ZOOPLANKTON COMMUNITY STRUCTURE IN THE COASTAL WATERS OF MANJUNG, PERAK AND PENANG NATIONAL PARK, PENANG

by

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STRUKTUR KOMUNITI ZOOPLANKTON DI PESISIRAN PANTAI MANJUNG, PERAK DAN TAMAN NEGARA, PULAU PINANG

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ABSTRAK

Kajian ini dijalankan untuk menentukan struktur komuniti zooplankton di pesisiran pantai di Manjung, Perak dan Taman Negara Pulau Pinang (PNP), Pulau Pinang serta hubungan antara komuniti zooplankton dan kualiti air di kawasan tersebut. Lima stesen persampelan berdekatan dengan stesen jana kuasa (Stesen Jana Kuasa Sultan Azlan Syah) di Manjung dan lapan stesen persampelan di PNP telah dipilih untuk kajian ini. Sampel zooplankton dan air telah dikutip setiap bulan dari November 2009 hingga Oktober 2010. Kaedah persampelan zooplankton adalah secara menunda plankton net (WP-2) di permukaan air. Sejumlah 51 takson zooplankton telah dikenalpasti di Manjung dengan purata kelimpahan dan biojisim masing-masing berjumlah 3689.96 $\pm$ 663.31 ind m^{-3} dan 25.51 $\pm$ 0.82 mg m^{-3}. Di PNP, sebanyak 49 takson zooplankton telah direkod sepanjang tempoh kajian dengan purata kelimpahan berjumlah 1449.99 $\pm$ 158.51 ind m^{-3} dan purata biojisim berjumlah 15.64 $\pm$ 0.26 mg m^{-3}. Populasi kopepod merupakan kumpulan zooplankton yang mendominasi di Manjung dan PNP dengan kelimpahan relatif masing-masing sebanyak 71.09% dan 72.09%. Di Manjung, Stesen 5 (terletak di muara dan hukan bakau) mencatatkan biojisim dan kelimpahan zooplankton yang tinggi, manakala biojisim dan kelimpahan zooplankton yang rendah dicatatkan di Stesen 2 (titik ambil masuk jana kuasa). Manakala, di PNP, kelimpahan dan biojisim zooplankton yang tinggi dicatatkan di Stesen 7 (terletak di Teluk Kampi dengan minima aktiviti manusia), manakala Stesen 1 (terletak di Teluk Bahang yang menerima kesan aktiviti manusia) mencatatkan kelimpahan dan biojisim zooplankton yang rendah.

Kelimpahan zooplankton yang tinggi dicatatkan di stesen yang terletak berhampiran bakau berkemungkinan disebabkan oleh populasi fitoplankton yang tinggi (diukur sebagai kandungan klorofil-*a*) yang menjadi sumber makanan zooplankton. Aktiviti antropogenik juga memainkan peranan dalam mempengaruhi struuktur komuniti zooplankton. Zooplankton berkait secara positif dan signifikan dengan klorofil-*a* dan nutrient, menunjukkan taburan zooplankton dipengaruhi oleh pengeluaran primer di Manjung. Klorofil-*a* juga berhubugan positif dengan bekalan nutrien. Di samping itu, di PNP komuniti zooplankton berkait secara negatif dengan ketelusan air, suhu, kemasinan dan kekonduksian. Dalam kajinan ini, ia mencadangkan komuniti zooplankton dipengaruhi oleh sumber makanan dan aktiviti antropogenik masing-masing di Manjung dan PNP.

ZOOPLANKTON COMMUNITY STRUCTURE IN THE COASTAL WATERS OF MANJUNG, PERAK AND PENANG NATIONAL PARK, PENANG

ABSTRACT

This study was carried out to determine the zooplankton community structure in the coastal waters of Manjung, Perak and Penang National Park (PNP), Penang and the relation between zooplankton community and water quality of the study area. Five sampling stations adjacent to a power plant station (Sultan Azlan Shah Power Station) in Manjung and eight sampling stations surrounding the PNP were selected in this study. Zooplankton and water quality samples were collected monthly from November 2009 to October 2010. Zooplankton samples were collected by horizontal towing with a plankton net (WP-2). A total of 51 zooplankton taxa were recorded in Manjung, with mean abundance and biomass of 3689.96 $\pm$ 663.31 ind m^{-3} and 25.51 $\pm$ 0.82 mg m^{-3} respectively. In PNP, 49 zooplankton taxa was recorded with mean abundance accounted for 1449.99 $\pm$ 158.51 ind m^{-3} and biomass 15.64 $\pm$ 0.26 mg m^{-3}. Copepods population was the dominant group recorded in Manjung and PNP with relative abundance amounted for 71.09% and 72.09% respectively. In Manjung, zooplankton biomass and abundance were recorded highest at Station 5 (located at the estuary and mangrove forest) whereas the lowest biomass and abundance was recorded at Station 2 (intake point of the power plant). Meanwhile, in PNP, Station 7 (located at Teluk Kampi with minimal human activities) recorded highest zooplankton abundance and biomass while lowest abundance and biomass was recorded at Station 1 (located at Teluk Bahang and highly impacted by human activities). Higher abundance of zooplankton recorded at stations nearer to mangrove

estuary might be due to greater phytoplankton population (measured by chlorophyll-*a* content) that provides food for zooplankton. Anthropogenic activities also play a role in influencing the zooplankton community structure. Zooplankton showed significant positive relation with chlorophyll-*a* and nutrient, showing that their distribution was influenced by primary production in Manjung. Chlorophyll-*a* was positively correlated with nutrient concentration. In addition, in PNP, zooplankton was significantly negatively correlated with water transparency, temperature, salinity and conductivity. In the present study, it was suggested that zooplankton community was highly influence by food availability and anthtopogenic activities in Manjung and PNP respectively.

CHAPTER 1

INTRODUCTION

The marine environment which covers nearly 70% of the Earth's surface is the most extensive and uniform realm on Earth. The coastal zone is the border between land and water. Therefore, the physical and biological processes of the coastal zones are influenced by land. These zones are important because they serve as habitat for a diversity of flora and fauna. Estuaries, mangrove, beaches, coral reefs and sea grass beds are the major ecosystems of the coastal areas (Stiling, 1996).

The strategic location of the Straits of Malacca supports a variety of tropical coastal ecosystem and species. Its coastal area is rich in mangroves, estuaries, coral reefs, mudflats, beaches and small island ecosystems (Chua et al., 2000; Omar, 2003). However, the coastal zones of West Coast Peninsular Malaysia recently suffered a lot of anthropogenic activities such as shipping, coastal power plants, industries, aquaculture, fisheries, tourism, transportation and sewage discharge that brought along environmental pollution issues to the coastal region (Abdullah et al., 1999; Omar, 2003; Mazlan et al., 2005).

Currently, Peninsular Malaysia's electrical generating capacities is 21817 MW, which is still highly dependent on fossil fuel such as natural gas (~60%) and coal (~25%) as their primary source of energy (Suruhanjaya Tenaga, 2010). The Malaysian government have a policy to shift away from the highly reliance on natural gas for electric power generation to coal-fired power plant. It is estimated that in the year 2020, there will be equally dependent on natural gas and coal as a generating fuel in Peninsular Malaysia. Malaysia also has made initiatives on renewable energy and promotes it under 8^{th} and 9^{th} Malaysia plan to ensure a sustainable development. Under the Fifth Fuel Policy of 8^{th} and 9^{th} Malaysia plan, Malaysia has focused on biomass as one of the potential renewable energy (Lim et al., 2006).

Due to heavy dependence on thermal power plant in Malaysia, effluents of heated sea water from power plants into coastal areas became a major environmental concern in marine ecosystem. Power plants require large quantities of water to cool down the turbine and release the heated water back to the surrounding sea. One of the environmental issues that need to be considered is the thermal stress during the continuously discharge of heated water into the marine ecosystem. Several studies indicated that a temperature variation affects the metabolic rate, reproduction, growth, survival, distribution and abundance of marine organisms (Capuzzo, 1980; Neuman, 1983; Houde, 1989; Lardicci et al., 1999; O'Connor et al., 2007).

Heated water discharge from power plants is only one of several sources of environmental concern. During the cooling process, power plants withdraw and pump in vast amount of cooling water and there is a potential for the entrainment of marine organism. Plankton is capable to pass through the intake screens and potentially subject to passage through power plant cooling systems. Mayhew et al. (2000) indicated that survival of entrainment was high with improvement of plant-operating design. During the entrainment processes which are high temperature elevation, however, low mortality of crustacean zooplankton was recorded (Karas, 1992). Besides, there may also be problem of entrapment of larger fish and other organisms at water intake structures (Azila and Chong, 2010). According to Chae et al. (2008), large amount of the gelatinous plankton (*Salpa*) clogged at the intake screen which disturbed the cooling water supply and eventually caused interruption of electrical generation in Uljin nuclear power plant, Korea.

In addition, the coastal area is under increasing pressure of anthropogenic activities and pollution resulting in reduced water quality (Ghazali, 2006). Such pollution had caused severe impact on the ecology and economy of the area. According to Yusoff et al. (2000) and Omar (2003), river water quality deteriorated with discharge of agriculture and industrial waste into river system, and poses its negative effects on the population within the river system in the downstream area. Hence, water quality becomes an important parameter in determining pollution and environmental condition (Maiti, 2004; Suthers et al., 2009). Therefore, proper environment management was needed to monitor and manage the coastal zone.

Zooplankton is crucial in the functioning of marine food web because of their secondary production role in the ecosystem (Redden et al., 2009). It plays a key position in the flow of energy from primary producers to the higher trophic levels that are commercially and ecologically important. Zooplankton communities are highly diverse and thus perform a variety of ecosystem functions. Studies have shown that zooplankton is an important food sources for fish larvae (Turner, 2004; Winder and Jassby, 2010). It is amazing that the largest animal in the ocean such as whale also feed on zooplankton (Beardsley et al., 1996). Lately, zooplankton communities have been widely used as a biological indicator. Study of zooplankton community can provide useful information on the biological production and the variations of water quality parameters that will directly affect the abundance and composition of zooplankton.

In Malaysia, earlier studies of zooplankton focused mostly on the plankton abundance and diversity (Chua and Chong, 1975; Zubir, 1993). Recent work focused on quantitative studies of marine zooplankton in the Straits of Malacca (Johan et al., 2000; Idris et al., 2000; Rezai et al., 2000; 2004; 2009; 2011; Yoshida et al., 2006; 2012). However, some studies were performed during the several survey cruise (Chew et al., 2008; Rezai et al., 2000; 2004; 2009), while continuous observation of zooplankton was rather limited to Idris et al. (2000) and Yoshida et al. (2006), while Idris et al. (2000) only focused on the copepod of Straits of Malacca. Nevertheless, several studies of zooplankton were carried out at other various ecosystems such as freshwater (Ali, 1990; Intan, 2009), mangrove (Zaleha et al., 2008; Chew and Chong, 2011) and coral reef (Nakajima et al., 2008).

However, in Malaysia studies of zooplankton species diversity in the coastal water at the vicinity of thermal power plants are rather limited. Previous impact study on the thermal effluent from power plants concentrated more on fish and invertebrate organisms (Azila and Chong, 2010), and little attention had been paid to plankton community. Hence, the knowledge about the influence of thermal power plant on the plankton community, which is food resources in the marine ecosystem is lacking in Malaysian coastal waters. Therefore, the information on zooplankton community is necessary and important for future monitoring purposes because released of heated effluent into the open environment may affect the organisms in the vicinity of thermal power plants.

Zooplankton community had been used in bio-monitoring of the marine ecosystem and integrity of water. It had been recognized that abundance and distribution of zooplankton varied with ecological and hydrological conditions.

Zooplankton growth, abundance and distribution were highly reliant on the biotic (eg: food availability, predation etc) (Castonguay and FitzGerald, 1990; Godhantaraman 2001; Winder and Jassby, 2010) and abiotic factor (eg: salinity, temperature, dissolved oxygen etc) (Heinle, 1969; Fang et al., 2004).

In the present study, the abundance and distribution of zooplankton in Manjung, Perak and Penang National Park, Penang was evaluated. A thermal power plant is situated at the Manjung coast with continuous discharge of thermal effluent. Besides, Penang National Park is a protected and recreational area with several anthropogenic activities in certain part of the area. To the best of our knowledge, this is the first study in the region where monthly observation of zooplankton community from thermal power plant was carried out. Hence, it is important to investigate the zooplankton community structure and water quality status in order to assess the environmental conditions in the coastal waters.

The objectives of this study are as follows:

1. To determine the status of water quality in the coastal waters of Manjung, Perak and Penang National Park, Penang.
2. To study the composition and abundance of zooplankton in the coastal waters of Manjung, Perak and Penang National Park, Penang.
3. To study the relation between zooplankton community and water quality of the coastal waters of Manjung, Perak and Penang National Park, Penang.

CHAPTER 2

LITERATURE REVIEW

2.1 Coastal Marine Ecosystem

The coastal areas of the tropical marine environment support many unique and diverse ecosystems. It encompasses ecosystems from upland, freshwater portion of river basin through the interface estuary, mangrove, and coral reefs until to the open ocean (Stiling, 1996). The various conditions at the coastline such as tidal exposure, coastal current, temporal and spatial changes, monsoon, freshwater and nutrient input represented their unique characteristic. This near-shore area is also a highly natural productive area. The particular combinations of various environmental factors may contribute to the area-specific characteristic of an ecosystem, and ultimately determines the specific ecological attributes of the system.

Major ecosystems in the coastal areas are constituted by mangrove, estuaries, coral reefs, sea grass bed and beaches. Presently, there are 108,800 hectares of mangrove forest in Peninsular Malaysia, while the Larut-Matang area which is situated in the north coast of Perak alone contributed 40,711 hectares (Omar, 2003). Mangroves are tide-influenced wetlands made up of mangrove forests, estuaries and associated habitats along the coastlines (Ong, 1995; Kathiresan and Bingham, 2001; Bagarinao and Primavera, 2005). It serves as a productive ecosystem and supports high abundance and a diverse variety of marine organisms. Estuaries are partially enclosed water bodies where freshwater from river merges with the ocean (Telesh and Khlebovich, 2010). Furthermore, mangrove and estuary provides a feeding, breeding and nursery ground for juvenile fish and crustacean (Beck et al., 2001;

Kostecki et al., 2010; Chew and Chong, 2011). For example, mangroves support the shrimp as well as the offshore fisheries such as molluscs, crabs, and fish (Kathiresan and Bingham, 2001), while giant freshwater prawn (*Macrobrachium rosenbergii*) hatched their eggs in the brackish water environment of the estuary. Besides, mangroves also acted as a buffer region against tidal erosion to protect ecosystem (Bagarinao and Primavera, 2005).

In addition, coral reefs and sea-grass beds also highly support marine biodiversity and sustain human activities (Chua et al., 2000). They contribute to fisheries, marine tourism, shoreline protection, nursery and feeding grounds (Arshad et al., 2011). Coral reef and sea-grass beds ecosystems served as the important habitat for sea turtles (Jackson, 1997) and the highly endangered dugong (Fortes, 1990; Mansor et al., 2005). According to McClenachan et al. (2006), sea turtle nesting sites were gradually declining and 50% of the remaining nesting sites were reduced to dangerous low population in Caribbean. It is in close agreement with Mazlan et al. (2005) and Chan (2006) studies which reported that threats and loss of turtle nesting habitat in Malaysia due to beachfront development. Recreation and tourism activities have brought along human encroachment to beaches. The extensively used of coastal areas for fishing activities, boat landings, sewage and construction materials with minimum enforcement have increased the concern on the environmental impact.

The Straits of Malacca coast suffered a lot of anthropogenic activities. Growing human population and coastal developments had resulted in the widespread of land-based and sea-based sources of pollution (Abdullah et al., 1999). Shipping activities and discharge, land reclamation and coastal power plants, domestic and industry discharges, aquaculture and fisheries and tourism have brought along the environmental pollution issues to the coastal region (Chua et al., 2000; Omar, 2003).

Mangroves in the Strait of Malacca had decreased gradually in recent years through the conversion of mangroves into shrimp ponds farming, agriculture farms and urbanization (Ong, 1995; Kathiresan and Bingham, 2001; Alongi et al., 2002; Bagarinao and Primavera, 2005; Mazlan et al., 2005). In addition, poor management practices and lack of enforcement by the authorities lead to water quality degradation from the effluent of aquaculture and agriculture farms (Ong, 1995). The degradation of mangrove ecosystem resulted in the lost of food supply and marine diversity (Kathiresan and Bingham, 2001; Alongi et al., 2002). Furthermore, over-exploited of fisheries and human pressure also contributed to the depletion of fish species and habitat loss.

In sea-grass beds, dugong was less frequently observed as earlier reported in the past due to the heavy vessel traffic in the Straits of Malacca (Mansor et al., 2005; Mazlan et al., 2005). Human activities such as land reclamation, deforestation, oil spill, blast fishing, coastal aquaculture and sedimentation had endangered the sea-grass beds habitat (Fortes, 1990; Mansor et al., 2005). Although coral reefs can degrade naturally due to current, storms and star fish infestation, however, studies indicated that coral reefs habitats at the Straits are being degraded because of pollution and sedimentation from coastal development activities, tourism industry and boat anchoring (Omar, 2003; Mazlan et al., 2005).

2.2 Straits of Malacca

The Straits of Malacca is one of the busiest strait in the world because it served as an international route for the Indian and Pacific Oceans, and for Asia and Australia (Purwaka, 1998). It is located between Indonesia, Malaysia and Singapore. It was greatly influenced by the Andaman Sea and South China Sea as well as the drainage from the river systems of Peninsular Malaysia and Sumatra (Moosa, 1988).

The Straits of Malacca can be geographically subdivided into 3 regions; the northern, central and southern regions. It is a funnel shape straits with a broader entry at the northern region, while becoming narrower at the southern region (Hii et al., 2006).

The strait is a very important and productive coastal ecosystem, rich in marine and fisheries resources (Mazlan, 2000). However, there is a concern over increasing human population and anthropogenic activities in the surrounding area. According to Abdullah et al. (1999), the multiple-use of the Straits of Malacca had resulted in the increase of pollutants such as oil spills, domestic, industrial and agricultural wastes.

2.3 Thermal Power Plant

In Malaysia, the demand of electricity for domestic, commercial and industrial usage is rapidly expanding (Oka and Embi, 2007). In 2009, electricity demand for Peninsular Malaysia was 14,245 MW and the demand was forecasted increase to 19,389 MW in year 2020 (Suruhanjaya Tenaga, 2010). Therefore, additional of generation capacities from power plant is needed to enhance the future electricity supply. For instance, the operation of the coal-fired power plant in Jimah

Energy Ventures Sdn. Bhd., Port Dickson will increase the electrical generating capacity to 21,817 MW in year 2009 (Suruhanjaya Tenaga, 2010).

Currently, Malaysia is still very dependent on fossil fuel such as natural gas and coal for the generation of electricity (Oka and Embi, 2007; Suruhanjaya Tenaga, 2010). However, renewable energy such as hydroelectricity, wind, solar and biomass are less common. With the increase in fuel price, the Malaysian government realized the constraint of highly reliant on fossil fuel for both economic and environmental reason. Hence, renewable energy had been emphasized in the Fifth-Fuel Policy under the 8^{th} and 9^{th} Malaysia Plan which comprises of oil, natural gas, coal, hydro and renewable energy to diversify the energy sources in the future (Lim et al., 2006). However, the Fifth-Fuel Policy under the 8^{th} Malaysia Plan did not achieve the targeted 500 MW of electric generation by renewable sources but only delivered 12 MW of electric generation. Therefore, Fifth-Fuel Policy is continued into the 9^{th} Malaysia Plan to promote and develop the renewable energy.

According to the Energy Commission of Malaysia, the contribution of coal as an energy source of power generation will increase due to their abundance and affordability (Oka and Embi, 2007). In order to meet the government policy, coal has been focused as energy sources to shift away from highly dependent on natural gas for electric generation to coal-fired power plant. In 2012, it is estimated that ~52% of energy sources was contributed by coal in Peninsular Malaysia (Suruhanjaya Tenaga, 2010). Coal-fired power plant generated electric by burning the coal in a boiler to produce steam. The high pressure steam will be injected into a turbine which spins a generator to produce electricity. In the process, the steam is then condensed back to water as it passes over a series of condenser tubes through which cold sea water from the main cooling water system is circulated. Therefore, thermal power plant required large volume of sea water for the cooling purpose and continuously discharge heated sea water back into the sea.

The increased demand for coastal power plant has been associated with an increased concern over environmental impacts on coastal ecosystems (Hung et al., 1998; Kulkarni et al., 2011). It had been shown that the effluent impacted water quality (Zargar and Ghosh, 2006), as well as abundance and composition of fish (Neuman, 1983), plankton (Hoffmeyer et al., 2005; Poornima et al., 2005; 2006) and benthic organisms assemblages (Markowski, 1960; Lardicci et al., 1999) in coastal areas. Hence, monitoring of environmental variation of coastal water was crucial for better understanding the effects to marine ecosystem.

One of the environmental issues associated with the operation of power plants is the potential thermal stress to aquatic organisms in its vicinity. In Taiwan, thermal effluents from nuclear power plants had resulted in fish body abnormalities and coral bleaching (Hung et al., 1998), as well as affecting the biomass and productivity of periphyton and phytoplankton (Chuang et al., 2009). Studies showed that zooplankton abundance steeply decreased in areas close to heated water discharge, while higher mortalities was also observed at discharge sites (Hoffmeyer et al., 2005).

2.4 Water Quality

The coastal areas are subjected to various environmental conditions; every factor plays their important role in the ecosystem. Hence, an environmental change such as variation of sea water quality may affect natural ecosystem. Marine organisms in the ecosystem are sensitive to environmental changes (Suthers et al., 2009). Therefore, the knowledge of water quality changes in coastal areas play a crucial role in detecting the natural environmental changes in coastal waters. In addition, it helps to distinguish the changes caused by natural process or anthropogenic activities. This information could also serve as a background data for future monitoring and providing an overview of the existing trends of environmental quality.

Besides, water quality can act as useful tools for pollution monitoring (Maiti, 2004), simultaneously species diversity in the ecosystem is also closely related to environmental condition (Webber et al., 2005). Aquatic organisms are usually influenced by a combination of several environmental factors. Thus, it is hard to demonstrate the individual relationship between the environmental factors alone.

Water quality parameters observed in the present study were total suspended solids (TSS), water transparency, pH, conductivity, salinity, temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), chlorophyll-*a*, ortho-phosphate (PO_4-P), ammonium-nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N) and nitrite-nitrogen (NO_2-N).

Total suspended solids (TSS) is the amount of suspended solid matter in water (Maiti, 2004) and determination of TSS is crucial in the analysis of polluted water. Increase of TSS will reduce the visual clarity of water column. High suspended solids could provide a refuge from predators (Estlander et al., 2009), but the reduction of light transmission through the water column will lower the photosynthesis in aquatic plants (Gameiro et al., 2011). Castonguay and FitzGerald (1990) reported that the daily horizontal migration of *Eurytemora affinis* into the dense algal biomass was apparently to avoid predation by sticklebacks. In addition, Roman et al. (2001) suggested that the hydrodynamic processes which are the re-suspension and trapping of suspended solids in an estuary is expected to have the similar effects on zooplankton biomass.

Water transparency refers to the interference of light penetration by suspended solids in the water. This characteristic varies with the combined effects of color and turbidity (Bartram and Balance, 1996). Suspended solids reduced water transparency by absorbing and scattering light. It leads to warmer sea water because suspended solids absorbed heat from the sunlight, which also resulted in lower dissolved oxygen levels. Eventually, it resulted in the fall of dissolved oxygen level and lesser sunlight available for photosynthetic use by aquatic plants.

pH is crucial in water quality monitoring. The variability of pH was closely related with the concentration of total dissolved CO_2, alkalinity, temperature and pressure (Hinga, 2002). Basically, daily variation of pH is caused by the metabolic processes of photosynthesis and respiration. pH increases because photosynthetic activity consume CO_2, whereas it declines because of the release of CO_2 during respiratory activity. The pH of seawater in coastal environments is in the range of 7.5 to 8.5 (Hinga, 2002). In addition, reduced sea water pH had been of concern because of the ocean acidification (Doney et al. 2009). In forest ponds, low pH value was directly contributed to low zooplankton biomass (Holopainen, 1992).

Conductivity is a measure of the ability of water to conduct electrical current (Maiti, 2004). The presence of inorganic dissolved solids such as anions or cations affected conductivity in water. Sources of pollutants such as waste water from sewage treatment plants, agricultural runoff, and urban runoff increase available ions in water. Additionally, conductivity is a good indirect measurement of salinity by detecting concentration of chloride ion from the sea water (Suthers et al., 2009).

Salinity is defined as the total dissolved salt in seawater and is widely measured. It fluctuated seasonally and influenced by variations in sea level, tidal flow, freshwater discharge and evaporation. Hence, salinity plays a critical role in the structuring and functioning of aquatic organisms especially in estuaries (Telesh and Khlebovich, 2010). Species composition and diversity change gradually with salinity. The narrow salinity range served as an ecological border for the distribution of the aquatic organisms in the marine environment (Telesh and Khlebovich, 2010).

Temperature is another important environmental variable, which affects the survival, growth and reproduction of aquatic organisms (Stiling, 1996). Studies indicated that both temperature and salinity were strongly influenced by differential heating, air temperature, precipitation and river input (Visser et al., 1996). In Taiwan, water temperature changes during thermal discharge from power plants probably become a more important factor compared to nutrient in influencing the biomass of phytoplankton and zooplankton (Fang et al., 2004).

In tropical areas, coastal water temperature is high throughout the year without any extreme seasonal changes. However, temperature deviation can influence the physical, chemical and biological characteristic of seawater. For example, increase in temperature of seawater results in an increase in the metabolic rate of the organisms, as well as reduction of its dissolved oxygen concentration. In general, tropical aquatic organisms experience a thermal regime relatively close to their thermal tolerance limit. According to Jiang et al. (2008), thermal tolerance of zooplankton varied widely among species and duration of exposure to thermal stress.

Dissolved oxygen (DO) is a useful indicator of aquatic health (Tebbutt, 1998). Its presence is essential to maintain the life of aerobic organisms. Atmosphere is the major source of dissolved oxygen to the water column. Besides, photosynthesis also contributes to the concentrations of DO. DO concentrations decrease during decomposition of organic matter and respiratory activity of aquatic organisms. Studies suggested that low DO concentration potentially affected the trophic interaction in the estuarine food web at Chesapeake Bay (Breitburg et al., 1997). Purcell et al. (2001) reported that the jellyfish tolerate low DO concentrations much better than fishes; potentially give jellyfish an adaptive advantage over fishes in the eutrophic coastal environments.

Biochemical oxygen demand (BOD) is an indirect measure of biodegradable organic compounds in water by measuring the quantity of oxygen used in the oxidation of organic matter (Maiti, 2004). BOD concentration indicates the level of organic pollution in aquatic systems which adversely affect the water quality. Consequently, a high BOD concentration reflects high concentrations of substances that can be biologically degraded, thereby consuming oxygen and potentially resulting in low dissolved oxygen in the receiving water.

Chlorophyll-*a* is the main green photosynthetic pigment found in all plants (Maiti, 2004). Hence, measurement of chlorophyll-*a* concentration provided an indirect estimation of photosynthetic plankton density and biomass. The growth and density of phytoplankton appeared to be influenced by nutrient input, predator, water temperature, light and turbidity. Studies showed that upwelling process resulted in a higher primary productivity in the surface water (Susanto and Marra, 2005).

Nutrients are chemicals that are essential for the proper health and growth of plants. Excessive of nutrient input resulted in eutrophication. The most important and major nutrients affecting primary productivity are the compounds of nitrogen and phosphorus. Growth and abundance of phytoplankton is dependent on the availability of dissolved nitrogen and phosphorus (Moore and Sander, 1982; Trevisan and Forsberg, 2007). Studies showed that changes of nutrient concentration affect the phytoplankton composition at the Jiaozhou Bay, China (Yao et al., 2010).

Nitrogen usually occurs in natural waters as ammonium-nitrogen, nitrate-nitrogen and nitrite-nitrogen. Ammonium is an inorganic substance released from dead aquatic plants, feces and dead animals. Then, ammonia is oxidized to form nitrite-nitrogen and nitrate-nitrogen. Nitrate-nitrogen is an important nutrient for plant growth. Fertilizers, precipitation, domestic and industrial waste also contributed to nitrate input (Gruber, 2008; Liu et al., 2010).

In addition, phosphorus is another essential nutrient for aquatic organism. Generally, phosphorus exists in either particulate phase or a dissolved phase (Föllmi, 1996). It can be found in living and dead plankton, organic phosphorus excreted by organisms, soil, water and sediment in the form of chemical compounds.

2.5 Zooplankton

Zooplankton is the animal portion of the plankton. Zooplankton is referred as microscopic aquatic organisms that are non-motile and drift in the water column (Rissik and Suthers, 2009). They are found everywhere in all oceans and coastal waters, at all depths and are also found in other inland aquatic systems. The marine zooplankton comprises a broad spectrum of species ranging from protozoans such as microscopic ciliates with only a few microns up to giant jellyfish with 2m in diameter (Lenz, 2000; Redden et al., 2009). Hence, zooplankton can be range into size categories of picoplankton (<2 µm), nanoplankton (2<20 µm), microplankton (20<200 µm), mesoplankton (0.2<20mm), macroplankton (20<200mm), and megaplankton (>200mm).

It can be further classified into proto-zooplankton and meta-zooplankton (Lenz, 2000). Proto-zooplankton is the protozoa especially with naked ciliate. Their division rate is rapid which enable them to almost keep pace with phytoplankton, while meta-zooplankton comparatively has longer lifespan such as small crustacean.

Zooplankton plays an important role in the marine ecosystem as a secondary producer. It is located at the intermediate position in a food web that forms a link between primary producers to higher trophic levels (Redden et al., 2009). Zooplankton are more abundant in the regions with elevated phytoplankton biomass, which suggested that zooplankton production was closely related to food availability (Godhantaraman, 2001; Turner, 2004; Trevisan and Forsberg, 2007). On the other hand, studies indicated that zooplankton are important food resources for fish larvae (Turner, 2004; Winder and Jassby, 2010). Thus, the variations in the availability of zooplankton were suspected to be associated with larval survival and subsequently affected fish population. According to Chew and Chong (2011), copepod was the major food resources in pelagic food web that their abundance will imply considerable influence to mangrove ecosystem.

Zooplankton is characterized by a short life cycle and highly dependent on the movement of water masses. It responds directly and sensitively to biotic and abiotic changes that existed in the environmental ecosystem (Ferdous and Muktadir, 2009). According to Chen et al. (2011), modification of zooplankton composition was observed in estuarine and coastal areas. These suggested that zooplankton biomass and composition was greatly influenced by a variety of ecological and hydrological conditions such as riverine discharge, eutrophication, nutrient, food quality and predation. On the other hand, temperature is one of the crucial factors that affect mortality, growth, reproduction, feeding rate, metabolic rate, distribution and abundance of zooplankton (Heinle, 1969). Lavaniegos (2009) reported that the cooling and freshening upper layer of marine water by the intrusion of subarctic water had been resulted in the drop of zooplankton biomass. In addition, studies suggested that calanoids, rotifers and mysid declined due to the predation of clam, *Corbula amurensis* and reduced of food availability (Winder and Jassby, 2010). Hence, changes of marine ecosystems either natural or human-induced, could be observed through alteration in zooplankton communities including diversity, composition and abundance (Beaugrand, 2005). Therefore, zooplankton becomes a suitable model for the study of ecological structure, as well as their spatial and temporal dynamic in the marine coastal system.

There are many factors that affect zooplankton distribution and abundance, but the association between the effects of thermal power plant discharge and how zooplankton reacts to them is a matter for speculation. The increase of temperature at ambient coastal water due to the discharged of heated effluent affected the growth and productivity of phytoplankton (Poornima et al., 2005; 2006), which subsequently influenced other higher trophic levels organism that are dependent on phytoplankton. In addition, the rising of temperature in the vicinity to power plants had been commonly reported and the increase of water temperature will influence mortality, abundance and distribution of zooplankton (Carpenter et al., 1974; Melton and

Serviss, 2000; Hwang et al., 2004; Hoffmeyer et al., 2005; Dias and Bonecker, 2008). Therefore, the information gained might provide a background data for future monitoring and will be useful for pollution control measures.

2.5.1 Taxonomic Composition

Although all the phyla are represented in the zooplankton, the most commonly encountered are phyla Cnidaria, Arthropoda, Annelida, Mollusca, Bryozoa, Ctenophora, Chordata, Nematoda, Chaetognatha and Echinodermata (Lenz, 2000; Conway et al., 2003). Phylum Arthropoda is made up of small crustaceans which are mostly represented by cladocerans, ostracods, copepods, cirripeds, mysids, amphipods, euphausiids and decapods. On the other hand, gelatinous zooplankton can be referred to medusae, ctenophores, appendicularians, doliolids and salps.

Copepods are aquatic crustacean which are the most numerous, diverse and biologically important zooplankton groups in the ocean (Suthers et al., 2009). In general, the main orders of copepods are Calanoida, Cyclopoida, Poecilostomatoida and Harpacticoida. According to Rezai et al. (2009), copepods were the dominant zooplankton group along the Straits of Malacca which contributed 50-70% of the total zooplankton. In addition, during 4 cruises along the Straits of Malacca, 117 copepod species were identified which were dominated mainly by Families Paracalanidae, Oithonidae, Euterpinidae, Corycaeidae and Oncaeidae (Rezai et al., 2004).

Cnidaria includes the jellyfish, anemones, corals and hydroids. Hydrozoa is a group that contains most the diverse of planktonic member such as medusae and siphonophores (Conway et al., 2003). It is usually found close to the surface layer in the marine ecosystem. On the other hand, ctenophores which is commonly known as comb jelly are not common in the tropics but occur regularly in the samples. In addition, ctenophore can be differentiated from cnidaria by the lacking of the stinging cell character to capture prey (Conway et al., 2003). According to Graham et al. (2001), gelatinous zooplankton aggregation was influenced by geographical and physical environment as well as biological interaction.

Usually, planktonic larvae observed were from phyla mollusca, echidodermata and annelida. According to Schwamborn et al. (2002), planktonic larvae are found commonly in the surface layer of tropical water. Chaetognaths commonly known as the arrow-worms because of their slender arrow like nature are predators and have fins on the side of their bodies.

2.5.2 Zooplankton Biomass and Abundance

Quantitative measurement of zooplankton is important to develop the understanding of plankton community and their role in the marine coastal ecosystem. Zooplankton concentration can be determined by zooplankton biomass or enumeration and identification method (Postel et al., 2000). Although the observation of zooplankton biomass is rapid and economical, this method is usually used to study mixed sample which do not distinguish live or dead organism. Therefore, it is usually used as a compliment and substitution to the information provided by numerical abundance data.

Zooplankton biomass and abundance was higher in coastal areas, which is probably caused by the increased of nutrient and chlorophyll-*a* (Rezai et al., 2000). It is in agreement with a study on copepods that higher abundance was observed at near shore but reduced towards upstream and offshore water (Chew and Chong, 2011). Simultaneously, higher biomass is probably influenced by river runs off and extensive mangrove forest in the coasts (Rezai et al., 2003). In addition, high productivity in the Straits of Malacca contributed to higher zooplankton biomass compared to South China Sea (Rezai et al., 2000).

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Site

The present study was carried out at the northern and central regions of the coastal waters of the Straits of Malacca. Two sampling sites were selected in this study, which is in Manjung, Perak and Penang National Park, Penang (Figure 3.1).

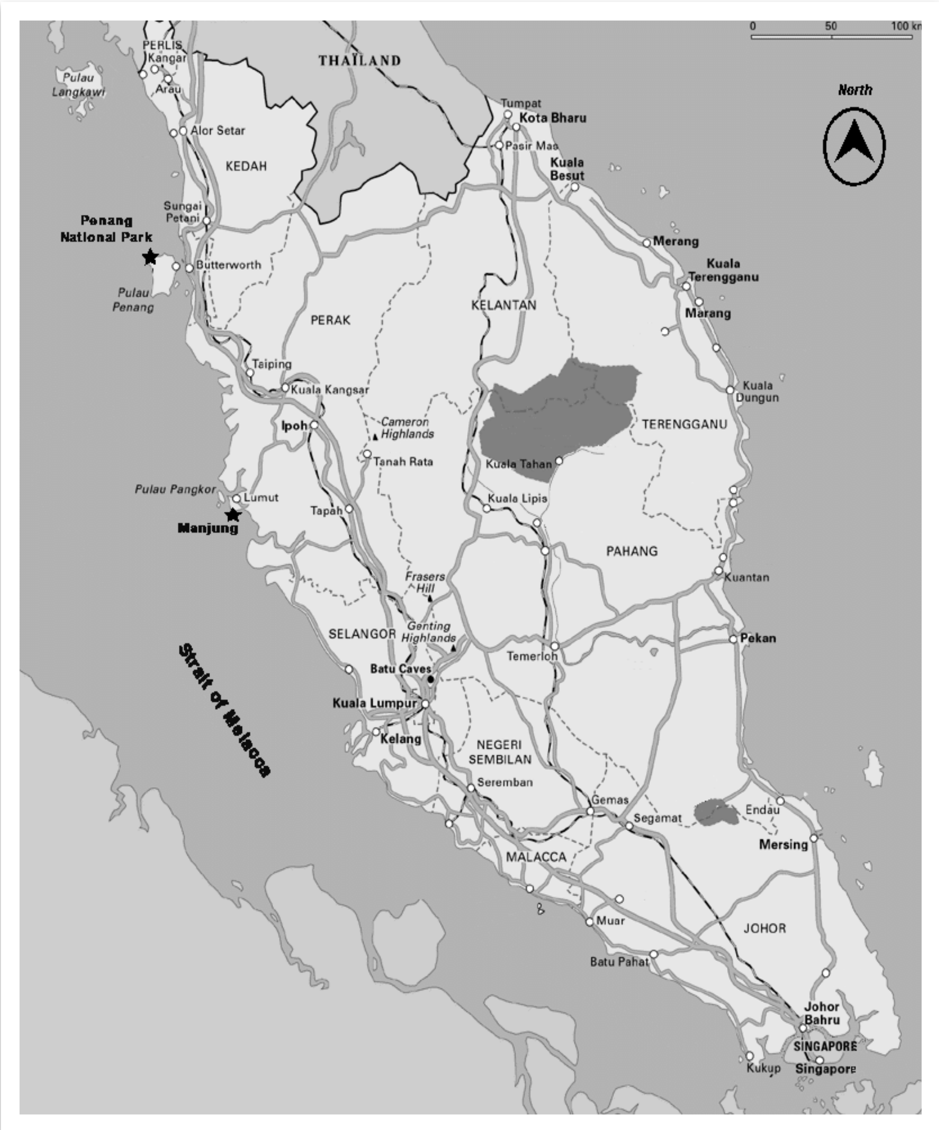

Figure 3.1: Study sites (Penang National Park and Manjung) of the zooplankton in the coastal waters of Straits of Malacca.

3.1.1 Manjung, Perak

Manjung is a district in the south-western part of Perak, Malaysia. It is the city of tourism with famous tourist attraction, the Pangkor Island. Sultan Azlan Shah Power Station (SASPS) is located at the Manjung coast, which is situated along the Straits of Malacca. SASPS (Lat 4º09’44”N, Long 100º38’48”E) is a coal-fired thermal power plant that was constructed on a man-made island in July 1999. Since 2003, SASPS was generating 2,100 MW of electricity from its three 700MW steam turbines to cater for rapidly rising electricity demand (TNBR, 2007). Sea water is used as coolant water. The circulating water system takes in sea water from intake points further offshore to the three condensers, and the resulting heated sea water is released via a discharged outlet. Ash generated during the process is disposed in the ash ponds.

Five sampling stations (Table 3.1) were selected at the surrounding waters of the thermal power plant (Figure 3.2). S1 and S5 were situated further from the thermal effluent; meanwhile S2, S3 and S4 were located close to the intake point, discharged and ash treatment pond of power plant respectively.

Table 3.1: Location and description of the sampling stations at Manjung, Perak

Station	Geographical Remarks
S1	S1 was between Pulau Katak and the mainland.
S2	S2 was characterized by intake point of the power plant.
S3	S3 was located in front of the discharged point of the power plant.
S4	S4 was close to ash treatment pond.
S5	S5 was characterized as estuaries and closed to mangrove forest.

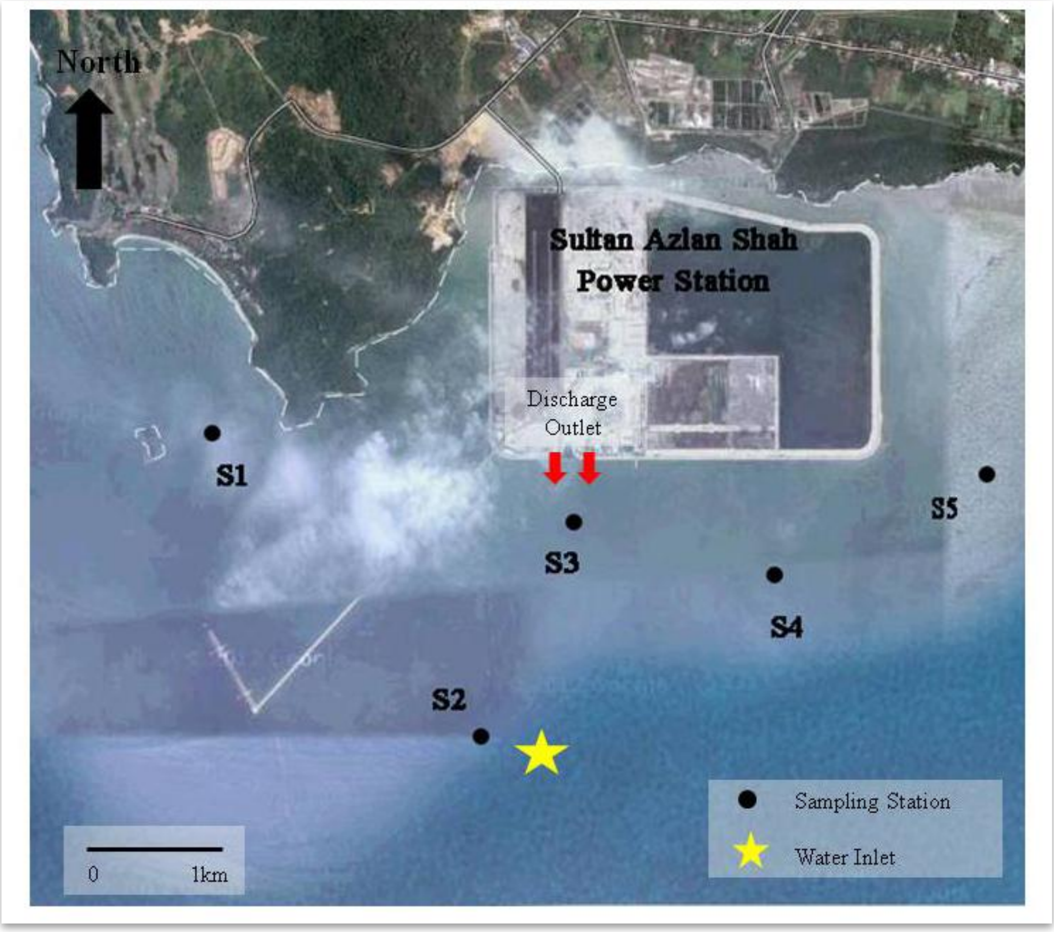

Figure 3.2: Sampling stations for the study of zooplankton and water quality in the coastal waters of Manjung, Perak.