CHAPTER 2

LITERATURE REVIEW

2.1 MARINE ENVIRONMENT

Marine environment predominantly covered 71% or two-thirds of the earth leaving only 29% of the total surface to the continental land-masses, thus playing a very important role in the earth system (Duxbury *et al.*, 2000; Moorcraft, 1972). The marine environment is divided into two distinct realms as shown in Figure 2.1. The division is based on the characterised ecological features, the associated plants and animals known as a pelagic region and a benthic region representing the water mass and the floor of the ocean, respectively (Duxbury *et al.*, 2002; Stowe, 1979; Duxbury, 1971).

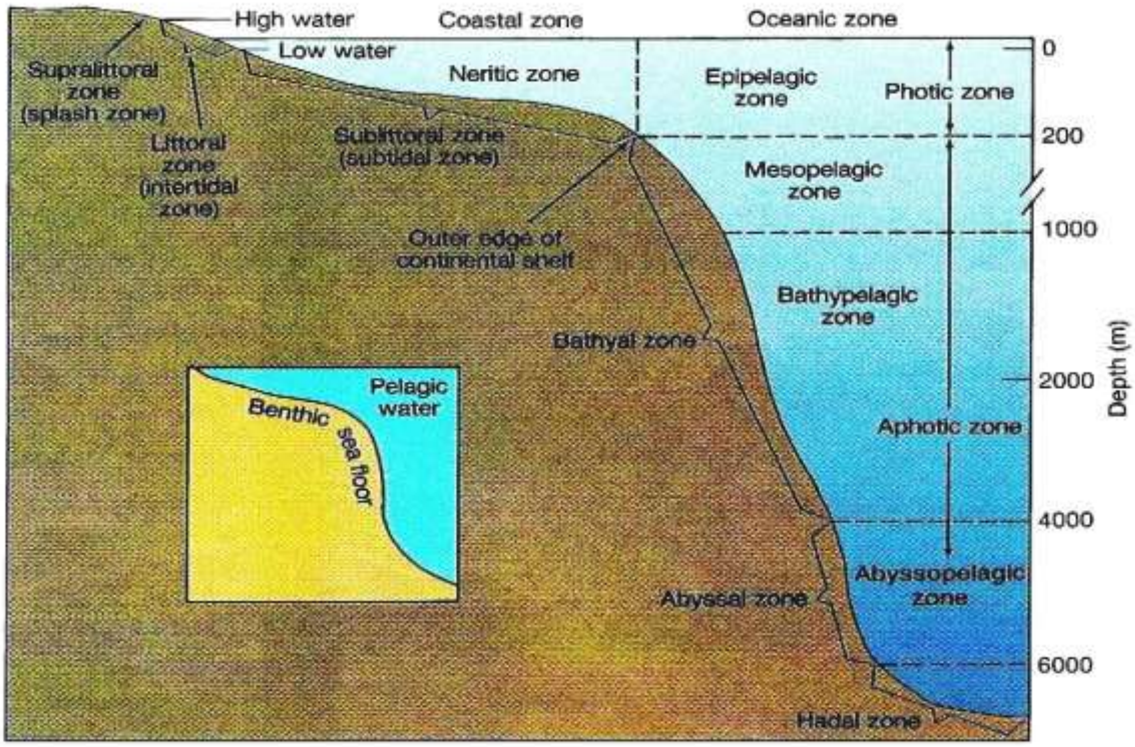


Figure 2.1: The classification of the pelagic and benthic marine environment (Duxbury *et al*., 2002).

Marine environment allowed the occurrence of many interactions of physical properties and chemical energy between ocean and atmosphere which affect the climate, weather and also abundance of dissolved gases in the sea namely nitrogen, carbon dioxide, oxygen and hydrogen sulphide (Thurman and Trujillo, 2004).

Marine environment make up the largest water reservoir of the world. It is functionally essential in the process of moisture exchange between earth and atmosphere that controls the circulation of water in the hydrological cycle through evaporation and precipitation (Duxbury, 1971). Similarly, this cycle also modify and manage the temperature of the earth by heating and cooling. The world's ocean is described as the 'global thermostat' responsible in the energy balance of the earth (Duxbury *et al.*, 2000; Moorcraft, 1972; Weyl, 1970). Thus, this unique thermal property provides suitable living environment for bewildering array of life-forms.

Marine environment has greater surface of defined area or ecosystem to support the variety of marine biodiversity. There are 275,000 marine flora and fauna species which ranges from microscopic phytoplankton, single-celled organisms to the largest fish, the whales, that yet the total number of species in the marine is unknown (Duxbury *et al.*, 2002). Variations in temperature, dissolved gases, substrate, nutrients, light, pressure and salinity affect the development of life in the sea (Garrison, 2005; Weisberg and Parish, 1974). Furthermore, marine environment is a vast area which consists of physical, geological, chemical and biological factors with distinct structure of different ecosystems such as open ocean waters, seamounts, deep sea floor, cold seeps, hydrothermal vents, coral reefs, and coastal that controls the distribution of the biota and upholds diversity of marine life (Duxbury *et al.*, 2002; Weyl, 1970).

As far as human-being is concerned, coastal area is probably the most important part of the marine environment. It has true significance to mankind. Even though coastal zone is only a small fraction of the marine world (12.5% of the earth's surface and only about 4% of the ocean's volume), it is a highly productive zone which supply enormous amount of protein source such as crustaceans, molluscs and fish (Mann, 2000; Gross, 1967). This enables to satisfy nutritional needs of the world's 6.1 billion people (Garrison, 2005). Over 90% of fishing products came from areas within the coastal (Ross, 1978). In fact, fishing industry is a big business that had employed more than 15 million people worldwide (Garrison, 2005; Mann, 2000). Moreover, coastal zone also provided valuable marine mineral resources such as petroleum and natural gas which can be found buried or lying within the sediments of the continental shelf that gave significant contribution to current world needs (Thurman and Trujillo, 2004; Ross, 1978).

Actually, coastal zone is the region of continents composed of soft, unconsolidated materials such as sand (Baretta-Bekker *et al.*, 1998). It used to describe those land edges that border the sea including bays, cliffs, coves, fjords, deltas, salt marshes, mangrove swamps, river mouths, as well as, shores where the width of the coast varies (Baretta-Bekker *et al.*, 1998). This is determined by local geography, vegetation, climate change or change in sea level over geologic time and some remnants of these changes can still be seen in present coastlines (Sverdrup and Armbrust, 2009). The coastal zone extends from the edge of the continental shelf to the limits of geologically recent marine influence (Beer, 1983). The most familiar feature of a depositional coast is a beach. According to Garrison (2005), the beach is a zone of loose particles that covers part or all of a shore where the landward limit of a beach may be vegetated, scattered with permanent sand dunes where drift logs are left.

2.1.1 Beach Profile

Beach is defined by the presence of an accumulation of sediment (sand, gravel and shells). It mainly occurs in the intertidal zone, between land and sea which is influenced by marine processes such as winds, waves, tides and an intermittent extreme storm conditions (Sverdrup and Armbrust, 2009). Weisberg and Parish (1974) mentioned that beaches are composed mainly of sediments namely sand. It is based on the Wentworth scale (Appendix 1). The colour and composition of beach sand vary from one part of the world to another.

The beach is a moving, changing and dynamic system. Indeed no two beaches are exactly identical. The beach sediments are constantly being moved landward, seaward and along the shore by nearshore wave and tidal currents action which primarily alter the shape and configuration of the beach (Sverdrup and Armbrust, 2009). Within the beach province, in the foreshore are the low tide and high tide water level which is influenced by wave action and continual rise and fall of the seawater (Sverdrup and Armbrust, 2009). Meanwhile, a flat area known as a berm which has flat tops like the top of a terrace often appear at the foot of cliffs or dunes in the backshore area (dry region) (Duxbury *et al.*, 2002). It submerged only during the highest tides or severest storms (Trujillo and Thurman, 2005).

Scarp is an abrupt change in the beach slope formed by the erosional action of waves at the normal high-tide (Duxbury *et al.*, 2000). Usually, a small ridge or the berm crest and the berm formed upslope from the scarp (Duxbury *et al.*, 2000). The almost featureless section of the beach is the sloping beach face that lies between the lower scarp and the lower-water mark due to constant reworking of its material by moving water (Duxbury *et al.*, 2002). From the beach features, it had been shown that the band of beach alternately covered and uncovered by tidal action, allowing the sediment interaction with waves and the range of tide. Nevertheless, wind also became the factor that controls the beach. Some beaches lose sand due to wind that drives it inland, others gained sand from interior desert regions (Duxbury, 1971). Figure 2.2 depicts the profile of a beach region. It can be noted that not all features shown are likely to be found on a single beach.

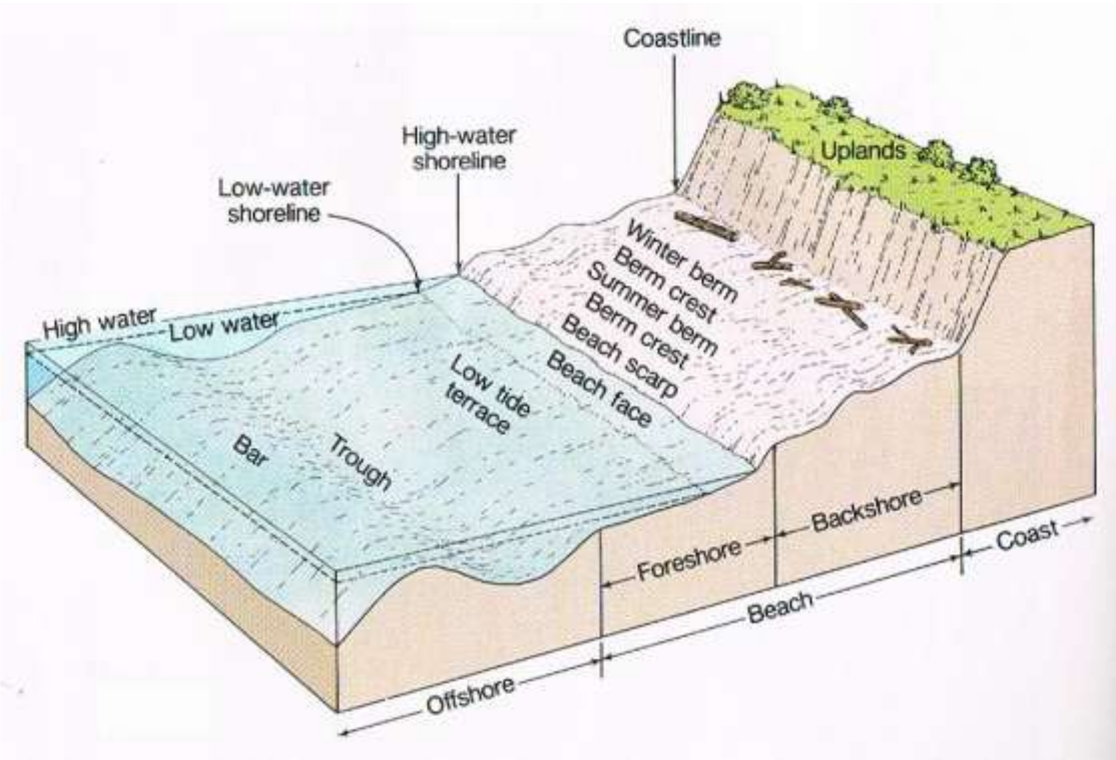


Figure 2.2: A typical beach profile with associated features (Duxbury *et al.*, 2002).

Man also interferes with processes that control beaches since it is necessary to make modifications particularly to the coastline for navigation, harbour, food production, fisheries, and even recreation with recent technological developments (Pethick, 1984). These actions not only have their ramification problems but also can contribute pollution threat to the coastal system and marine environment.

2.2 MARINE POLLUTION

Marine environment have long served as major repositories for many thousands of pollutants as a result of material usage and energy production. Coastal zone and especially nearshore oceanic water had been altered by man in many ways. The enlargement and increasing residential settlement, commerce and recreation activities along the coastline had became the starting place of escaping and increasing pollution to the ultimate seaward (Trujillo and Thurman, 2005). Hence, there are many possible behaviours and interactions between each pollutant with the living and non-living components of the marine environment. The implication of these changes can be great or small, long-lasting or transient, widespread or extremely localized (Clark, 2001; Goldberg, 1976).

According to Ross (1970), there are three main types of pollution that have an effect on the marine environment, as follow:-

a) Substances which directly destroy the organisms within the polluted area,
b) Substances which alter the physical and chemical properties of the environment and thus favour a particular type of organism,
c) Substances which are dangerous to higher forms of life such as human but are relatively harmless to lower forms of life.

In addition, Baretta-Bekker *et al.* (1998) stressed that pollution effects can be exerted at any integration or organization level in the natural environment such as:-

- On molecular and cellular levels,

- On physiological processes in organs and organisms,
- On behaviour of individuals or populations,
- On habitats and ecosystems.

Pollution is broadly known as measurable amounts of harmful substances generated from human by-products. Still, there are many argument and confusion about the exact definition of pollution as the ecological knowledge on marine environment is so limited. Therefore, most of the marine scientists refer to the term recommended by the international advisory bodies, United Nations Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP). It defined pollution of the marine environment as, *"the introduction by man, directly or indirectly, of substances or energy into the marine environment, resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fisheries, impairment of quality for use of seawater, and reduction of amenities"* (Clark, 2001).

Examples of the main types of marine pollution which can have severe deleterious effects on marine biota particularly in coastal ecosystems are oil, heavy metals, synthetic organic chemicals, sediment, sewage, waste heat, introduced species and also solid waste (Garrison, 2005; Kennish, 1994). Oceans are vast and consist of a good solvent (water) with good mixing mechanisms (waves, tides and currents) with the capacity to absorb, dilute or remove these pollutants e.g. wastes (Trujillo and Thurman, 2005). However, too many wastes discharge and at a rapid rate placed a great burden to oceans as it still have limited ability to disperse all the wastes (Sverdrup and Armbrust, 2009).

Man's first large scale introduction of pollutants into the marine environment came with the agricultural revolution (Moorcraft, 1972). Synthetic organic chemicals present in pesticides and herbicides like dichlorodiphenyltrichloro-ethane (DDT), aldrin and dieldrin are among the more dangerous substances that entered the marine environment through runoff from agricultural areas and via the atmosphere (Clark, 2001; Siriwong *et al.*, 1991). DDT for instance is used extensively for killing insects and thus increasing crop production. In spite of its advantages to human, DDT was the most widespread and prevalent chlorinated hydrocarbon hazardous to top carnivores in a marine food web. The damage is caused by biological amplification (Garrison, 2005). The danger of DDT first became apparent in the marine environment during 1960's in Anacapa Island off southern California in USA (Trujillo and Thurman, 2005). The high concentration of this chemical in the fish eaten by marine birds such as brown pelicans (*Pelecanus occidentalis*) had declined the birds populations due to egg-shell thinning and reproductive failures (Trujillo and Thurman, 2005; Goldberg, 1976). Fortunately, after the ban on DDT they are making remarkable comebacks (Trujillo and Thurman, 2005).

Domestic and industrial development too created common form of pollution with the ability to alter natural physical, chemical and biological balance of seawater (Thurman and Trujillo, 2004; Ross, 1970). These included sewage and eutrophication pollutions which occur when excessive nutrients such as nitrogen and phosphorus are released into marine water from wastewater treatment plants or factory effluent (Clark, 2001). It stimulates the growth of some marine species which is detrimental to other species (Garrison, 2005). Sediments generated from harbour works, dredging or other maritime construction also contribute to eutrophication but in general this pollution change water quality, reduce light penetration and photosynthetic activity that can cause smothering of bottom dwelling species and impairing fish spawning (Wilson, 1988; Beer, 1983). Similarly, waste heat or thermal pollution happened when many industries especially power plants discharged hot water into the river which finally reach the oceans. This elevated water temperatures influenced both the water quality and interfered with the physiological processes of the aquatic organisms, thus frequently result to their death (Kennish, 1992).

Furthermore, heavy metals are toxic to aquatic organisms and even to human above threshold availability. This is proven in the case of severe mercury poisoning in Minimata Bay, Japan (Nemerow, 1985). Many people equate marine pollution with oil pollution. This situation is due to the fact that spillage of oil is the major source of pollution in the marine environment and certainly attracted the most publicity (Ross, 1978). Oil spills were the result of loading or unloading accidents, collisions, tankers running aground and routine transportation activities that can destroy large quantities of marine organisms and devastate ecological effects (Trujillo and Thurman, 2005; Clark, 2001). Three most significant oil spills ever recorded were the sinking of the *Amoco Cadiz*, the grounding of the *Exxon Valdez*, and the 1991 Persian Gulf War oil spill (Sverdrup and Armbrust, 2009).

Pollution by solid waste represents the latest pollutant in the marine environment. Even though disposal of solid waste into the oceans already existed long ago, its seriousness to the marine environment was only recognized during the past two decades (Stefatos *et al.*, 1999). Using the oceans as a dump for solid wastes such as plastics, metals, wood products, glass, cloths and others that originated from land-based and sea-based, was and is a common practice around the world (Sverdrup and Armbrust, 2009; Goldberg, 1976). The presence of this man-fabricated waste in marine environment is one of the uglier features of the modern environment due to its visibility (UNESCO, 1994; Beer, 1983).

2.3 SOLID WASTE MANAGEMENT

Solid waste is mainly a useless, unwanted and with no economic value materials that derived from commercial, domestic or residential, institutional, industrial, municipal services and agricultural activity (Agamuthu, 2001). A rapid growth of world's population has resulted with vast quantities of solid wastes generation. It is estimated that the population of humans on the earth currently increased from 6 billion in 2000 to 6.8 billion in 2010 (United States Census Bureau, 2009). Thus, global generation of 318 million tonnes in 2000 had increased to about 585 million tonnes in 2010 (Agamuthu *et al.*, 2009).

Solid waste generation has become a more serious environmental problem around the world. Common practices in solid waste management include the control of generation, storage, collection, transfer and transport, the processing and disposal of solid waste in accordance to the best principle of economics, engineering, conservation, aesthetics, public health, as well as, environmental considerations (involving administrative, financial, legal, planning and engineering functions) (Agamuthu, 2001). There are many published works which reviewed solid waste management practices in developing and developed countries such as in China, India, USA, Portugal, Greece and Japan (Zhang *et al.*, 2010; Hazra and Goel, 2009; Contreras *et al.*, 2008; Magrinho *et al.*, 2006; Andreadakis *et al.*, 2000; Tanaka, 1999).

In Malaysia, local authorities in each state are responsible to manage municipal solid waste (MSW) for many years as stipulated under the Local Government Act 1976 (Latifah *et al.*, 2009). They were expected to 'provide, directly or through contract, public cleansing services of equitable and acceptable quality to all urban and semi-urban communities within its jurisdiction, and must dispose of the collected waste in a sanitary manner' (Latifah *et al.*, 2009). However, federal government is in the process of taking over the solid waste management from the local authorities after the Solid Waste and Public Cleansing Act 2007 was approved on 30 August 2007 (Latifah *et al.*, 2009). Generally, MSW generated from multiple sources is managed by the Ministry of Housing and Local Government (MHLG) through a 6 steps process as shown in Plate 2.1.

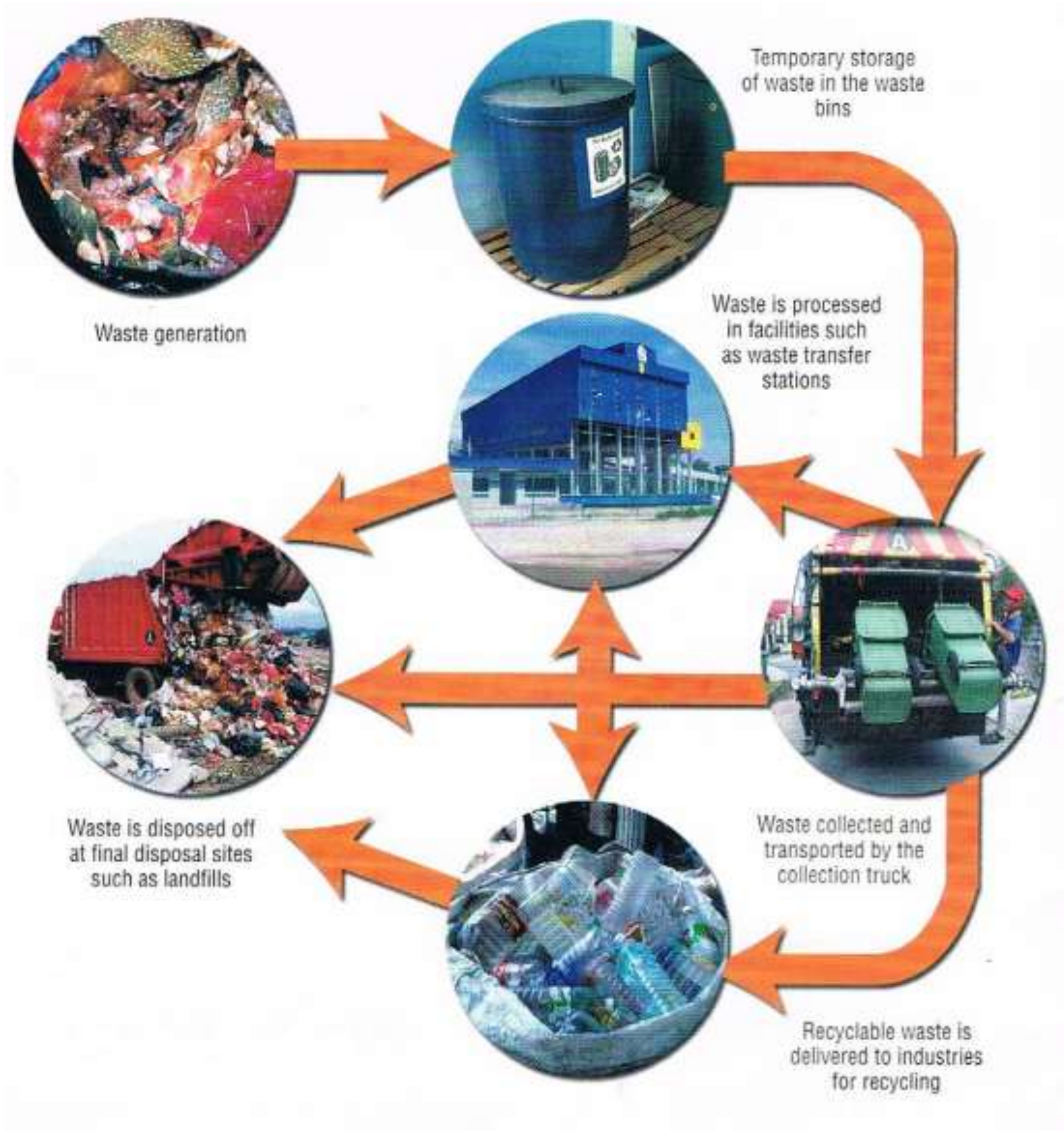


Plate 2.1: Solid waste is managed by a 6-step process (Source: Theng and Raihani, 2007).

2.3.1 Solid Waste Generation

Solid waste generation has inexorably been increasing rapidly along with urbanisation, rural-urban migration, changing of consumption pattern and high population growth rate (Agamuthu *et al.*, 2009; Idris *et al.*, 2004). The level of urbanization trend too affects the composition of solid waste from mainly organic to plastic, paper and packaging materials (Idris *et al.*, 2004).

Developed country such as USA and Denmark had higher in the per capita generation rate of MSW compared to other countries in the year 2005 with 2.05 and 2.03 kg/capita/day respectively (Table 2.1) (Zhang *et al.*, 2010). Developing country like China indicated increased in MSW generation which ranked second after USA in terms of the total amount of MSW due to urbanization, population growth and industrialization (Zhang *et al.*, 2010).

Table 2.1: Generation of municipal solid waste in selected countries.

Countries	**Total amount of MSW generation (1000 tonnes)**	**MSW generation rate (kg/capita/day)**
USA (2005)	222,863	2.05
France (2005)	33,963	1.48
Germany (2005)	49,563	1.64
Denmark (2005)	3,900	2.03
Switzerland (2005)	4,855	1.78
Poland (2005)	9,354	0.68
Portugal (2005)	5,009	1.29
Hungary (2005)	4,632	1.26
Mexico (2005)	36,088	0.93
Japan (2005)	51,607	1.10
Korea (2005)	18,252	1.04
China (2006)	212,100	0.98

Source: Zhang *et al.* (2010).

Developing country like Malaysia also has to face the increase of annual MSW generation which has reached 11 million tonnes, associated with rapid development and high level of income (Agamuthu *et al.*, 2009; Fauziah *et al.*, 2009). At present, the solid waste generation rate is expected to reach 1.5 kg/day in most cities in Malaysia since it was 1.3 kg/day in the year 2006 (Agamuthu *et al.*, 2009). Kuala Lumpur (KL) the capital city of Malaysia, saw increase in its waste generation yearly and it is expected to grow from 3.2 million tonnes/year to 7.7 million tonnes/year in the next twenty years (Hassan, 2002). Table 2.2 shows the trends of MSW generation in major urban areas in Peninsular Malaysia from 1970 to 2006. By using this table, it is estimated that KL alone produces more solid waste every day compared to other states. This is due to uncontrollable consumption from the increasing population, attitude towards shopping and high living standard in KL (Saeed, 2009).

Table 2.2: Generation of municipal solid waste in major urban areas in Peninsular Malaysia (1970 – 2006).

Urban centre	**Solid waste generated (tonnes/day)**				
	1970	**1980**	**1990**	**2002**	**2006**
Kuala Lumpur	98.9	310.5	586.8	2754	3100
Johor Bharu (Johor)	41.1	99.6	174.8	215	242
Ipoh (Perak)	22.5	82.7	162.2	208	234
Georgetown (P.Pinang)	53.4	83.0	137.2	221	249
Klang (Selangor)	18.0	65.0	122.8	478	538
Kuala Terengganu (Terengganu)	8.7	61.8	121.0	137	154
Kota Bharu (Kelantan)	9.1	56.5	102.9	129.5	146
Kuantan (Pahang)	7.1	45.2	85.3	174	196
Seremban (Negeri Sembilan)	13.4	45.1	85.2	165	186
Melaka	14.4	29.1	46.8	562	632

Source: Agamuthu *et al.* (2009).

2.3.2 Solid Waste Disposal

It cannot be denied that solid waste is a major visible urban environmental problem. Hence, effective solid waste disposal practices with economically and environmentally viable approaches are highly required to remove such wastes from physical environment to prevent pollution.

Landfilling (surface tipping) and incineration are two of the disposal methods of which require the wastes to be segregated, collected, transported and possibly processed prior to disposal (Bridgwater and Mumford, 1979). In Malaysia, landfilling is the only method used for the disposal of current MSW and the construction of more sanitary landfills were highlighted (Latifah *et al.*, 2009; Agamuthu *et al.*, 2008). Similar with other developing Asian countries, Malaysia have problems with constructing new landfills sites due to increase of land prices and land scarcity (Latifah *et al.*, 2009; Idris *et al.*, 2004). On the other hand, incineration method is the priority in Singapore compared to landfilling because of the land constraint where 73% of the total 8000 tonnes/day is incinerated (5840 tonnes/day) (Bai and Sutanto, 2002).

Conversely, many nations still dump solid waste into the oceans to avoid expensive costs of building plants and cleaning up process of solid waste although many of them realised that dumping of waste materials in the marine environment is recognized as the wrong solution to waste problems (Duxbury *et al.*, 2002). It is true that oceans can assimilate degradable organic and inorganic substances, but unassimilated materials such as synthetic compounds will accumulate and remain unaltered in marine environment (Kennish, 1994; Park and O'Connor, 1981).

2.4 MARINE DEBRIS POLLUTION

Marine debris is referred to the solid waste that has inevitably found its way into the marine environment which is likely to be present in the oceans and on beaches (Allsopp *et al.*, 2006). According to Coe and Rogers (1997), quoted by Gregory and Andrady (2003), marine debris is generally defined as "any manufactured or processed solid waste material (typically inert) that enters the marine environment from any source."

Marine debris is always difficult to control as it became one of a pervasive marine pollutants which impacts has been underestimated before (Stefatos *et al.*, 1999). However, marine debris pollution is receiving more and more attention and adequate understanding in recent years. Extensive research and monitoring programmes were conducted by scientist to identify the distribution, composition and state of pollution caused by marine debris in order to overcome this growing problem (Abu-Hilal and Al-Najjar, 2004; Dixon & Dixon, 1981).

2.4.1 Distribution of Marine Debris

Many studies have been carried out in different nations and oceans estimating the quantity of marine debris in marine environment, as shown in Figure 2.3. Countries that have reported on marine debris problems are Argentina, Australia, Brazil, Belize, Barbados, Benin, Bermuda, Colombia, Chile, Cyprus, Dominica, Dominican Republic, Denmark, Egypt, Ecuador, France, Grenada, Germany, Greece, India, Indonesia, Ireland, Italy, Israel, Jamaica, Japan, Kenya, Kiribati, Kuwait, Malaysia, Malta, Mexico, New Zealand, Nigeria, Netherlands, Norway, Panama, Papua New Guinea, Philippines, Peru, Portugal, Saudi Arabia, Singapore, Spain, Sweden, South Africa, Thailand, Turkey, United Kingdom, United States and Venezuela (UNEP, 2001).

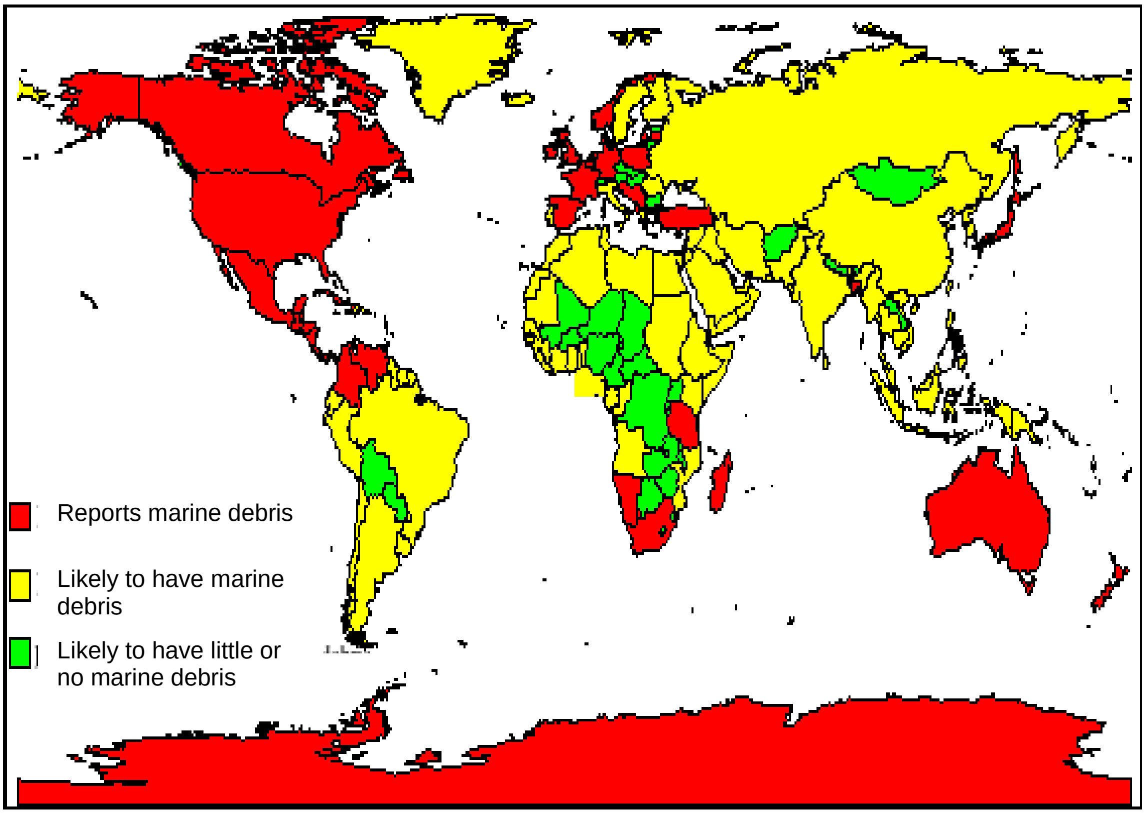


Figure 2.3: Distribution of the marine debris problem around the world (Topping, 2000).

According to the US Academy of Sciences, the total input of marine debris entering the world's oceans had been estimated at 6.4 million tonnes per year and another calculation revealed that eight million items of marine debris are discarded into the seas every day (UNEP, 2009). Marine debris particularly debris manufactured from synthetic materials that are released into the sea will be circulated in the water column for a long time before temporarily or permanently deposited on the seafloor and on shorelines (Stefatos *et al.*, 1999).

The abundance and composition of floating marine debris have been studied actively in the North Pacific (Shiomoto and Kameda, 2005). A study showed that almost one million items per square km were found in the North Pacific Gyre (Allsopp *et al.*, 2006).

Marine debris floats and drifts in the sea or gotten stranded on shorelines (Henderson, 2001). It can be noted that the existence of floating marine debris had caused major impacts to the marine environment (Walker *et al.*, 1997). As for stranded marine debris, almost 41,000 kg of debris per km was collected by the State of New Jersey from New Jersey beaches in 1991-1993 (Molinari, 1997). During the past 23 years, International Coastal Cleanup (ICC), an actively non-government organization (NGO) for addressing public awareness on marine debris issues, have recorded more than 103 million pieces of debris all around the world (UNEP, 2009). Table 2.3 below shows the total distribution of marine debris on shorelines and also underwater sites in some of the countries that participated in the survey.

Table 2.3: Total distribution of marine debris on shorelines and underwater sites.

Countries (ICC 2005/2006/2007)	kilogram (kg)	kilometre (km)	kg/km	Total people participated
Denmark (2007)	300.10	3.86	77.75	60
Turkey (2007)	10,860.00	1,649.58	6.58	3,051
Australia (2007)	2,495.90	2,346.91	1.06	450
Indonesia (2007)	1,545.54	37.01	41.76	296
Malaysia (2007)	3,075.27	1,717.82	1.79	999
Singapore (2007)	10,137.43	31.70	319.79	3,082
France (2005)	3,684.53	16.09	229.00	146
Portugal (2005)	385.10	4.83	79.73	55
Germany (2006)	1,200.66	3.22	372.88	32
United Kingdom (2007)	28,884.90	189.10	152.75	4,147
Netherlands (2005)	1,705.51	12.87	132.52	127
Italy (2005)	2,351.42	33.79	69.59	526
Greece (2007)	9,765.66	63.09	154.79	2,330
Republic of Korea (2007)	113,618.27	27.52	4,128.57	4,672
Japan (2007)	37,196.84	48.44	767.90	16,450
Egypt (2007)	898.11	22.37	40.15	268
Saudi Arabia (2007)	865.77	6.44	134.44	212
India (2007)	58,156.94	104.29	557.65	6,873
Sri Lanka (2007)	232.69	3.70	62.89	19

Table 2.3. (continued)

Countries (ICC 2005/2006/2007)	kilogram (kg)	kilometre (km)	kg/km	Total people participated
Chile (2006)	96,040.47	397.42	241.66	6,697
Peru (2007)	4,649.32	4.02	1,156.55	2,500
Barbados (2007)	1,085.07	3.22	336.98	74
Belize (2007)	3,833.37	117.64	32.59	2,218
Dominican (2007)	25,809.41	8.05	3,206.14	577
Mexico (2007)	82,352.19	1,850.43	44.50	8,010
Netherlands Antilles (2007)	163,028.28	14.48	11,258.86	602
Trinidad & Tobago (2007)	15,402.50	394.45	39.05	2,250
Venezuela (2007)	417.30	7.40	56.39	110

Source: UNEP (2009).

2.4.2 Composition of Marine Debris

Marine debris includes all objects that occur unnaturally in the marine environment and may consists of any man-made objects such as plastic and polystyrene, rubber, wooden, metal, paper and cardboard, textile and leather, glass, pottery and ceramics (UNEP, 2001). Individual object can contributes certain impact to marine environment. Based on Frost and Cullen (1997), composition surveys on marine debris are important because

- It determines the types and amount of debris accumulate,
- It determines debris deposition rate over time,
- It identifies the sources of the debris,
- It relates debris deposition to relative beach usage.

A beach survey is one of the established monitoring techniques to evaluate the general trend of marine debris distribution, and types of debris items that remain on beaches (Ribic, 1998). The beach survey can also be used to determine the rates of floating debris loss from the ocean, and to predict the surface transport of marine debris such as winds or waves activity (Shiber, 1989). Investigations on quantities of marine debris on the beaches can be done based on systematic, continuous and representative or random transects (Spengler and Costa, 2008; Gregory and Andrady, 2003).

A survey conducted by the annual ICC from 1989 to 2007 were compiled and used to record the composition of debris items collected (UNEP, 2009). The survey indicated that dominant debris are remnants of plastic containers, plastic food packaging, and smoking materials (UNEP, 2009). Table 2.4 depicts the number of item found during beach clean-up by ICC.

Table 2.4: 'Top ten' marine debris items - Global ICC totals (1989-2007 combined).

Debris items	**Number of items**	**Percent of total debris items (%)**
Cigarettes/cigarette filters	25,407,457	24.6
Bags (paper and plastic)	9,711,238	9.4
Caps/lids	9,398,977	9.1
Food wrappers/containers	9,191,575	8.9
Cups/plates/forks/knives/spoons	7,426,964	7.2
Beverage bottles (plastic) < 2 litres	5,684,718	5.5
Beverage bottles (glass)	4,991,860	4.8
Beverage cans	4,796,554	4.6
Straws, stirrers	4,508,085	4.4
Rope	2,215,329	2.1
Total debris items	**103,247,609**	**80.7**

Source: UNEP (2009).

Plastic debris is the major component of man-made debris compared to other items both in weight and number (Kusui and Noda, 2003). According to Frost and Cullen (1997), plastics were the major type of marine debris, followed by glass, metal and wood. A study in Fog Bay, Northern Australia found that plastic items were the most frequently found items (45%) followed by metal and glass at 35% and 16% respectively (Whiting, 1998). Another study of marine debris composition on the Jordanian shores of the Gulf of Aqaba (Red Sea) showed that from the 101,000 items collected, plastic contributed more than 50% while the rest were metal, cardboard, glass, wood and other debris materials (Abu-Hilal and Al-Najjar, 2004).

2.5 PLASTIC DEBRIS POLLUTION

Lost or discarded fishing nets and net fragments, synthetic rope and line, plastic strapping bands, plastic bags and other manufactured plastic items, small plastic beads and particles which degrade into small fragments are the example of plastic debris that may last for years or decades in the marine environment (Laist, 1987; Wolfe, 1987). Scientist believed that plastic can be carried far from the origin, thus is difficult to trace the diverse source (Corbin and Singh, 1993). Nondegradable plastics that contained in most of the modern products made plastic the fastest growing waste component (Moore, 2008). The growing of plastic debris pollution has been alerted but only a few specific or systematic observations were done which are not extensive enough to document the situation adequately (Pruter, 1987).

2.5.1 Distribution of Plastic Debris

The scale of plastic debris pollution is vast as the characteristic of plastic allow itself to reach everywhere from polar regions to the equator, floating far in all world's oceans, submerged on the seabed specially nearby coastal regions or ubiquitous on beaches from highly populated place to very remote islands (Allsopp *et al.*, 2006). Proportion of plastics among marine debris worldwide from 33 out of 37 literatures showed that plastic debris make-up more than 50%, as shows in Table 2.5 (Derraik, 2002).

Moreover, studies on the beaches and ocean bottom in Southern California revealed that plastic debris were the most common type of human-made debris found in the region (Moore *et al.*, 2001). Meanwhile, plastics comprise up to 90% of floating marine debris in most studies (UNEP, 2006).

Table 2.5: Plastics proportion among marine debris worldwide (per number of items).

Locality	**Litter type**	**% of debris items represented by plastics**	**Source**
1992 International Coastal Cleanups	Shoreline	59	Anon (1990)
St.Lucia, Caribbean	Beach	51	Corbin and Singh (1993)
Dominica, Caribbean	Beach	36	Corbin and Singh (1993)
Curacao, Caribbean	Beach	40/64	Debrot *et al.* (1999)
Bay of Biscay, NE Atlantic	Seabed	92	Galgani *et al.* (1995a)
NW Meditterranean	Seabed	77	Galgani *et al.* (1995b)
French Meditterranean Coast	Deep sea floor	>70	Galgani *et al.* (1996)
European coasts	Sea floor	>70	Galgani *et al.* (2000)
Caribbean coast of Panama	Shoreline	82	Garrity and Levings (1993)
Georgia, USA	Beach	57	Gilligan *et al.* (1992)
5 Meditterranean beaches	Beach	60-80	Golik (1997)
50 South African beaches	Beach	>90	Gregory and Ryan (1997)
88 sites in Tasmania	Beach	65	Gregory and Ryan (1997)
Argentina	Beach	37-72	Gregory and Ryan (1997)
9 Sub-Atlantic Islands	Beach	51-88	Gregory and Ryan (1997)
South Australia	Beach	62	Gregory and Ryan (1997)
Kodiak Is, Alaska	Seabed	47-56	Hess *et al.* (1999)
Tokyo Bay, Japan	Seabed	80-85	Kanehiro *et al.* (1995)
North Pacific Ocean	Surface waters	86	Laist (1987)
Mexico	Beach	60	Lara-Dominguez *et al.* (1994)
Transkei, South Africe	Beach	83	Madzena and Lasiak (1997)
National Parks in USA	Beach	88	Manski *et al.* (1991)
Meditterranean Sea	Surface waters	60-70	Morris (1980)
Cape Cod, USA	Beach/harbour	90	Ribic *et al.* (1997)
4 North Atlantic harbors, USA	Harbour	73-92	Ribic *et al.* (1997)
Is. Beach State Park, New Jersey, USA	Beach	73	Ribic (1998)
Halifax Harbour, Canada	Beach	54	Ross *et al.* (1991)
Price Edward Is., Southern Ocean	Beach	88	Ryan (1987b)

Table 2.5. (continued)

Locality	Litter type	% of debris items represented by plastics	Source
Gough Is., Southern Ocean	Beach	84	Ryan (1987b)
Heard Is., Southern Ocean	Beach	51	Slip and Burton (1991)
Macquire Is., Southern Ocean	Beach	71	Slip and Burton (1991)
New Zealand	Beach	75	Smith and Tooker (1990)
Two gulfs in W. Greece	Seabed	79-83	Stefatos *et al.* (1999)
South German Bight	Beach	75	Vauk and Schrey (1987)
Bird Is., South Georgia, Southern Ocean	Beach	88[a]	Walker *et al.* (1997)
Fog Bay, N. Australia	Beach	32	Whiting (1998)
South Wales, UK	Beach	63	Williams and Tudor (2001)

[a]76% of total consisted of synthetic line for long-line fisheries.
Results are arranged in alphabetical orders by author.

Source: Derraik (2002).

Once plastic debris reached the ocean, it can travel and disperse widely (Derraik, 2002). There are 86% and 60 – 70% of floating plastic observed in the North Pacific Ocean and Mediterranean Sea, respectively, during sea sighting surveys of all man-made debris (Laist, 1987). In addition, over 13,000 pieces of floating plastic debris for every square km of ocean surface has been estimated (UNEP, 2009).

Plastic debris can also be found lying on beaches and shores. A study in Orange County, California showed that 99% of the beach debris collected was plastic (Moore *et al.*, 2001). An average density of 3.6 items/m^2 stranded debris was reported on beaches along the Caribbean coast of Panama where plastics related to fast-food operations were the common items found (Garrity and Levings, 1993).

2.5.2 Degradation of Plastic Debris

Two factors that make plastic production in the twentieth century a significant problem are the amount generated and the nature of the plastic litter (Frost and Cullen, 1997). According to Garrison (2005), plastic material is estimated to begin decomposition only after more than 400 years because plastic have high resistance to aging and minimal biological degradation in the marine environment.

Plastic can be degraded when it is exposed to ultraviolet B (UVB) or medium wave radiation, as well as, through slow oxidation and hydrolysis exposure from the atmosphere and seawater which lead to polymer chain scission (O'Brine and Thompson, 2010). Plastic material that loss its useful physical or mechanical properties and chemical changes is believed to have experience the degradation process (Gregory and Andrady, 2003). This degradation process caused the occurrence of various size of plastic debris such as micro-litter material which is retained at 63 μm sieve, meso-litter (size range less than 5-10 mm or more than 10 mm) and macro-litter (size range more than 10-15 cm) due to the physical breakdown or degraded fragments of plastics (Gregory and Andrady, 2003).

Large plastic debris that was accumulating on beach may slowly degraded and then partially or fully buried in sediment by physical actions included wind, wave, current and tide (Corcoran *et al.*, 2009; Uneputty and Evans, 1997). Moreover, the degradation of plastic debris on the beach was enhanced when exposed to ultraviolet radiation and slow thermal oxidation (Ryan *et al.*, 2009; Gregory and Andrady, 2003). These processes reduce the mechanical strength of plastic materials which may undergo very slow embrittlement and breakdown into very fine debris (Gregory and Andrady, 2003).

2.5.3 Characteristics of Plastic

Plastics can be defined as a solid material which can be moulded or deformed into any desired shape under the right conditions and retain its new shape indefinitely (Gait and Hancock, 1970). Plastics state is a liquid of very high viscosity originated from organic chemicals called polymers which have long molecules capable of being synthesised or depolymerised (Oswin, 1975). The 1862 Great International Exhibition in London had demonstrated the creation of the first man-made plastic by Alexander Parkes which was synthesized from cellulose nitrate (organic material) known as parkesine that can be moulded when heated but retained its shape when cooled (Lytle, 2009; Andrady, 2003a).

Plastics have considerable commercial and social importance to human daily utilization since their existence over a century ago (Gorman, 1993). The usage of plastics became a great demand for manufacturing materials and alternative products because of their characteristics. Plastics are durable, inexpensive, lightweight and strong compare to other materials (Trujillo and Thurman, 2005). The usual intended use of plastic items is for one-time only, thus plastic debris become more abundant when they are released into the marine environment (Laist, 1987). Therefore, the release of plastic debris jeopardized and damaged marine environment as they do not biodegrade or breakdown easily because they are durable (Trujillo and Thurman, 2005).

Additionally, plastic items are mass-produced and being used in almost everything as they are inexpensive (Trujillo and Thurman, 2005). These normally float and concentrate at the ocean surface because they are lightweight which can entangle marine wildlife (Trujillo and Thurman, 2005).

Plastics are resistant to natural biodegradation processes unlike plant, animal or natural mineral based material (Lytle, 2009). However, plastics can break down into smaller debris over time by sun exposure known photo-degradation process, as well as, plastic fragmentation process due to wave, sand action, oxidation, weathering and microbial action (Lytle, 2009; Pruter, 1987). The degradation of plastic debris has been estimated to range from 450 to 1000 years but also depending on the physical and chemical properties of the polymer (Lytle, 2009; Gregory, 1978). Thus, these processes of degradation and fragmentation allow the plastics that presence in the marine environment to break down into small pieces debris which then can be classified into film, foam, fragment, line and pellet (McDermid and McMullen, 2004).

2.5.4 Classifications of Plastic

2.5.4(a) Film

Among the class of polymers there is a subset which in the plastics state possesses the ability (‘spinnbarkeit’) to be drawn out into threads (Oswin, 1975). These ‘filar’ materials include some which can also be drawn out into two directions at right angles, to form sheets or films (Oswin, 1975).

Films are planar forms of plastic thick enough to be self-supporting but thin enough to be flexed, folded or creased without cracking (Sweeting, 1971). Over the years reduction in the thickness of available films has been pursued as a matter of economy, it is now possible to obtain a 2 μm film while the upper limit of thickness for a film is vague, and lies between 75 and 150 μm depending on the plastic itself (Sweeting, 1971).

Initial film applications were mainly confined to industrial packaging such as covers for equipment packed inside wooden crates, electrical resistors and as drum liners (Briston, 1983). Then, high clarity grades of polyethylene films were developed and it became the cheapest transparent film available, hence films are selected for packaging uses for food and beverages, cosmetics, pharmaceuticals, toiletries, textiles and stationery, as well as, for display and non-packaging purposes such as electrical construction, musical instruments, horticultural and agricultural applications (Briston, 1983).

Plastics film such as abandoned thin plastic shopping bag or small pieces of balloon may be accumulated and break down in marine environment (Moore, 2008). It is a serious concern as plastics film can alleviate the risk of ingestion-related impacts to marine animals from larger invisible species until smaller invertebrate filter feeders (Gregory and Andrady, 2003). Other types of plastic which are also commonly mistaken as food by the marine animals is foam.

2.5.4(b) Foam

Foam is a form of cellular plastics, having a porous cellular structure in which the cells are intercommunicating (Wordingham and Reboul, 1964). A range of plastic foams weights nearly from 4.5 to 27.3 kg per cubic foot which is similar to the range of weights available in various species of wood (Patton, 1976). The applications of foam fall into three broad types namely insulation, cushion and structure (Patton, 1976). Foam is lightweight, soft and resilient, and stronger and stiffer than the other types of plastic that are capable to support stress (Andrady, 2003a; Patton, 1976).

Plastics that are commonly foamed included polystyrene foam, PVC foam, polyethylene foam, urea-formaldehyde foam, rigid polyurethane foam, installation of polyurethane foam, flexible polyurethane foams and other foams (Patton, 1976). Foams are selected for a variety of products such as cushioning materials, toys, furniture, panels for buildings, thermal insulation, sponges, plastic boats and other usage (Encyclopædia Britannica, 2010).

Nearly all beach surveys reported that major component of plastic debris found is pieces of polystyrene foam which originated from sections of bait or fish boxes discarded by fishermen and fragments of foam packaging materials littered by beach users (Gregory and Andrady, 2003). Similar problem is also reported from the presence of fragment plastic.

2.5.4(c) Fragment

Fragment is a small fraction of polymers derived from multiple sources of manufactured plastic products which undergo some form of degradation and fragmentation processes (Ng and Obbard, 2006). According to Costa *et al*. (2009), plastic fragments with sizes between 1 mm and 20 mm are termed small while fragment items smaller than 1 mm are specifically called microplastics.

These plastic fragments break down and degrade slowly from larger plastic items to small fragments due to photochemical if exposed to ultra-violet radiation, physical factors such as waves, winds and sand abrasion, or chemical factors caused by salting and burial in the sand rich in organic matter (Costa *et al.*, 2009; Dixon and Dixon, 1981). Concentrated plastics fragment in marine environment are believed to derive from airblast cleaning media, hand cleaners and cosmetic preparations plants before discharged into marine waters and dispersed by currents (Derraik, 2002; Gregory, 1996). Aside from plastic fragments, plastic line is also threatening marine debris.

2.5.4(d) Line

Monofilament line is continuous thread comprising of a single filament that is produced by the extrusion process (Wordingham and Reboul, 1964). Monofilament lines are manufactured in a various colours (e.g. white, blue, green, fluorescent) and they are strong and low cost but it can degrade over time when exposed to heat and sunlight (Wikipedia, 2010). These monofilament lines are applied over a wide field such as brush filling, fishing net and line manufacture, and rope making (Wordingham and Reboul, 1964). Plastic nylon made from monofilament line are very tough, have high resistance to abrasion and chemical attack and have an exceptionally low coefficient of dry friction that they are used specially for manufacture of small bearings or gears in marine fishery (Gait and Hancock, 1970).

Plastic lines mostly made up of fishing debris lines that lost from vessels are increasingly polluted marine environment even on beaches in remote area (e.g. Alaska) and subantarctic islands (Derraik, 2002; Walker *et al.*, 1997). Also commonly formed in the marine environment is pelletized plastic.

2.5.4(e) Pellet

Pellets are small granules of plastic, usually called as "nurdles" that have a diameter from 1 to 5 mm (Goettlich, 2005; Mato *et al.*, 2001). Pellets can be shaped into cylindrical, ovoid or spherical with most regularly clear, white or off-white in colours (Goettlich, 2005; USEPA, 1992).

Plastics pellet are the raw material for plastics industry which will be utilized to produce "user plastics" product (Takada, 2006). The wide variety of plastic products manufactured internationally has created a highly demand for many different polymers or resins (USEPA, 1992). These pellets commonly are produced from polyethylene, polypropylene and polystyrene (USEPA, 1992). These pellets are packaged and transported worldwide via train, truck and ship to manufacturing sites for melting or molding process into final plastic products (Mato *et al.*, 2001). Approximately 27.3

billion kg of plastic pellets are manufactured annually in the USA alone in 1992 (Goettlich, 2005).

Their persistence in the marine environment is speculated from carelessly handled in places and unintentional spills during transport by ship or effluent from plastic processing plants into the sea (Derraik, 2002; Laist, 1987). There are 100,000 of pellets per meter found accumulated on a beach in New Zealand (Gregory, 1978). Thus, this clearly indicated the detrimental impact caused by plastic debris to further pollute the marine environment.

2.6 STATE OF POLLUTION BY PLASTIC DEBRIS

Marine environment is affected by a greater quantity of plastic debris not only from larger objects but also such small plastic that composed of film, foam, fragment, line and pellet (McDermid and McMullen, 2004). These small plastics debris are originated from pre-production thermoplastic industry feedstock or fragments broken from larger objects (Moore, 2008).

The wide range of persistent plastic pollutant originated from the increased anthropogenic activity from a burgeoning population, especially in the coastal zone. It has been estimated that sources of plastic debris can be divided into two: 80% is from land-based sources and remaining 20% is from sea-based sources (GESAMP, 1982).

2.6.1 Land-based Sources

Plastics were the most frequent found litter mainly sourced from land-based activities namely recreational and urban runoff (UNESCO, 1994). Normally, the inputs of beached debris are left carelessly by beachgoers at recreation area (Moore, 2008; Pruter, 1987). The annual ‘International Coastal Cleanup’, organized by the Ocean Conservancy reported that almost 58% of the litter could be attributed to recreational activities along the shore (UNEP, 2006). For example, greater amount of plastic debris accounted over 90% of the total debris were collected in Baltic beaches (UNEP, 2006). Also, recreational activity also contributed 62% of the total litter found in Halifax Harbour, Canada (Ross *et al.*, 1991).

Plastic materials also end up in the marine environment through discharged or accidentally lost into storm drains and nearby waterways from the processing plants (Wilber, 1987). Then, these discharged plastics are carried by urban municipal drainage systems, storm waters or rivers and find their way into the sea or indirectly deposited on beaches (Williams and Simmons, 1997; UNESCO, 1994). Furthermore, many of the landfills that located downhill or downstream from nearby oceans which are lacking of sanitary infrastructure can also be the reason of plastic waste runs off to the coastal area and the sea (Allsopp *et al.*, 2006). Many estuaries in the USA have been reported to be polluted by domestic and industrial wastes from nearby landfills (Nollkaemper, 1994).

2.6.2 Sea-based Sources

Since durable and elastic plastic materials (polypropylene, nylon nets, plastic lines) were introduced over 35 years ago and have replaced natural fibres (tarred cotton, linen webbing, hemp) in the maritime industry, it has resulted with large amounts of plastic debris in the ocean which are also washed ashore (Henderson, 2001). High concentrations of plastic debris are found mainly near busy shipping lanes and fishing area (Clark, 2001). Ships are estimated to discharge 6.5 million tonnes of plastic per year, mostly within 400 km of land (Clark, 2001). The world’s commercial fishing fleet dumped approximately 26,000 tonnes of plastic packaging materials and another 149,000 tonnes of fishing gear including traps, ropes, nets and buoys mainly from plastic every year (Sverdrup and Armbrust, 2009).

A survey of synthetic debris originated from fishing industry in the southeast Bering Sea and Gulf of Alaska for 1980-1983 had reported that 35-65 nets by 300-325 groundfish trawlers were lost annually (Laist, 1987). Studies in many islands in Southern Ocean and Antarctica areas showed that discarded fishing gear was the most common debris found on Bird Island while plastic bottles or containers and fishing floats or polystyrene fragments derived from net floats were apparent in Saunders and Signy Islands (Convey *et al.*, 2002; Walker *et al.*, 1997).

Additionally, plastics waste may presence in the marine environment due to accidental loss, indiscriminate littering, deliberately thrown overboard or illegal disposal activity (Allsopp *et al.*, 2006). These activities are contributed by recreational boaters, merchant, military and research vessels, as well as, offshore oil and gas platforms (Allsopp *et al.*, 2006). In USA, recreational fishing and boating disposed 51.96% of all garbage dumped in US waters while world navies discarded around 74 million kg of trash into the ocean yearly (UNESCO, 1994).

2.7 THE EFFECTS OF PLASTIC DEBRIS

Plastic debris in the seawater surface or submerged onto the seafloor or stranded and buried on the beach is a large problem, which deteriorates the overall environmental quality. Abundance of plastics debris not only remain steadily in the coastal and ocean environment but also affect marine wildlife severely, impaired aesthetic and coastal economies, as well as, threatened human health and safety wherever they accumulate (Uneputty and Evans, 1997; Laist, 1987).

2.7.1 Loss of Marine Wildlife

Countless impacts from the accumulation of discarded plastic debris in the marine environment are increasingly significant. Threats to seabirds, turtles, fishes and marine mammals which either entangled in it or ingest it is rather serious (Mascarenhas *et al.*, 2004; Sazima *et al.*, 2002; Bjorndal, 1994; Pruter, 1987). These synthetic materials are a great factor towards the widespread mortality of marine wildlife similar to the effect of toxic wastes, heavy metals contaminant and oil spills (Sverdrup and Armbrust, 2009).

Laist (1997), quoted by Derraik (2002), listed that at least 267 species worldwide are affected by entanglement and ingestion of marine debris especially plastic. This includes 86% of sea turtle species, 44% of seabird species and 43% of marine mammal species (Derraik, 2002). However, the total number of species listed is possibly an underestimate figure because most victims are likely undiscovered as they either rapidly decomposed and sink into sea or consumed by predators (Derraik, 2002; Laist, 1987; Wolfe, 1987).

2.7.1(a) Entanglement

As stated by Bauer *et al.* (2008) and Clark (2001), the marine animals' entanglement is mainly due to plastic nets and ropes, monofilament long lines, six-pack rings, plastic straps, plastic wrapping bands and drift nets or known as 'ghost nets'. Lost and discarded derelict fishing gear, termed 'ghost nets' continued to trap marine animals even though they are abandoned by their owners in the water (Moore, 2008; Matsuoka *et al*., 2005). This may cause death if the marine animals cannot escape (Matsuoka *et* *al*., 2005). The organisms that had been entangled previously may attract predators which then will also get trapped and this continuous process is known as 'ghost fishing' (Allsopp *et al.*, 2006). In this case, 'ghost nets' can actively be a silent murder weapon for many marine animals in the past, and even in the present.

There are more than 15 out of 32 world species of pinnipeds have been seen entangled with plastic debris (Fowler, 1987). From a research conducted at South-east Farallon Island, California, a total of 914 pinnipeds were observed entangled in or with body constrictions from synthetic materials (Hanni and Pyle, 2000). This involved immature and sub-adult among five studied species namely Northern Fur Seals, Northern Elephant Seals, Pacific Harbour Seals, California Sea Lions and Steller Sea Lions (Hanni and Pyle, 2000).

Juveniles and sub-adults are the majority of entangled animals compared to older seals (Henderson, 2001; Jones, 1995). For instance, young fur seals commonly were attracted by floating debris and thus causing their head trapped in loops and holes of these plastic (Mattlin and Cawthorn, 1986). Yoshida *et al.* (1985) claimed that 'individuals of this age are noted to investigate and insert their head through floating objects as part of play behaviour.' Scientists estimated at least 40,000 fur seals are killed by plastic entanglement annually when numerous seal pups grow with the plastic collars which sever the seal's arteries or strangles it when it tightens (Weisskopf, 1988).

Entanglement has been reported in 56 species of marine and coastal birds due to monofilament line, plastic fishing net and six-pack rings (Sverdrup and Armbrust, 2009; Allsopp *et al.*, 2006). A study by Schrey and Vauk (1987) on gannets (*Sula bassana*) at Helgoland, German Bight reported that entanglement accounted for 13-29% of deaths in these birds. Entanglement also posed hazards to several species of marine fishes including whales, sharks and salmon (Clark, 2001; DeGange and Newby, 1980). On the coast of Sao Paulo in Southeast Brazil, plastic rings which is recognized as detachable parts of bottle lids with 36-42 mm internal diameter were found circling the gill or mouth region of three juveniles Brazilian sharpnose shark (*Rhizoprionodon lalandii*) that caught in gillnets (Sazima *et al.*, 2002).

Entanglement is a serious threat to marine wildlife because it may drown or suffocated, thus causing fatality (Jones, 1995). Entanglement reduces marine wildlife's ability to catch food or to escape from predators (Derraik, 2002). Once an animal is entangled, it struggles to survive by freeing itself from the trapping materials but causing wounds which later lead to the loss of limbs that caused further pain and suffering to the animal (UNEP, 2001). In the 1989-1991 study by Jones (1995), reported 96% of entangled animals had physical injury caused by neck collars. For instance, turtle trapped with nets and lines may loss its ability to dive and search for prey or from surfacing to breath, caused by limbs amputation while it's open wounds can attract predators (Mascarenhas *et al.*, 2004).

Plate 2.2 to Plate 2.6 illustrate the impacts of plastics entanglement on the marine wildlife. Sea lions and seals die by the hundreds each year after becoming entangled in plastic debris, especially broken fishing nets and discarded strapping bands (Plate 2.2). A common murre entangled in a six-pack yoke probably poses the greatest threat to seabird species (Plate 2.3). A fish trapped in a six-pack ring that had caused its death (Plate 2.4). Dorso-lateral viewed of the head of a juvenile (*Rhizoprionodon lalandii*) female shark, showing damage to tissue on the gill region surrounded by a plastic debris collar (Plate 2.5). Green turtle (*Chelonia* midas) trapped in a 'ghost' (lost) fishing net in Cayman Islands, Caribbean Sea, Atlantic Ocean (Plate 2.6).

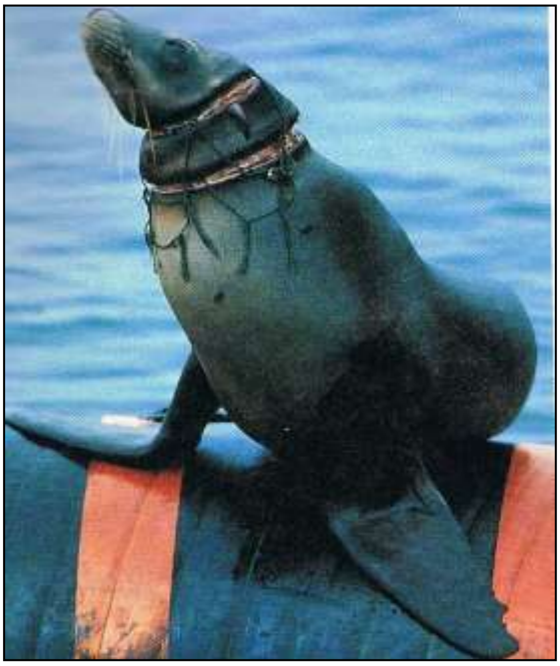


Plate 2.2: Young seal entangled in a broken fishing net (Source: Garrison, 2005).

Plate 2.3: A common murre entangled in a six-pack yoke (Source: Duxbury *et al.*, 2002).

Plate 2.4: A fish trapped in a six-pack ring (Source: UNEP, 2001.)

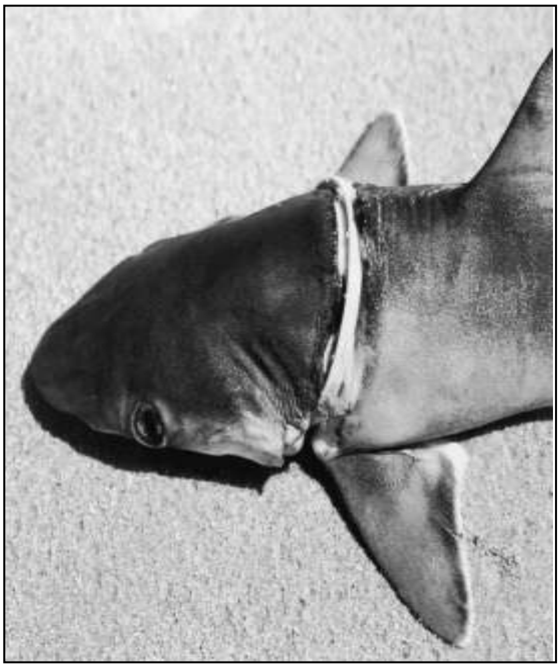


Plate 2.5: Plastic debris collars on a juvenile female shark (Source: Sazima *et al.*, 2002).

Plate 2.6: A green turtle trapped in a 'ghost' fishing net that was lost in the sea (Source: www.arkive.org).

2.7.1(b) Ingestion

Marine wildlife such as sea turtles, seabirds, cetaceans and others are known to ingest everything from large pieces of plastic sheeting to tiny plastic resin pellets (Plate 2.7) (Tomás *et al.*, 2002; Baird and Hooker, 2000; Spear *et al.*, 1995). Ingested materials may clog and injure their digestive tracts and lower the food intakes (Jones, 1995). Direct ingestion of harder plastic debris could cause ulcerations and tissue necrosis to the affected marine animals (Barreiros and Barcelos, 2001). Furthermore, the accumulation of plastics debris in the animals' stomach will block their intestines, displace sense of fullness, hinder vital nutrient gain, and slowly starve the animals to death (Sheavly, 2005; Tomás *et al.*, 2002).

Based on the research by Bugoni *et al.* (2001), a total of 92 stranded sea turtles were found on the coast of Rio Grande do Sul State, Brazil. The stomach of 38 juvenile green *Chelonia mydas*, ten adults and sub-adults logger-head *Caretta caretta*, and two leatherback *Dermochelys coriacea* turtles (adult or sub-adult) were examined and reported to contain ingested debris mainly white and colourless pieces of plastic bags (Bugoni *et al.*, 2001). Additionally, in other study conducted by Mascarenhas *et al.* (2004), two stranded sea turtles (*Chelonia mydas* and *Lepidochelys olivacea*) found along the coast of Paraiba died due to the ingestion of hard plastics and plastic blue, green, white and transparent coloured bag.

All species of sea turtles are prone to eat floating plastic pieces and the remains of weather balloons which normally are mistaken as squid or jellyfish, the major food sources in turtle's diet (Whiting, 1998; Carr, 1987). Loads of necropsies showed that non-natural sea turtles' fatality is primary a result of the intake of plastic and other anthropogenic debris such as tar (Mascarenhas *et al.*, 2004).

Source: Sverdrup and Armbrust (2009).

Source: UNEP (2003).

c

Source: Moore (2008).

d

Source: Lytle (2009).

Plate 2.7: The impacts of plastics ingestion on the marine wildlife. (a) A Loggerhead with a partially ingested plastic bag mistakenly identified plastic as a jellyfish. (b) Kemp's Ridley swallowed balloon with ribbon. (c) Laysan albatross chick at Kure Atoll, 2002. (d) Small plastic found in Rainbow Runner fish stomach.

Many seabirds also have a higher incidence of plastic debris ingestion. Mostly ingested plastics are plastic pellets and plastic fragments because it is confused as planktivores (Allsopp *et al.*, 2006; Azzarello and Van-Vleet, 1987). Day *et al.* (1985) reported that more than 50 species of seabirds commonly albatrosses, auklets, petrels, phalaropes, puffins and shearwaters are identified to swallow plastic debris.

A study on seabirds from the Eastern North Pacific by Blight and Burger (1997), reported that eight of the 11 species (73%) caught as bycatch had ingested plastic particles including 29% industrial pellets and 71% fragments of discarded products.

90% of the Laysan albatrosses (*Diomedea immutabilis*) chicks surveyed in the Hawaiian Islands were found to contain plastic debris in their upper gastrointestinal (GI) tract as they may receive and ingest plastic particles by regurgitation during feeding time (Fry *et al*., 1987).

Also, marine mammals and several species of fish were discovered to have ingested plastic debris. A total of 439 salvaged Florida manatees (*Trichechus manatus latirostris*) were completely examined and the result indicated that 63 of this endangered species contained in their GI tract more than one type of debris including plastic bags, monofilament fishing line, synthetic sponges, paper, cellophane, fish hooks and others (Beck and Barros, 1991).

A juvenile harbour porpoise (*Phocoena phocoena*) was found dead on a beach in Nova Scotia, Canada and was also documented to ingest a balled up piece of black plastic that probably blocked the oesophagus which resulted to its death (Baird and Hooker, 2000). According to Derraik (2002), various species of fish feed selectively on white plastic spherules which were found in their guts while 21% of flounders (*Platichthyes flesus*) and 25% of sea snails (*Liparis liparis*) were heavily contaminated by polystyrene spherules in Bristol Channel.

2.7.2 Human Health and Safety

The deliberation of discarding plastic debris in marine environment especially stranded and buried plastic on beach is a result of irresponsible human activities. Coastal residents or tourist can get serious injuries from contact of sharp materials including small fragments of plastic, broken glass and torn aluminium cans during bathing, boating and fishing (Spengler and Costa, 2008; Whiting, 1998). Plastic trash that includes plastic diapers, sanitary and medical waste which can be found on beaches worldwide pose a public health hazard (Moore, 2008). Corbin and Singh (1993) emphasised that trash stranded on the shoreline within Caribbean islands can bring risks to beach users' health and safety. It was considered as one of the primary concern as this incident can be detrimental to the tourism industry of these islands (Corbin and Singh, 1993).

Besides, drifting plastic debris that is present in the seawater can also threat marine recreational values. Human can get entangled in the same way as marine wildlife during underwater diving or snorkelling activities. For example, SCUBA divers may swim into invisible ghost net without noticing it before they become entangled and some have experienced serious injuries or drowning (UNEP, 2001; UNESCO, 1994). On 9th September 1987, two children were injured by floating plastic timbers while swimming at Mantoloking beach in New Jersey (Ofiara and Brown, 1999).

2.7.3 Aesthetic and Economic Impact

Plastic debris that has been washed ashore damages the value of the beach. This kind of scenery can be aesthetically offensive. It is an eyesore and can displease the tourists and other beach users (Plate 2.8 and Plate 2.9). The degradation of aesthetic values of beach caused by plastic debris can have serious effect on many beach users including naturalists, adventurers, campers, bush walkers and recreational fishers whom want to enjoy the natural scenery of beaches (Whiting, 1998).

Negative impacts caused by the debris on the beaches reduced recreational value, aesthetic quality and amenity. Thus, these impacts decreased satisfaction and enjoyment derived in beach usage. Eventually, it will reduce daily usage of the beach and beaches closed to the public will cause economic loss (Silva-Iñiguez and Fischer, 2003). These unattractive factors forced the coastal communities and government to spend funds in beach maintenances, as well as, increasing beach clean-up efforts by virtue of avoiding loss of tourism revenue and bad publicity (Ten Brink *et al.*, 2009; UNEP, 2009).

Plate 2.8: Marine debris comprising of small plastic pieces, washed ashore by tidal movement on a beach in Cocos (Keeling) Islands, Indian Ocean, Australia (Source: http://www.oceanwideimages.com).

Plate 2.9: Large abundance of marine debris particularly plastic found washed ashore and accumulate on (a) Haitian Coast and (b) Kaho'Olawe Beach are examples posed aesthetically displeasing picture of beaches view (Source: Lytle, 2009).

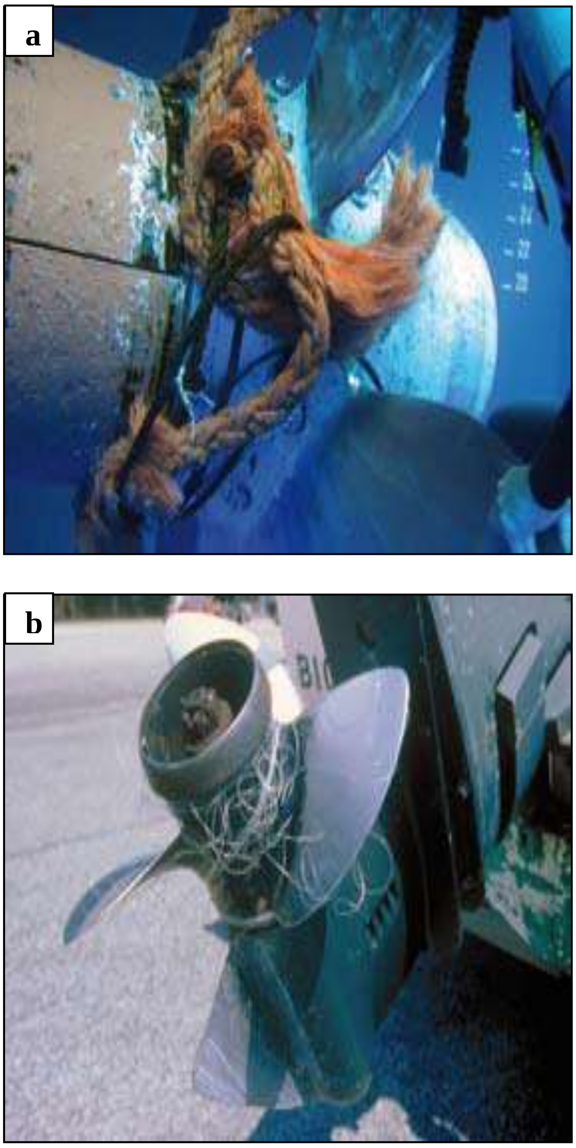
Meanwhile, the presence of submerged plastic debris in the benthic environment can be an aesthetic concern for swimmers and divers as they want to view the natural beauty of coral reefs habitat and benthic organisms (Moore, 2008). Moreover, plastic debris also can be a nuisance to coral reef. Plastic bags covered corals can be killed instantly when needed sunlight is block (Plate 2.10) (Lytle, 2009).

Physically, plastic fishing line can be destructive to living coral reefs as the fishing line can tangle in branch which scour, smother, abrade and destroy fragile reefs resulting from the movement of currents and tides (Ten Brink *et al.*, 2009; Bauer *et al.*, 2008). As studied by Chiappone *et al.* (2002), the damages to fire coral (83%), colonial zoanthids (77%) and branching gorgonians (69%) were due to hook-and-line gear.

Plate 2.10: Plastic on coral (Source: Lytle, 2009).

Furthermore, plastic debris have cause serious economic losses to various authorities and sectors. Shipping industry for example had to bear the cost of damaged vessel engines, fouled propellers, debris removal and waste management in harbours (Ten Brink *et al.*, 2009). Plastic bags present hazards to vessels by clogging or blocking water intakes which can burn out water pumps while ropes and lines of net can foul propellers or rudders (Plate 2.11) (Ten Brink *et al.*, 2009; Jones, 1995).

Small craft's propeller too can get wrapped by floating pieces of plastic foil (Gerlach, 1981). These incidents are very costly to be repaired, causing lost of time and also risks the life of crews and boaters while working to remove plastic debris (Ten Brink *et al.*, 2009; Moore, 2008). A survey by O'Callaghan (1993) from 1990-1992 estimated that the average cost to repair damages for commercial fishing vessels was 500 USD with additional 200 USD for the lost of time (Jones, 1995).



(a) Rope and cable found wrapped around the propeller of the Esperanza of the Greenpeace fleet, off the coast of St Helena, South Atlantic (Source: FAO, 2009).

(b) Nylon fishing tackle entangling an outboard motor propeller (Source: UNEP, 2009).

Plate 2.11: Attachment of (a) ropes and (b) nets to propellers.

2.8 PLASTIC DEBRIS MANAGEMENT

Removing plastic debris from marine environment is an extremely difficult and complex task. However, efforts to reduce the dumping of solid wastes especially plastic into the marine environment such as by imposing strict legislation, invention of new technologies in products to reduce the usage of plastic, educating public and promoting attitude change, and clean-up activity organized by many NGOs are showing some signs of success. The efforts to manage this debris hopefully may reduce and finally will terminate the detrimental impacts of plastic debris to man and environment.

2.8.1 Global Initiatives and Legislation

The International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL 73/78), is an international convention which controlled quantities of polluting substances discharged into the sea from the shipping sector (UNEP, 2001). One of the six annexes (Annex V) in MARPOL 73/78 discusses plastic debris prevention. Annex V was formally adopted in 1988 which then came into implementation in 1989 and has been ratified by 139 countries including Malaysia (UNEP, 2009; Henderson, 2001). It prohibits dumping of garbage especially plastics from ship into the world's oceans and it also requires ports to provide facilities of garbage loading from incoming ships (Andrady, 2003b; Chan *et al.*, 1996; UNESCO, 1994).

According to Pearce (1992), the Annex V of MARPOL "restricts at sea discharge of garbage and bans at sea disposal of plastics and other synthetic materials such as ropes, fishing nets, and plastic garbage bags with limited exceptions." Johnson (1994) had reported reduction in the accumulation of plastic debris in the oceans when Annex V was brought into force. Convention for the Prevention of Marine Pollution by Dumping of Wastes and Other Matter known as London Dumping Convention (LDC) was implemented in 1972 also forbids the dumping of persistent plastic materials into oceans during shipboard operations under Annex 1 (Derraik, 2002; Wolfe, 1987). Additionally, some countries have their own legislation related to plastic debris management such as Protection of the Sea (Prevention of Pollution from Ships) Act, 1983 (Australian), and

The Marine Plastic Pollution and Control Act of 1987 (USA) (Sverdrup and Armbrust, 2009; Jones, 1995).

There are a number of other international and national initiatives that commit to the problems of marine debris. For examples, the Convention for the Protection of the Mediterranean Sea against Pollution, as well as, the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities are the programmes that focused on the sources and negative effects of land-based activities on the marine environment (Allsopp *et al.*, 2006). Many other sea programs and action plans also have been adopted in regards to marine debris problem including Helsinki Convention, 1974; Kuwait Regional Convention, 1978; Oslo Convention, 1972; Regional Convention for the Conservation of the Red Sea and the Gulf of Aden Environment (Jeddah Convention), 1982.

2.8.2 Technology Invention

Invention of new technologies in products can be used to reduce the usage of plastics and uncertainties about how to decrease their disposal into the marine environment. Plastic-free bait box that used no plastic liner or straps was created by the Tasmanian Parks and Wildlife Service, and a container manufacturing company in 1990 had reduced the usage plastic in fishing gear applications (Jones, 1995). This plastic-free bait box is cheaper than the strapped bait box and it is reported to be the first of its type in the world (Jones, 1995).

Many of the commercial plastics today originated from petroleum-based polymers that are nondegradable (Moore, 2008). McCarthy (2003) emphasised that “nondegradable plastics packaging is blamed for shortening the life expectancy of commercial landfills, increasing the operational cost, contaminating the environment, and posing a threat to animal and marine life." One possible way to mitigate these problems is using biodegradable and enhanced-photodegradable plastic (Gregory and Andrady, 2003; Derraik, 2002). Researchers from University of Science Malaysia (USM) recently had produced biodegradable and environmental-friendly plastics product called the "Fruitplast" which is made from tropical fruits waste namely banana, rambutan and star fruits that took only one week of conversion process into plastic layer, suitable to replace regularly non-biodegradable plastics used in packaging utilization (Kosmo, 2010). This bioplastics invention may increase sustainable industry product and decrease environmental effects particularly to the marine environment (Swift, 2003).

2.8.3 Education and Attitude Changes

Educating about the precious value of marine environment and how to defend the nature from devastation may be the salvation of this ecosystem for future generations. Government agencies, NGO's, schools and other academic institutions, national marine parks and many other entities are working hard to provide scientifically based environmental information to citizens so that they can realize and be conscious about the importance to protect marine environment. Marine users had been targeted through posters, brochures, magazines articles, publications, signage and also annual beach clean-ups programmes (Plate 2.12) at national level to increase awareness among the public about the hazard of plastic debris (Barnes *et al.*, 2009; Jones, 1995).

In addition to environmental education programmes, the change of attitude is also necessary to minimize generation of solid waste specifically plastics, and to reduce the amount of waste dumped into the oceans and coastal area. It is the individual responsibility of beachgoers, fisherman or captain of a vessel to maintain a healthy and sustainable marine environment (UNESCO, 1994). Since plastics is made of crude oil which is a non-renewable resource, alternative options such as waste reduction at source, reuse of products and recycling of material should be promoted to conserve the earth's raw material resources and indirectly prevent plastic generation which could end up as plastic debris (UNESCO, 1994; Staudinger, 1974).

(a) A sign showed a sewer in Colorado Springs warning the local people to not pollute the local stream with solid waste. This is because 80% of marine debris reaches the sea via rivers through urban runoff and sewer (Source: www.reference.findtarget.com).

(b) Beach clean up programme organized by ICC in Thailand educates the public especially children (Source: UNEP, 2009).

(c) A poster can be a tool to convey information and raise awareness on the problem of marine debris (Source: Wu, 2009).

Plate 2.12: (a) Signage, (b) beach clean-up and (c) poster are example efforts to increase awareness among the public.

2.8.4 Clean-up Activity and Monitoring Programme

Collaboration and commitment among the community can be seen through the clean-up activity and monitoring programme. Beach cleanups by public remove marine debris mostly plastic, yield information on the amount and types of debris found, and educate the general public as they participate in the clean-up programmes. Besides, the information obtained can be used to reduce marine debris and enhance marine conservation.

Many of the local authorities, government bodies, volunteers and especially NGOs from all over the world work hand by hand in contributing towards coastal clean-up operations. The United Nations Environmental Programme (UNEP) and Environmental Protection Agency (EPA) had organized and funded various programmes to manage coastal cleanup event even though the cost can be very expensive (Allsopp *et al.*, 2006).

64 local communities in the North Sea region participated in beach clean-up in 1998 had spent six million US dollars (UNEP, 2005). Moreover, the National Oceanic and Atmospheric Administration (NOAA) spent two million US dollars annually to remove 50-60 tonnes of derelict fishing nets and gear from the Northwestern Hawaiian Island (Moore, 2008).

Regional Seas Programme (RSP) which is established under the auspices of UNEP plays an important part in organizing, implementing and promoting regional activities on marine debris around the world. RSP integrated 18 Regional Seas (Figure 2.4) where more than 140 countries including Japan, Philippines, Republic of Korea, Kenya, Thailand, Singapore and Malaysia participated (UNEP, 2009).

One of the RSP main activities is involvement in a regional cleanup day within the framework of the ICC campaign, coordinated globally by Ocean Conservancy (US-based ocean conservation NGO). It surveys beach, benthic and floating marine debris to gather scientific information on the types of debris collected for global database, the sources and impact of debris to environment, and also develop general global monitoring guidelines for marine debris (UNEP, 2009; Sheavly, 2005).

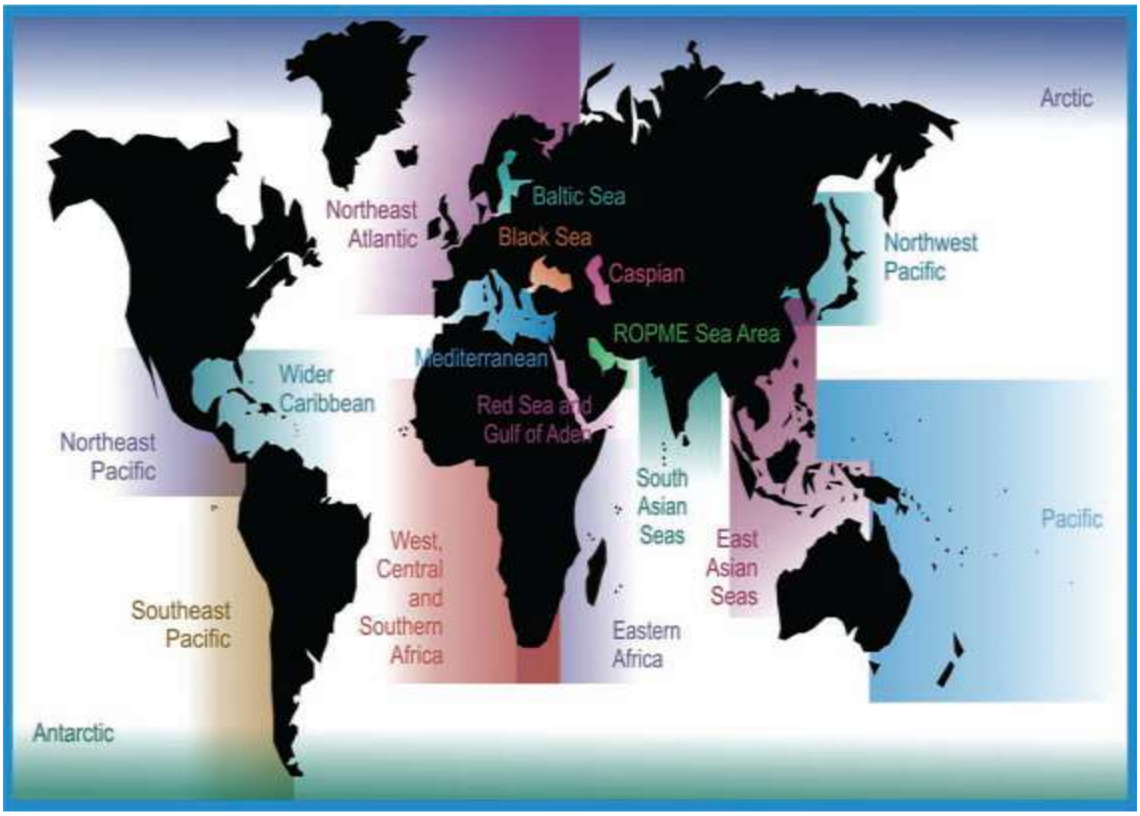


Figure 2.4: The 18 Regional Seas in UNEP–assisted marine debris activities (UNEP, 2009).

Ocean Conservancy which is funded by EPA and headquartered in Washington with support from almost 500,000 members and volunteers around the globe is the world's leading advocate for the ocean (Sheavly, 2007). One of the Ocean Conservancy's biggest success was the implementation of National Marine Debris Monitoring Programme (NMDMP) that comprised of federal agencies, scientists and other groups that are working on marine debris monitoring for five years to assess the status of marine debris along the USA coasts and islands (Figure 2.5) (Sheavly, 2007). The data from the study reported that 48.8% of all collected debris is land-based source, followed by general items and ocean-based source with 33.4% and 17.7% respectively (Sheavly, 2007).

Figure 2.5: NMDMP consists of 9 survey regions along USA coasts and islands (Sheavly, 2007).

Another clean-up program is the "Clean-Up the World" program, also under UNEP which gather not less than 40 million people from 120 countries during its operation (UNEP, 2005). NGOs such as Marine Conservation Society in United Kingdom and HELMEPA in Greece also conduct local beach clean-ups every year to raise public awareness on marine debris problem and to remove debris from the beaches (Allsopp *et al.*, 2006). In addition, 'adopt-a-beach' campaigns by civil society or private sectors are also promoted as a new approach to increase awareness among the general public and to keep beaches clean (UNEP, 2009).