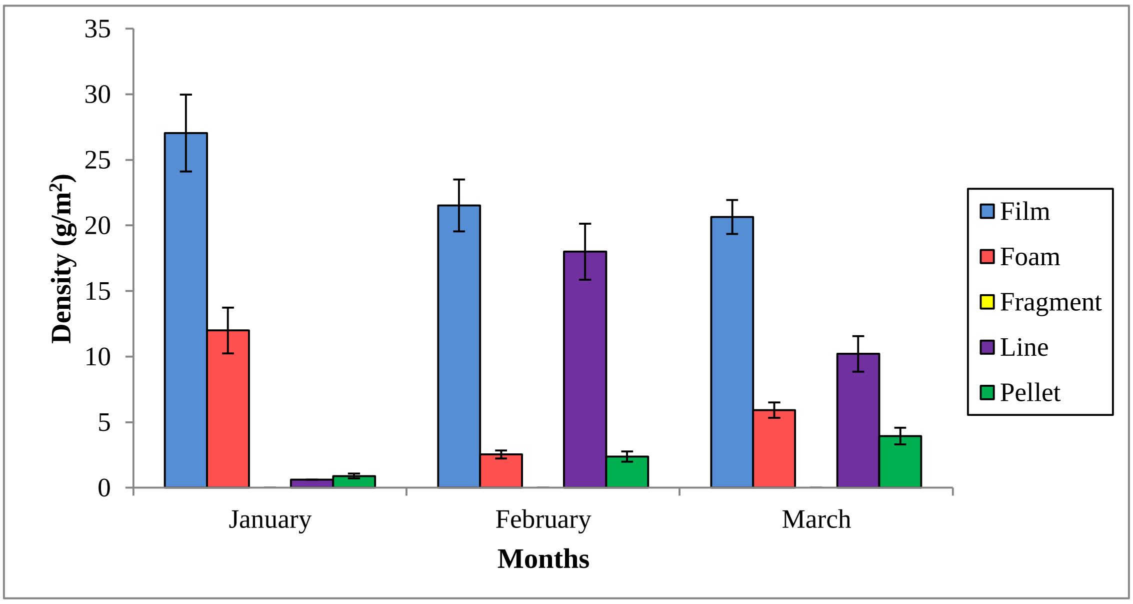

Figure 4.45: Density of small plastic debris according to classification at the Teluk Likas Beach. (ANOVA: P>0.05).

Film was the most dominant type of debris found in TLB, which outnumbered other items (171 – 220 items/m^2 and 20.64 – 27.05 g/m^2). It is followed by foam (21 – 48 items/m^2) and line (9 – 21 items/m^2) with corresponding densities ranging from 2.54 – 11.99 g/m^2 and 0.61 – 18.00 g/m^2, respectively. Pellet only makes up small percentage in TLB (5 items/m^2 and 0.89 g/m^2 – 3.94 g/m^2).

Film was the predominant item and accounted for more than 50% of the total debris collected in TLB. Since the study area is close to the river, runoff of plastics film may have contributed to its abundance. This type of plastic was carried seaward by river, submerged onto the seafloor and in some way deposited on beaches. Spengler and Costa (2008) and, Williams and Simmons (1997) had also reported the similar observation. Plastics film may also come from the ships before being degraded into smaller pieces and cast ashore. It has been previously noted that ships are a major source of plastic debris (Morishige *et al.*, 2007).

As for line and foam found in TLB, these might originate from nearby local villagers that lived at the mainland or opposite island that used nets line or foam buoys for their fishery purpose. For example, lost fishing items derived from frequent fishing activities had been reported to contaminate beaches in Kodiak Island, Alaska (Hess *et al.*, 1999).

Pellet that have been introduced to the oceans, probably lost through accidental spillages from ships. Pellets which are spilled during cargo handling operations at ports or transportation at sea can be directly dispersed by waves and currents, and finally tend to accumulate on beaches (Takada *et al.*, 2010). This might have occurred in TLB as the port is situated near the beach.

4.4.2(c) Abundance of Small Plastic Debris according to Tidal Zone

Figure 4.46 presents the quantity of small plastic debris (items/m^2) in the beach tidal zones which was at low tide, high tide and berm. Also, Figure 4.47 presents the corresponding density (g/m^2) of the debris in the study area.

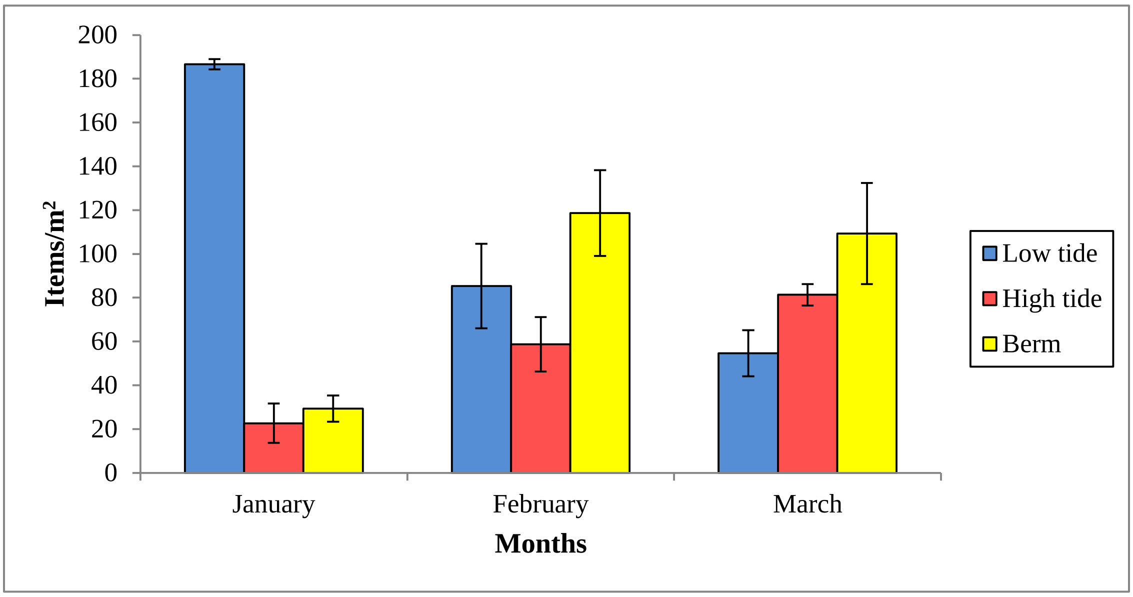

Figure 4.46: Quantity of small plastic debris according to tidal zone at the Teluk Likas Beach. (ANOVA: P>0.05).

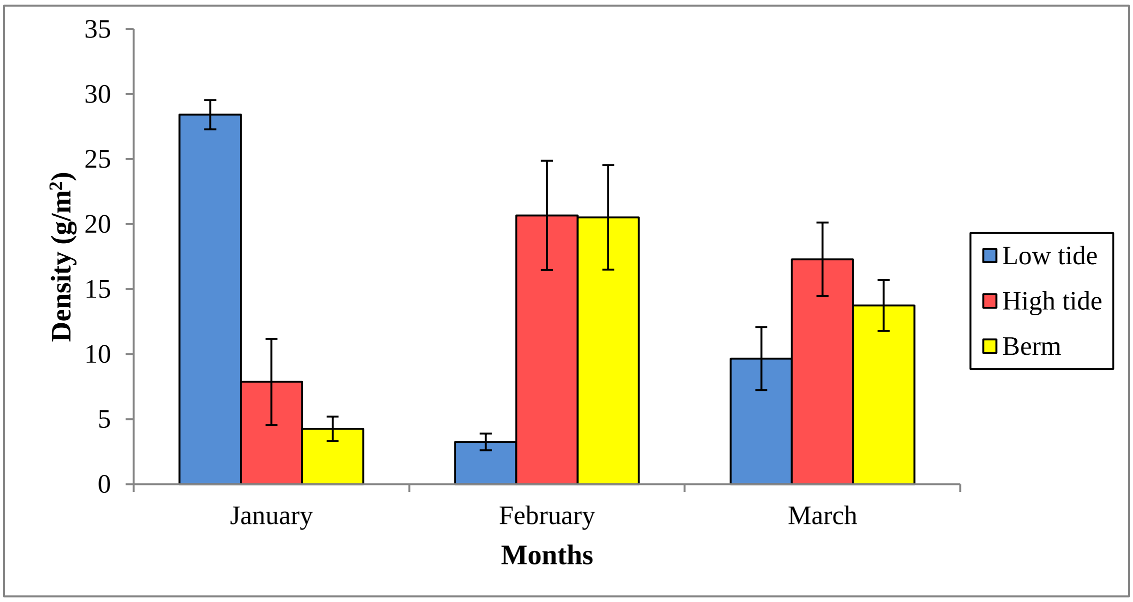

Figure 4.47: Density of small plastic debris according to tidal zone at the Teluk Likas Beach. (ANOVA: P>0.05).

In the first sampling event, low tide shoreline in TLB had the highest abundance of plastic debris (187 items/m^2) with the density of 28.42 g/m^2. In the next sampling events, however, the highest abundance of plastic buried was at the berm (109 – 119 items/m^2 and 13.75 – 20.51 g/m^2). This could be a result of waves and action of winds which distribute plastic debris at different tidal zones. Seaborne plastic debris accumulated on beaches concentrate at the low tide zone where movement of debris will be reduced once trapped in the sands. It was reported that with strong wave surges, these plastic debris will be removed to higher places (Thornton and Jackson, 1998). This situation is believed to occur in the first sampling itself. Plastic debris was removed from the low tide and high tide sands to the berm area probably due to greater wave movement while in the second and third sampling events, lightweight debris (e.g. film and foam) which are abundant in the study area may also be transported by wind onto berm area before being buried in the sands. This situation has also been reported by Ryan *et al.* (2009) and Ross *et al.* (1991).

The difference in composition and density of small-buried plastic at different tidal zones in TLB might also interfere with the normal ecosystem functioning of beach sands. The trapping of plastics coated by shells and sands may inhibit gas exchange which subsequently induced hypoxia and anoxia in the benthos as reported in the seabed sediment at Tokyo Bay (Kanehiro *et al.*, 2005; Derraik, 2002). Similarly, the presence of plastic debris in TLB can alter the chemical and biological function in the sands. In TLB, the most affected could be the berm area where plastic debris is the most abundant.

4.4.2(d) Abundance of Small Plastic Debris according to size

Figure 4.48 illustrates the quantity of small plastic debris (items/m^2) according to size at different tidal zones, while Figure 4.49 illustrates the corresponding density (g/m^2) of the debris in the study area.

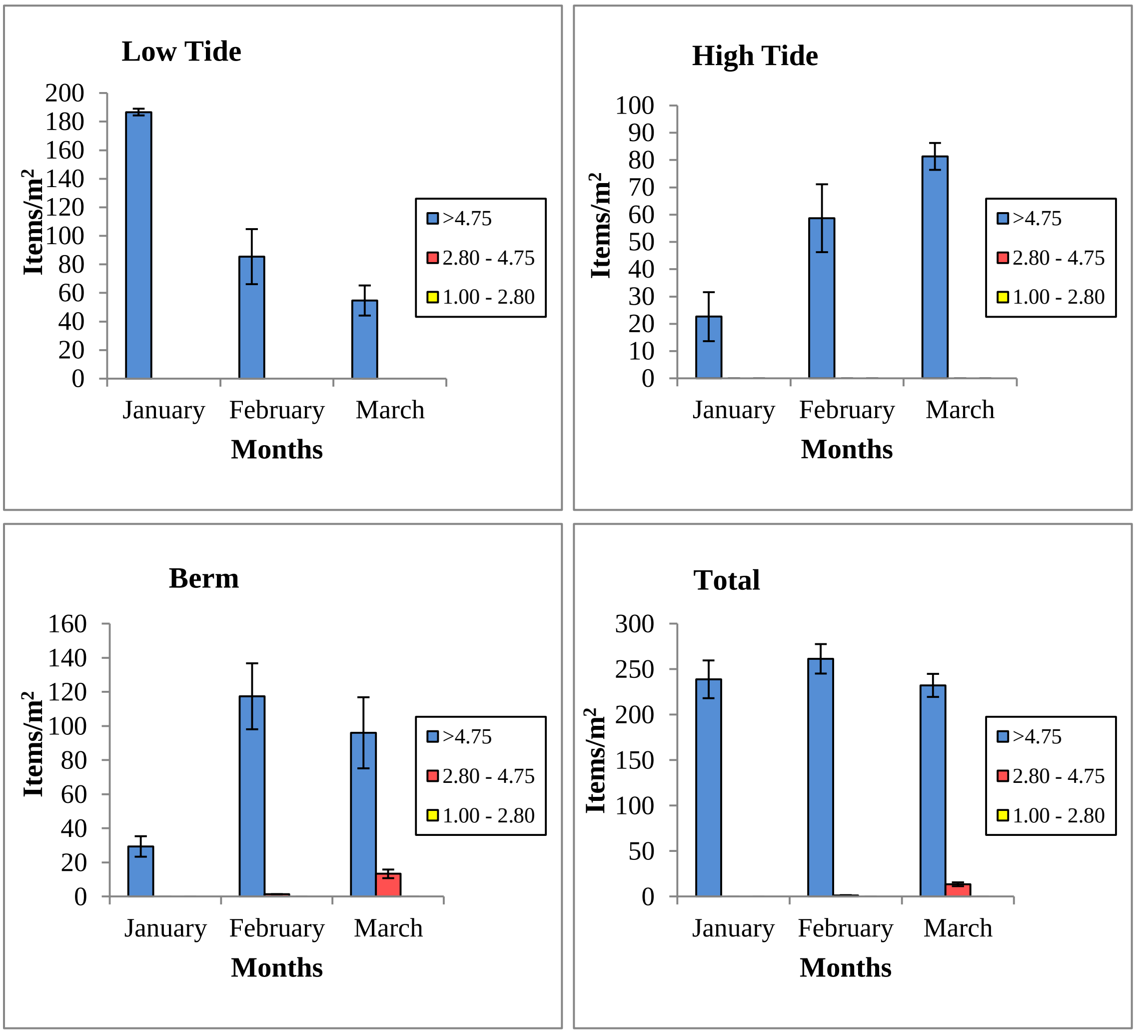

Figure 4.48: Total quantity of small plastic debris according to size range and at different tidal zone at the Teluk Likas Beach (ANOVA: P>0.05).

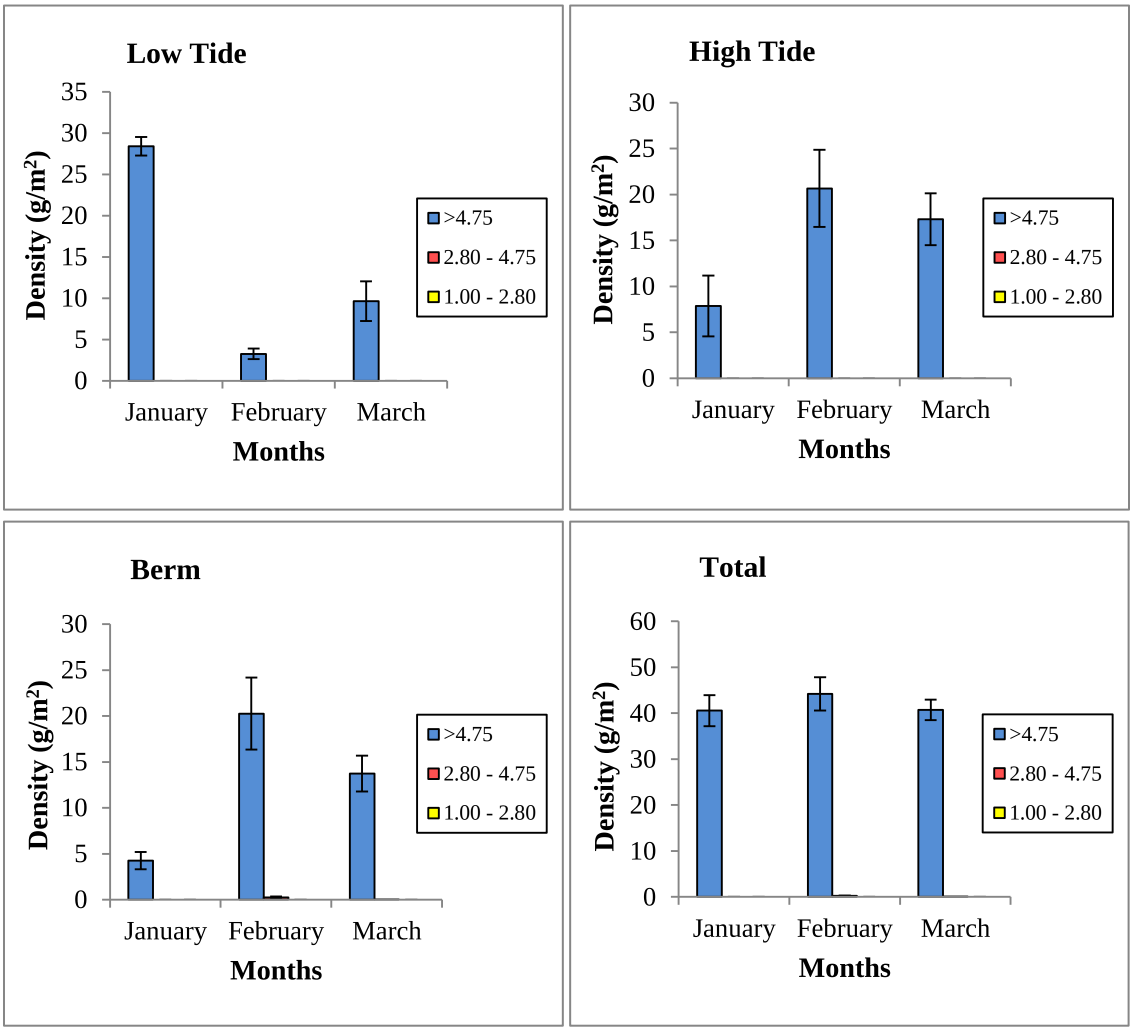

Figure 4.49: Total density of small plastic debris according to size range and at different tidal zone at the Teluk Likas Beach (ANOVA: P>0.05).

From the results, low tide and high tide shoreline in TLB recorded only plastic debris which exceeded 4.75 mm. At the berm, debris exceeding 4.75 mm was the most abundant, before by those that measured 2.80 - 4.75 mm.

In overall, the total number of small plastic debris in TLB which exceeded 4.75 mm was 244 items/m^2 with average density of 41.81 g/m^2. Debris with size range of 2.80 - 4.75 mm was only 5 items/m^2 with density of 0.08 g/m^2.

The existence of these small plastic particles in TLB is probably caused by plastic degradation process. This might be due to the similar mechanisms as in TAB. With the advent and introduction of rapidly-biodegradable plastic and enhanced-photodegradable plastic such as modern polylactic acid (PLA) and polyhydroxyalkanoate (PHA), it can be a mitigation strategy to solve the problems caused by persistent plastics debris. This fact has been supported by Moore (2008). But, this effort will be useless if the existence of plastics is continuously prevalent in marine realm as occurred in TLB. Nevertheless, the right pathways to decrease the plastic debris impacts are through public education, and stringent legislation to control the disposal of plastics into the marine environment.

4.4.3 Comparison between Tanjung Aru and Teluk Likas Beaches

From the study it was found that the types of plastic debris varied at each beach, reflecting the different activities taking place in the area. The small plastic debris in TLB had an average of 249 items/m^2 including line (fishing line) and film (plastic bags). TAB represents the recreational beach that generates less debris at an average of 192 items/m^2. This finding indicates that even though there is a periodic clean-up of the beaches conducted by the local municipality, plastic debris still exists on beach. Therefore, it is necessary that educational activities be encouraged to increase awareness, as well as, more trash bins should be placed to reduce beach contamination.

There was no pollution of plastic pellets in TAB while in TLB there are pellets in almost all the sampling events. This is not surprising because pellets may easily escape if a container is mishandled at the port or lost overboard during ship transportation; hence these pellets float with currents to the shore (Garrison, 2005). This situation might have occurred in TLB as the beach area is near the Kota Kinabalu port. However, abundance of pellets as high as 10 items/m^2 to 316 items/m^2 were also collected even at remote non-industrialized beaches in the South Pacific areas (Gregory, 1999). Hence, plastic pellets can act as a good indicator of an increasing plastic debris pollution if found in non-industrialized area like TAB.

The abundance of small-sized plastic debris in TAB and TLB may affect the marine species that colonize different tidal zones of the beach area. This is because, a variety of motile invertebrate predators and grazers which occupy in the beach sands and water edge during the low tide such as amphipods, echinoderms, gastropods polychaete worms and crabs have the tendency to use these plastics for protection, shelter and feeding or just simply due to curiosity (Costa *et al.*, 2009; Gregory and Andrady, 2003). So, attentions are needed as plastics debris posed potential adverse impacts to the marine species, as well as, disturbing their ecological niches.

4.5 CORRELATION BETWEEN QUANTITY OF SMALL PLASTIC DEBRIS AND MONTHLY RAINFALL

Table 4.1 shows the amount of monthly rainfall (mm) recorded from January 2010 till March 2010. The inquiry of monthly rainfall data was recorded by Malaysian Meteorological Department at three receiving stations namely Atherton Estate in Port Dickson (2º33’N, 101º55’E), Kuala Terengganu Airport in Kuala Terengganu (5º23’N, 103º06’E) and Kota Kinabalu Airport in Kota Kinabalu (5º56’N, 116º03’E). Table 4.2 shows the quantity of small plastic debris collected in all six beaches from the three sampling events.

Table 4.1: Records of monthly rainfall amount (mm) in January, February and March 2010 at three different stations.

Station / Month	January 2010 (mm)	February 2010 (mm)	March 2010 (mm)
Atherton Estate, Port Dickson	65.0	23.6	176.8
Kuala Terengganu Airport, Kuala Terengganu	203.4	148.6	18.2
Kota Kinabalu Airport, Kota Kinabalu	211.0	0.4	27.6

Table 4.2: Quantity of small plastic debris (items/m^2) in January, February and March 2010 in all six beaches.

Sampling sites / Month	January 2010 (items/m^2)	February 2010 (items/m^2)	March 2010 (items/m^2)
Teluk Kemang Beach, Port Dickson.	219	244	229
Pasir Panjang Beach, Port Dickson.	228	227	179
Batu Burok Beach, Kuala Terengganu.	1064	888	388
Seberang Takir Beach, Kuala Terengganu.	1164	944	528
Tanjung Aru Beach, Kota Kinabalu.	183	213	180
Teluk Likas Beach, Kota Kinabalu.	239	263	245

As seen in Table 4.1, the amount of rainfalls at each station in PD, KT and KK was irregular for every month. This is because the distribution of rainfall in Malaysia was influenced by several factors including monsoon season, topography of the area, morphology changes in the area and more. From Table 4.2, each beach in this study showed different distribution in amount of plastics debris which are based on the function of each beach. The correlation between the quantities of small plastic debris (items/m^2) in Kuala Terengganu (BBB and STB) with the monthly rainfall (mm) is illustrated in Figure 4.50.

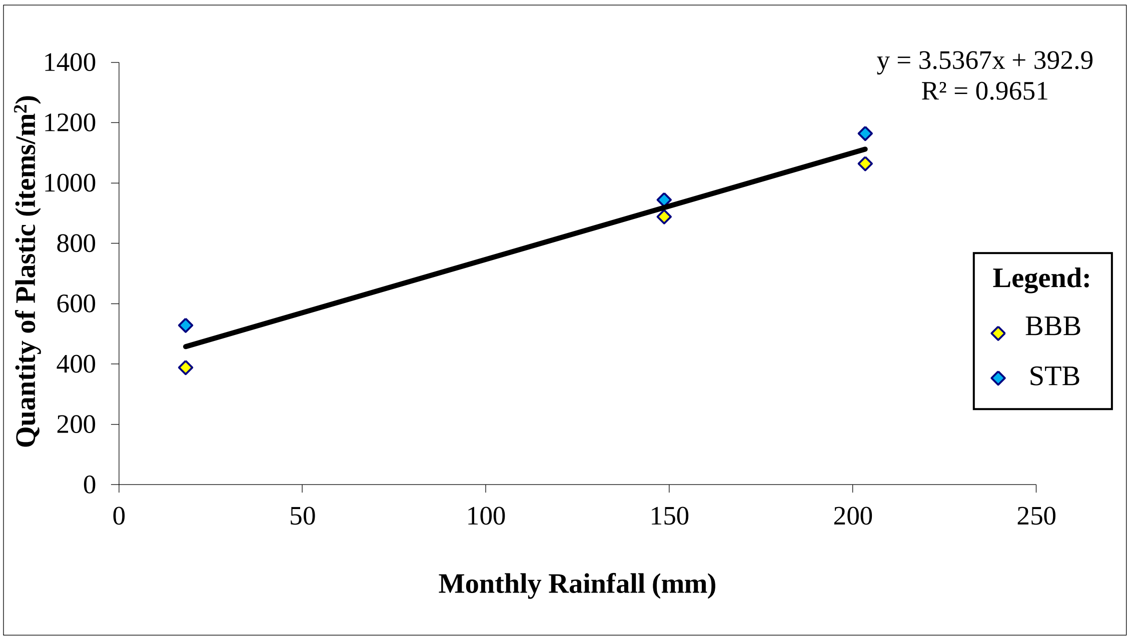

Figure 4.50: Correlation between quantity of plastic in Kuala Terengganu (BBB and STB) and monthly rainfall.

Based on the results, the quantity of plastic items in KT (BBB and STB) with monthly rainfall is positively correlated (0.9824) with R^2 = 0.9651. This signifies that higher rainfall in KT resulted with higher quantity of plastic and vice versa. According to Silva-Cavalcanti *et al.* (2009), Golik and Gertner (1992), Vauk and Schrey (1987), the number of debris deposited on beaches increase after rain events and storms. This is because the beaches in KT are affected by North-Eastern monsoon that brings heavy rainfall, flood and strong waves which may have contributed to the accumulation and deposition of plastic debris ashore. According to Frost and Cullen (1997), the effect of climatic factors with the occurrence of tropical cyclones (usually with heavy rainfall) accompanied by flooding is associated with the greater amount of beach debris distribution.

Moreover, water from land runoff which contained plastic fragment generated during heavy rain events in KT may be collected by storm drains and directly discharged into the sea. These plastic wastes from storm drains can be washed straight into the ocean or deposited on beaches (Allsopp *et al.*, 2006). Once deposited on the beaches, small plastics fragment suffers continuous fragmentation before being buried in sands (Ivar do Sul *et al.*, 2009). Thus, the abundance of small plastic debris present in KT beaches depend on the occurrence of heavy rainfall during monsoon besides the contribution of plastic debris from the beach activity there. Meanwhile, the source of plastic debris in PD and KK beaches were believed to be sourced from the usage of beach and did not depend on the amount of rainfall.

4.6 COMPARATIVE STUDY OF THE BEACHES

Figure 4.51 shows the total quantity of small plastic debris which were collected from all sampling sites (items/m^2), while Figure 4.52 shows the corresponding density (g/m^2) of these debris in the study area.

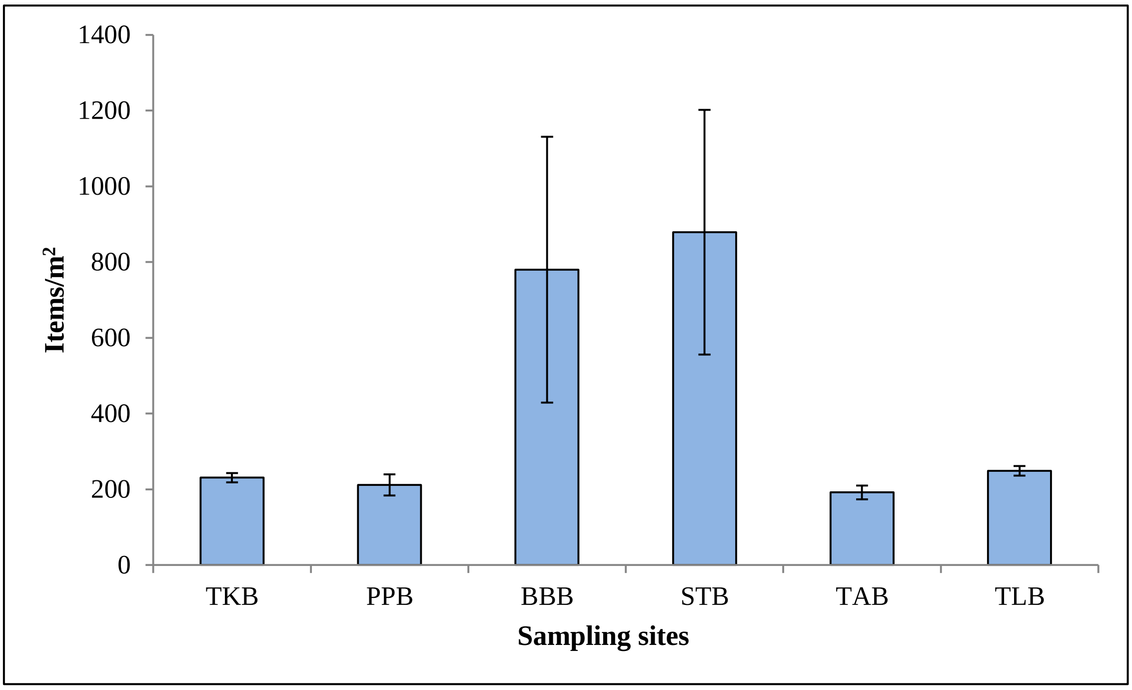

Figure 4.51: Total quantity of small plastic debris collected at each beach/sampling site.

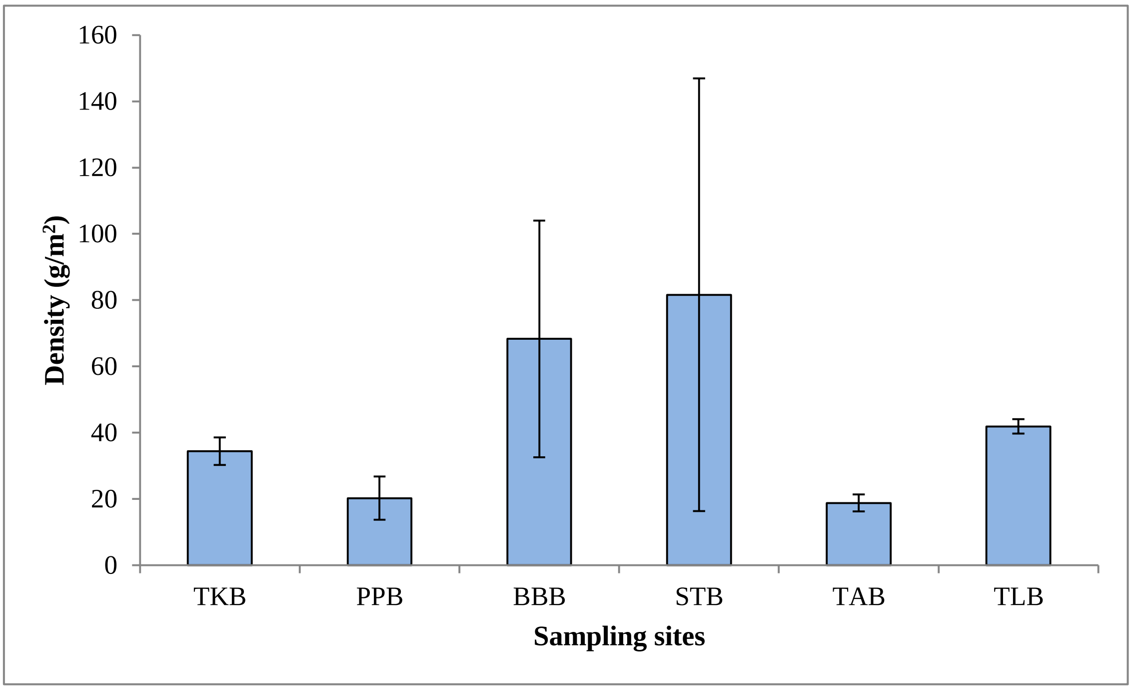

Figure 4.52: Total density of small plastic debris collected at each beach/sampling site.

Measureable quantity of small plastics debris were found in every sampling site with a total of 2,542 pieces and density sum of 265.30 g/m^2 (Appendix 10). The greatest abundance of small plastic debris occurred in KT beaches which were in STB and BBB.

STB had 879 items/m^2 (35%) of plastic pieces with a density of 81.62 g/m^2 (30%). While BBB had 780 items/m^2 (31%) and 68.31 g/m^2 (26%). Fishing activity in STB and recreational activity in BBB might have contributed to the abundance of plastic debris besides the heavy rainfall during monsoon season which enhanced the deposition of plastic in the beach sands.

This is followed by TLB in KK where the buried small plastic debris in the study area was 249 items/m^2 and a density of 41.89 g/m^2 giving a total percentage of 10% and 16%, respectively. The majority of buried plastic debris accumulated in TLB is a result of many points of entry such as fishing activities, river runoff, shipping routes and waste disposal by islanders.

The diminution of plastic debris is then followed by the beaches in PD namely TKB and PPB. Based on the quantity of plastic debris, TKB had 231 items/m^2 (9%) while PPB was 211 items/m^2 (8%). In terms of density, TKB and PPB were 34.44 g/m^2 (13%) and 20.26 g/m^2 (8%), respectively. The frequent usage of plastic due to the current lifestyle, culture of convenience and durability for many purposes such as for recreational in TKB and fishing activity in PPB resulted in a significant rise in plastics pollution which then posed negative impact to the marine environment.

The least quantity of plastic debris was in TAB in KK with only 192 items/m^2 (7%) and density of 18.78 g/m^2 (7%). Despite the beach-cleaning regimes being conducted in TAB, plastic debris still get accumulated on the beach. Thus, increased awareness and stringent legislations are necessary to reduce beach contamination.

4.7 GENERAL DISCUSSION

Beach management has continued to attract considerable concern due to activities with which it is often associated with such as picnicking. The impact of some activities may pose a threat to beach environment hence the need to investigate the deposition of plastic debris on selected Malaysian beaches (TKB, PPB, BBB, STB, TAB and TLB). This study confirms that the beaches in Malaysia were fouled with abundance of small plastic debris buried in the sands.

The presence of 2,542 pieces (265.30 g/m^2) of plastic debris within the studied beaches is similar to the results reported by McDermid and McMullen (2004) at 9 beaches throughout the Hawaiian archipelago, which recorded 19,100 pieces of plastic debris. However, the contrasting aspect is that the Hawaiian plastic debris were found only on remote Hawaiian beaches that lack dense human population or shipping traffic, while for Malaysian beaches the active beaches which were polluted. This could be due to the fact that most beaches are points of entry into some urban areas or serve as shipping routes. Plastics debris on the Hawaiian archipelago probably originated from exogenous sources and were possibly transported by ocean central gyre, winds and sea currents before washed ashore (Allsopp *et al.*, 2006; Sheavly, 2005; McDermid and McMullen, 2004; Moore *et al.*, 2001b; Corbin and Singh, 1993). The distribution of plastic debris on Malaysian beaches could be attributed to heavy anthropogenic activities (mostly fishing and recreation).

Findings from Malaysian beaches indicated that beach activities are contributing to the plastic debris deposition. Though no similar study is available to support or disagree with this finding, the distribution of different plastic types (581 $items/m^2$ of film in recreational area and 602 items/m^2 of line in fishing area) within the studied beaches showed that beach activity influenced plastic debris distribution.

Generally, there are various sizes of plastic debris buried in Malaysian beaches. It ranged from 1 – 30 mm for all plastic types, which are agreeable with results obtained in beaches around the world (Silva-Cavalcanti *et al.*, 2009; McDermid and McMullen, 2004). Table 4.3 shows the worldwide distribution of small plastic debris. Findings from studies of Malaysian beaches have provided a clearer understanding on the presence of plastic debris. It is rather crucial and if it is prolonged, it could cause adverse environmental impact. Therefore, commitments and efforts such as improving solid waste management practices through the 'reduce, reuse, recycle' approach (3Rs), as well as, supporting public awareness programmes and beach clean-up activities are essential in order to reduce or prevent plastic debris pollution (Agamuthu and Fauziah, 2011; Barnes *et al.*, 2009; Ryan *et al.*, 2009; UNEP, 2009).

Table 4.3: The worldwide distribution of small plastic debris.

Size (mm)	Habitat/sampling site	Reference
4 to 6	Beaches in New Zealand	Gregory (1977)
1 to 5	Beaches in Canada and Bermuda	Gregory (1983)
2 to 5	Western North Atlantic Ocean	Wilber (1987)
2 to 5	Faeces of fur seals in Macquarie Island	Erikson and Burton (2003)
<1 to > 10	Japanese and Russian beaches, Sea of Japan	Kusui and Noda (2003)
1 to 15	Beaches in Hawaii	McDermid and McMullen (2004)

Table 4.3. (continued)

Size (mm)	Habitat/sampling site	Reference
~ 2	Beaches, coastal sediments, and invertebrates in UK	Thompson *et al.* (2004)
>0.16	Beaches and coastal waters in Singapore	Ng and Obbard (2006)
2 to 20	Beaches, Fernando de Noronha	Ivar do Sul *et al.* (2009)
2 to 5	Archipelago, Equatorial Atlantic	Ivar do Sul *et al*. (2009)
1 to 20	Boa Viagem beach in Brazil	Silva-Cavalcanti *et al.* (2009)
1 to 30	Beaches in Malaysia	This report