PHYTOPLANKTON COMMUNITY STRUCTURE AND COASTAL WATER QUALITY CHARACTERISTICS OF MANJUNG, PERAK AND PENANG NATIONAL PARK, PENANG

by

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Thesis submitted in fulfilment of the requirements for the degree of Master of Science

February 2014

ACKNOWLEDGEMENT

Alhamdulillah and thanks to Allah S.W.T, whom with HIS willing giving me the opportunity to complete this thesis. First and foremost, I would like to express my sincere appreciation to my supervisor, Associate Professor Dr. Wan Maznah Wan Omar for her endless guidance, patience and valuable assistance throughout the whole process of completing this thesis. I wish to convey appreciation to Dr. Khairun Yahya who was the leader to this project for her support and guidance. A special thank to Mr. Sim Yee Kwang and Mr. Omar Ahmad for their support and assistance throughout the field work.

I would like to express my gratitude to the Tenaga Nasional Berhad Research (TNBR) for the financial support. Nevertheless, I would like to thank the technical and laboratory staffs of Centre for Marine and Coastal Studies (CEMACS) and School of Biological Sciences for their assistance in this research project. I am deeply indebted to Universiti Sains Malaysia for providing me with the opportunity to further my studies and the Ministry of Higher Education Malaysia for the scholarship.

Many thanks to my colleagues Chan, Chuah, Hazzeman, Intan, Masdialily, Syazwina, Bidarulmunir, Ruhayu, Shazana, Azmir, Diana, Basri, Wong, Lokman, Shafiq and all members for their support, kindness and friendship. Last but not least, I would like to express my utmost appreciation to my family members for their endless support, ultimate encouragements and understanding throughout this trying period. Thank you very much.

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
TSS	Total suspended solids
DO	Dissolved oxygen
BOD	Biological oxygen demand
NO_2-N	Nitrite-Nitrogen
NO_3-N	Nitrate-Nitrogen
NH_4-N	Ammonium-Nitrogen
PO_4-P	Ortho-Phosphate
TP	Total phosphorus
TN	Total nitrogen
ISI	Importance Species Index
PNP	Penang National Park
H′	Shannon-Wiener diversity index
J′	Evenness index
sp.	Species
In-situ	In position
et al.	and others
e.g.	Example given
etc.	*Et cetera*
SE	Standard error
TLDM	Tentera Laut Diraja Malaysia (Royal Malaysian Navy)
SASPS	Sultan Azlan Shah Power Station

LIST OF ABBREVIATIONS

Abbreviation	**Description**
TNB	Tenaga Nasional Berhad
TNBJ	TNB Janamanjung Sdn. Bhd.
PFR	Permanent Forest Reserve
IUCN	International Union for Conservation of Nature
CEMACS	Centre for Marine and Coastal Studies
WWF	World Wildlife Foundation
GESAMP	United Nations Joint Group of Experts on the Scientific Aspects of Marine Pollution
EIA	Environmental Impact Assessment
WFD	Water Framework Directive
GPS	Global Positioning System
OD	Optical density
APHA	American Public Health Association
ANOVA	Analysis of Variance
HSD	Honestly Significant Difference
SPSS	Statistical Package for the Social Science
PCA	Principal Component Analysis
Chl-*a*	Chlorophyll-*a*
DOE	Department of Environment
pH	Power of hydrogen (Acid balance)
MJ	Sampling stations in Manjung
MH	Sampling stations in Penang National Park

LIST OF ABBREVIATIONS

Abbreviation	Description
DOM	Dissolved organic matter

LIST OF SYMBOLS

Symbol	**Description**
Cell	Cell abundance
N	Geographical North
E	Geographical East
^{o}C	Degrees Celsius
mm	Millimetre
mm^2	Square millimetre
cm	Centimetre
m	Meter
µm	Micrometer
µg	Microgram
Km	Kilometre
km^2	Square kilometre
mg/l	Milligram per litre
µS/cm	Micro-Siemens per centimetre
µg/l	Microgram per litre
%	Percentage
ml	Millilitre
L	Litre
cells/ml	Cells per millilitre
cells/m^3	Cells per cubic metre

LIST OF SYMBOLS

Symbol	Description
MW	Megawatt
ha	Hectare
$^{0}/_{00}$	Parts per thousand
dm^{-3}	Decimetre per cubic metre
nm	Nanometre
rpm	Rounds per minute

STRUKTUR KOMUNITI FITOPLANKTON DAN CIRI-CIRI KUALITI AIR PESISIRAN PANTAI MANJUNG, PERAK DAN TAMAN NEGARA, PULAU PINANG

ABSTRAK

Kajian ini dijalankan untuk menentukan struktur komuniti fitoplankton dan ciri-ciri kualiti air pesisiran pantai di Manjung, Perak dan Taman Negara Pulau Pinang (PNP), Pulau Pinang serta mengkaji hubungan antara komuniti fitoplankton dan parameter persekitaran. Lima stesen persampelan berhampiran dengan stesen janakuasa pantai (Stesen Janakuasa Sultan Azlan Shah) di Manjung dan lapan stesen persampelan di PNP telah dipilih untuk kajian ini. Pengutipan sampel fitoplankton dan air serta pengukuran parameter kualiti air *in-situ* telah dilakukan pada setiap bulan semasa air pasang-surut perbani bermula pada bulan November 2009 hingga bulan Oktober 2010. Sejumlah 101 spesies fitoplankton (36 genera) dikenalpasti di Manjung manakala sejumlah 71 spesies (33 genera) dikenalpasti di PNP. Bacillariophyta merupakan kumpulan fitoplankton yang paling umum ditemui di Manjung (96.94%) dan di PNP (95.63%) dan diikuti oleh Dinophyta (Manjung: 0.59%; PNP: 3.74%), Cyanophyta (Manjung: 0.32%; PNP: 0.57%) dan Chlorophyta (Manjung: 2.15%; PNP: 0.06%). Di Manjung, *Odontella sinensis* mendominasi MJ2 (berhampiran kawasan pengambilan air penyejuk stesen janakuasa pantai; ISI: 6.28), MJ3 (berhampiran kawasan pelepasan haba stesen janakuasa pantai; ISI: 5.18) dan MJ4 (berhampiran kolam abu stesen janakuasa pantai; ISI: 6.91) manakala MJ1 (persekitaran terkawal; ISI: 4.54) dan MJ5 (berhampiran kawasan paya bakau; ISI: 6.90) masing-masing didominasi oleh *Pseudonitzschia heimii* dan *Chaetoceros*

curvisetus. Sementara itu, kesemua stesen persampelan di PNP telah didominasi oleh *Pleurosigma* sp. 1 (Julat nilai ISI: 18.84 – 29.61). Di Manjung, kelimpahan purata fitoplankton yang tertinggi direkod di MJ2 (82,414.35 ± 32,657.43 cells/m^3) manakala kelimpahan purata yang terendah direkod di MJ5 (44,946.61 ± 14,685.32 cells/m^3). Sementara itu, MH8 (Pantai Acheh) merekodkan kelimpahan purata fitoplankton yang tertinggi sebanyak $3.99 \times 10^8 \pm 1.12 \times 10^8$ cells/m^3 manakala MH3 (Teluk Aling) merekodkan kelimpahan purata yang terendah sebanyak $2.07 \times 10^8 \pm 3.94 \times 10^7$ cells/m^3 di PNP. Julat purata indeks kepelbagaian Shannon-Wiener (H′) di Manjung adalah antara 1.96 ± 0.19 (MJ5) hingga 2.33 ± 0.17 (MJ3) manakala julat purata di PNP adalah antara 2.15 ± 0.17 (MH6) hingga 2.35 ± 0.16 (MH2). Dalam kajian ini, variasi kelimpahan fitoplankton dan parameter persekitaran dipengaruhi oleh lokasi kawasan kajian serta musim monsun. Di Manjung, peningkatan suhu air akibat daripada pelepasan haba dariapada stesen janakuasa pantai telah menggalakkan perkembangan kepelbagaian spesies fitoplankton. Di PNP, kepelbagaian tersebut dipengaruhi oleh pencemaran air khususnya di Teluk Bahang. Pemantauan taburan dan kelimpahan spesies bio-indikator seperti *Pleurosigma* sp. 1 dan *Odontella sinensis* adalah penting untuk penilaian tahap kesihatan ekosistem marin yang dipengaruhi oleh aktiviti antropogenik serta mengkaji tindak balas mereka terhadap pencemaran air.

PHYTOPLANKTON COMMUNITY STRUCTURE AND COASTAL WATER QUALITY CHARACTERISTICS OF MANJUNG, PERAK AND PENANG NATIONAL PARK, PENANG

ABSTRACT

This study was carried out to determine the phytoplankton community structure and coastal water quality characteristics of Manjung, Perak and Penang National Park (PNP), Penang and to investigate the relationship between phytoplankton community and environmental parameters of the study areas. Five sampling stations adjacent to a thermal coastal power plant station (Sultan Azlan Shah Power Station) in Manjung and eight sampling stations surrounding the PNP were selected in this study. Collection of phytoplankton and water samples and measurement *in-situ* water quality parameters were done monthly from November 2009 to October 2010 during neap tide. A total of 101 phytoplankton species (36 genera) were identified in Manjung whereas a total of 71 species (33 genera) were identified in PNP. Bacillariophyta was the most common phytoplankton group found in Manjung (96.94%) and in PNP (95.63%), followed by Dinophyta (Manjung: 0.59%; PNP: 3.74%), Cyanophyta (Manjung: 0.32%; PNP: 0.57%) and Chlorophyta (Manjung: 2.15%; PNP: 0.06%). *Odontella sinensis* dominated MJ2 (near the inlet point of coastal power station; ISI: 6.28), MJ3 (near the outlet point of coastal power station; ISI: 5.18) and MJ4 (near the ash pond of coastal power station; ISI: 6.91) whereas MJ1 (reference site; ISI: 4.54) and MJ5 (near the mangrove areas; ISI: 6.90) were dominated by *Pseudonitzschia heimii* and *Chaetoceros curvisetus* respectively in Manjung. All sampling stations in PNP were dominated by *Pleurosigma* sp. 1

(ISI's value range: 18.84 – 29.61). The highest mean abundance of phytoplankton was recorded at MJ2 (82,414.35 ± 32,657.43 cells/m^3) whereas the lowest was recorded at MJ5 (44,946.61 ± 14,685.32 cells/m^3) in Manjung. In PNP, MH8 (Pantai Acheh) recorded the highest mean abundance of phytoplankton with $3.99 \times 10^8 \pm 1.12 \times 10^8$ cells/m^3 whereas MH3 (Teluk Aling) recorded the lowest with $2.07 \times 10^8 \pm 3.94 \times 10^7$ cells/m^3. The mean range value of Shannon-Wiener diversity index (H′) in Manjung was from 1.96 ± 0.19 (MJ5) to 2.33 ± 0.17 (MJ3) whereas in PNP, the mean range value was from 2.15 ± 0.17 (MH6) to 2.35 ± 0.16 (MH2). In this study, variation of phytoplankton abundance and environmental parameters was influenced by geographical locality of study sites and monsoon seasons. In Manjung, elevation of water temperature, as a result of thermal discharge from a coastal power station, promoted development of phytoplankton species diversity whereas in PNP, the diversity was influenced by water pollution particularly at Teluk Bahang. Monitoring the distribution and abundance of bio-indicator species such as *Pleurosigma* sp. 1 and *Odontella sinensis* is essential for evaluation of marine ecosystem health affected by anthropogenic activities as well as investigating their immediate response towards water pollution.

CHAPTER 1

INTRODUCTION

1.1 Background

Marine ecosystems (marine waters cover 361 million km^2) are the largest aquatic ecosystem of earth which includes estuaries, lagoons, mangrove, coral reefs, intertidal, salt marsh and oceans. In addition, the Northern Hemisphere is covered with more land and the ratio of water-to-land is 1.5:1.0 compared to the Southern with the ratio of 4:1 (Davis, 1977). Oceans are vital in recycling elements such as carbon, nitrogen, oxygen, phosphorus and sulphur that support living organisms (Daily & Power, 1997). Brown (1994) predicted about 22 to 50 percent of the world's oxygen supply is produced by the marine phytoplankton while absorbing measureless amounts of carbon dioxide. Moreover, ocean is one of the factors affecting the world's weather patterns which could lead to severe droughts or ruthless typhoons all over the world. Instead of solely blaming the nature, human activities such as overexploitation of the land and marine natural resources has contributed to the worsening of the pristine environment and depletion of the present ecosystem. In particular, the misuse of land and the emergence of coastal aquaculture and inshore fishing activities have led to various kinds of environmental impacts on the aquatic ecosystem. There is no doubt that these impacts have the potential to affect the interface area between marine and terrestrial known as the coastal zone ecosystem (Shahrizaila, 1991).

Many large power stations, including coal-fired and nuclear power stations, were built at coastal areas or adjacent to larger lakes and rivers because these water bodies provide large volumes of water for cooling purpose. However, the power stations endangered the aquatic life and also alterated the physical and chemical characteristics of aquatic environment in the vicinity. These alterations are caused by discharge of chlorine and heated cooling-water residues and pollutants including leachate from coal piles. Principally, coastal power stations collect greater volumes of water through large underwater pipes in the offshore and then circulate it through the condensing system for steam condensation. Later on, the heated cooling water is discharged back to adjacent water bodies. The once-through cooling system is harmful for most aquatic organisms and the threats being highlighted are entrapment of fish on water intake screens, entrainment of smaller fish, eggs and plankton through the intake screens and also impact of heat shock.

To date, numerous studies on phytoplankton diversity and distribution in the tropical marine waters of Malaysia, including the Straits of Malacca and South China Sea, were conducted by Shamsudin (1990), Boonyapiwat (1998), Boonyapiwat (1999), Alim (2001), Al-Gahwari (2003), Sidik et al. (2008), Nabi et al. (2010) and Siswanto and Tanaka (2012). However, several studies (Anton, 1989; Lee, 2003) regarding on the impact of thermal effluent on phytoplankton community structure in the Malaysian marine waters were noted. Hence, it is essential to carry out more studies relating to the response of phytoplankton community towards elevation of water temperature because phytoplankton, especially diatoms, is a good indicator for thermal pollution (Lee, 2003). Studies on the water quality characteristics and conditions of Malacca Straits were significantly highlighted by Thia-Eng et al.

(2000), Yap et al. (2005) and Hii et al. (2006). Furthermore, nowadays, the Straits of Malacca is continuously facing critical environmental problems such as water quality degradation and depletion of coastal and marine resources. These problems are primarily caused by human activities which led to coastal erosion (e.g. mangrove deforestation), sedimentation (e.g. increment of runoffs), coastline modification (e.g. land reclamation and agricultural and aquaculture activities) and pollution (oil-spill and urban discharge).

1.2 Manjung, Perak

Manjung is a district in the south-western part of the state of Perak Darul Ridzuan, Malaysia. Furthermore, it is the home for the Royal Malaysian Navy (TLDM) Lumut Naval Base and dockyard and also famous for its Pangkor Island, a major attraction of the state for tourism. Apart from the Pangkor Island, there are sandy beaches such as Teluk Batik, Teluk Rubiah, Pasir Panjang and Teluk Senangin which are popular among tourists. On the other hand, Teluk Penchalang (approximately 10 km south of Lumut) is the site for Sultan Azlan Shah Power Station (SASPS), a coal-fired power plant built by TNB Janamanjung Sdn. Bhd. (TNBJ) (a wholly owned subsidiary of Tenaga Nasional Berhad) (Tenaga Nasional Berhad [TNB], 2007). The power station was constructed on a man-made reclaimed island and elevated 4.5m above sea level. The SASPS generates 2,100MW from its three 700MW units to sustain about 80% electricity demand of Malaysia on natural gas (“Manjung Coal-Fired Power Plant, Perak, Malaysia,” n.d.). High load demand by consumers has forced the government to set up large amounts of base load electricity generating capacity to cope with the ever increasing demand and also harmony with nature. The location of the power station is in line with the government's aspiration to develop power production in the coastal area and residing close to load centres (Alstom, n.d.).

1.3 Penang National Park, Penang

Penang or also known as Pulau Pinang is recognized as one of the most rapidly developing states in the country in terms of industrialization and urbanization. However, irresponsible development planning has forced Penang to deal with degradation of the living environment and environmental hazards. According to Hong and Chan (2010), the temperature of Penang gradually increased especially in March due to the emergence of haze from the recurring Indonesia's forest fire. Therefore, as one of the mitigation efforts to reduce the warm temperature impact, 6,406 ha of land (about 6% of total land area) has been gazetted as Permanent Forest Reserve (PFR) followed by deployment of forestry departments and conservation plans provided in the National Forest Act 1984 (Weng et al., 2004). In April 2003, a portion of natural green area located in the northwest of Penang Island was declared as Penang National Park (PNP), inaugurated as the first protected area and legally gazetted under the National Park Act of 1980.

A national park or national forest is a reserve of natural, semi-natural, or developed land area possessed of special scenic, historical values, or scientific importance and declared and managed by the federal or state government of any respected countries (Hong & Chan, 2010). The International Union for Conservation of Nature (IUCN) listed natural parks as protected areas under the category II, ecosystem protection and recreation (Adams, 2006). In view of that, the PNP is classified under the same category and designated as a natural area of land and/or sea for ecological protection of present and tomorrow’s sustainability. Being the second largest national park in the nation, the 1,266 ha national park is comprised of coastal hill, meromictic lake, wetlands, mangroves, mudflats, coral reefs and nesting beaches for turtle (Hong & Chan, 2010).

On the other hand, the PNP also forms a coastal forest such as beach forest and mangrove areas as a result of the extension of inland forests towards the sea. Apart from the mangrove areas, PNP comprises eight forest beaches, rocky shores and the inner forest itself. The most popular and pristine sandy beaches around the forest are Teluk Bahang, Pantai Kerachut, Pantai Mas, Teluk Aling and Teluk Duyung (Monkey Beach). Sungai Duyong, Sungai Pantai Kerachut and Sungai Gemuruh are the rivers flowing towards the coastal water of PNP. In addition, he Centre for Marine and Coastal Studies (CEMACS), a field station of Universiti Sains Malaysia which conducts integrated and multidisciplinary studies related to marine and coastal ecosystems is located at Teluk Aling. Hong and Chan (2010) further noted that Pantai Kerachut, Pantai Mas, Teluk Kampi and Teluk Ketapang are the nesting beaches for turtles and for that reason a turtle hatchery has been set up at

Pantai Kerachut in 1995 by the Wildlife Department to enforce the protection and conservation.

1.4 Importance of phytoplankton study

In most aquatic ecosystems, phytoplankton functions as a primary producer and as an energy base in a food web. Furthermore, it is also involved in biochemical process of nutrient fixation. Communities of phytoplankton including diatoms, dinoflagellates and cyanobacteria are significantly associated with water quality conditions because they are the earliest organisms to respond towards abrupt changes in the aquatic environment. Principally, alteration of distribution and shift in composition of phytoplankton community reflects the present condition of water quality of any aquatic environment. Moreover, phytoplankton acts as a prompt biological indicator and provides useful warning signals of water quality degradation, thus it may facilitate researchers to assess the health status of an aquatic ecosystem (McCormick & Cairns, 1994).

1.5 Objectives

The main objectives of this study were:

(1) To determine the distribution, composition and abundance of phytoplankton in the coastal waters of Manjung, Perak and Penang National Park, Penang

(2) To determine the coastal water quality conditions of Manjung, Perak and Penang National Park, Penang

(3) To investigate the impact of human activities on phytoplankton distribution, abundance and water quality conditions

(4) To determine the potential biological indicator of thermal stress and coastal water pollution based on phytoplankton community structure

CHAPTER 2

LITERATURE REVIEW

2.1 Coastal Zone

The coastal zone can be defined as a transition area between land and the open ocean which receives loading of nutrients, organic matter (particulate and dissolved organic matter), sediment, contaminants and substantial amount of freshwater (Gazeau et al., 2004). A coastal zone is an area which extends seaward towards the edge of the continental shelf and also pointed out those natural systems and natural processes within the zone are susceptible to interruption by human activities (Malaysian National Conservation Strategy, 1992). Rissik and Suthers (2009) emphasized that the coastal zone consists of coastal waters out to 2 km offshore and comprised of areas such as mangroves, estuaries, seagrass beds and coral reefs and known to be the most productive zone of marine ecosystems (Amirrudin et al., 2004). Moreover, the shallow coastal zone permits light penetration towards the bottom region of the water column, thus promoting primary production and respiration (Gazeau et al., 2004).

Nowadays, coastlines are profoundly disturbed by human activities that merely desire profit rather than conserving one of the nature's majestic treasures. The demand for development as well as the pressure of population growth has jeopardized the pristine coastal zones around the globe. Modification of biological, chemical and physical conditions within the coastal zone as a result of pollutions and rapid exploitation of natural resources have increased the global concern about the fate of coastal zone sooner or later. Clark (1986) reported that sewage was the greatest volume of wastes discharged to coastal waters. Moreover, the low dissolved oxygen and high nutrient concentrations of the sewage could imbalance the equilibrium of biotic communities through food web (Parnell, 2003).

Malaysia has about 4,800 km of coastline comprising of the mangrove fringed mud flats and sandy beaches. The east coast of Peninsular Malaysia consists of straight sandy beaches in the northern part while the southern part is covered with spiral-shaped bays. The west coast of Peninsular Malaysia comprised mainly by mud flats with limited areas of sandy beaches. In the interim, the coastlines in Sarawak and Sabah are about equally divided between mud coast and sandy beaches (Sharifah Mastura, 1992).

Lay and Zsolnay (1989) reported the wind patterns near the equator generated a system with relatively low kinetic energy within the tropics, which in turn lowers the turbidity level in the coastal areas. However, human activities such as dredging, sewage discharge and water sports may influence the turbidity by increasing the levels. The combination of lower energy levels and the continuous warming of surface waters have caused a vertical stratification that prevents transportation of nutrient-rich deep water into the photic zone. Hence, the nutrient-poor surface waters condition will suffocate the existing biological standing stock.

The introduction of uncontainable sewage into the aquatic environment will increase the concentration of nutrients available, which in turn promotes eutrophication and increment of turbidity levels. In addition, accumulation of raw sewage may also decrease the oxygen levels due to a strong biological oxygen demand and in the meantime increase the amount of organic material locally.

2.2 Straits of Malacca

The Straits of Malacca is situated on the western part of Peninsular Malaysia. It is the longest and busiest strait in the Southeast Asian region and also known to be one of the most important shipping lanes in the world, connecting the Pacific Ocean and Indian Ocean. The 805 km stretch of water gives rise to major Asian economies such as China, India, South Korea and Japan. In geological aspect, the depth of the strait is approximately 90 m and deepest part covers the northern zone and gradually becomes shallower towards the southern zone with a depth of approximately 12 m (Martosubroto, 2000; Rezai et al., 2000). Most of Malaysians are situated within few kilometers from the coastline. Improper management of coastal area development and unawareness of ecological importance has created problems in some of the Malaysian coastal waters. The coastal water is bombarded with uncontainable fishing activity, excessive coastal aquaculture and agriculture waste dump-out, uncontrolled sewage management, thermal discharge and continuous discharge of domestic waste from tourism and recreation centers. In addition, marine transportation of oil, gas and other commercial products which involve supertankers and cargo ships also can harm the coastal zone due to accidents and oil-spill.

2.3 Impact of human activities on the coastal zone

2.3.1 Thermal pollution

Thermal pollution refers to the harmful increment of water temperature in any water bodies such as lakes, streams, rivers and coastal waters. The major cause of thermal pollution is the discharge of warm water from industrial factories and electric power plants. Most of the electric power plants produce heat by burning coal, oil, natural gas whereas nuclear fuels will undergo fission to release enormous amount of energy. Electricity is generated when the heat turns water into steam, which then spins the turbines. On the contrary, the used up steam must be cooled and condensed back into water. The condensation process begins when cool water, acquired from lake, river, or ocean, is brought into the plant and circulated next to the hot steam. The water warms about 5 ^{o}C to 10 ^{o}C and then discharged back to its natural environment.

Likewise, industrial factories contribute to thermal pollution by discharging the warm water after cooling their machinery. The effect of thermal pollution is widespread crisis and becomes a foremost concern around the world because the increment of only 1 ^{o}C or 2 ^{o}C might threaten native aquatic organisms. Shchur (2009) stated that the discharge of thermal effluent from a thermal and nuclear power plants into water bodies significantly disturbed the equilibrium in aquatic ecosystems. Animals and plants species that inhabit the aquatic environment are adapted to temperatures within a certain range. When water in an area warms beyond the tolerable temperature range, immobile species such as shellfish and rooted plants will die. In contrast, free-swimming species such as fish will escape the unfavorable area to continue their survival elsewhere. However, there are certain organisms that can endure the stressful warm water such as algae and other plants which grow rapidly, but they also may die rapidly.

Krishnakumar et al. (1991) noted that certain forms of life may be killed directly or indirectly as a result of behavioral changes. They also reported that, according to several studies around the world, a large number of planktonic larvae of near-shore fish and invertebrates were destructed due to usage of coastal waters in the cooling system of power plants. A study by Thomas et al. (1986) indicated warm water discharges had significantly affected the fauna in the intertidal mudflats by altering the intertidal communities. Furthermore, populations of bivalve, mollusk and warm water species were reduced whereas previously rare or absent warm water species were increased near the warm water discharge. Their study also pointed out that an algal growth was increased when exposed to a long-term high temperature particularly in waters containing much organic matter.

Indirect impacts of thermal pollution can be investigated by studying the effects of decreased oxygen concentration on fishes within the thermal plume. Generally, metabolic changes occur in fishes due to the increment or decrement of temperature. Typically, increasing temperature will subsequently increase the heart beat and oxygen consumption. Furthermore, more oxygen is required at higher temperatures as a result of a higher metabolic rate and lowered affinity for oxygen by haemoglobins (Krishnakumar et al., 1991). Krishnakumar et al. (1991) also mentioned that the endurance of phytoplankton at higher temperatures was better than zooplankton and also stated that important zooplankton groups such as copepods and mysids were in jeopardy.

Chemical and biochemical reactions can be accelerated by the increased rates of temperatures. In biological systems, enzymes functions efficiently at optimum temperatures. However, alteration of the enzyme reaction occurs when the optimum temperatures were deviated either by lowering or increasing it. Raising the temperature of the receiving waters may shift the optimum temperature for certain species but probably might favor other species as well. The respiration rate of biological community is expected to be doubled with the increment of $10^{o}C$ in the temperature of the receiving water. In addition, the solubility of oxygen in water is also reduced when the temperature increases. Krishnakumar et al. (1991) reported an approximation of $10^{o}C$ rise of temperature would reduce the solubility of oxygen up to 20%. They also envisaged that thermal stratification of a water column would be intensified, more stable and difficult to mix due to the floating thermal plume at the surface of the receiving water. In essence, the exchange of oxygen between atmosphere and subsurface water would be less efficient, resulting severe oxygen depletion. Laws (1981) noted that high ambient water temperature associated with thermally stratified water column during summer had contributed to the development of the oxygen depletion condition.

Wood and Johannes (1975) reported that power plants and other industrial installations had intensively threatened marine communities within the tropical regions by discharging heated effluents. Briefly, tropical organisms exhibit a narrow range of temperature tolerance by living at temperatures only a few degrees below their upper lethal limit. Youngbluth (1976), in his long-term study about zooplankton populations in a thermally polluted tropical embayment in Puerto Rico, reported lower species diversity of zooplankton at the outflow area of a fossil-fuelled power plant. However, a constant community structure within the outflow area suggested that a few species might tolerate the thermal impact. In addition, factors such as low phytoplankton biomass, high entrainment mortality and sub-lethal temperature effects contributed to the low densities and Species richness in the thermal cove. High diversity and low abundance recorded at the entrance of the bay indicated a possible mixing of zooplankton populations in the coastal area and bay. Thorhaug et al. (1978) emphasized the fate of tropical and subtropical ecosystems were in menace and potentially exceeding beyond tolerance limits as to sustain the increasing human activities. The capacity to assimilate human activities characterized the difference between marine tropics and marine temperate zones.

Thermal pollution issues in Malaysia have become a prolong concern as the need for an increase in power supply especially generated by coal-fired power plant. In 2008, Tenaga Nasional Berhad (TNB), the main Malaysian energy provider, proposed to the government to build a coal-fired power plant (power generation capacity of 300 MW) on the East Coast of Sabah, totalling up to the current generation capacity of 866.4 MW supplied by Sabah Electricity Sdn Bhd and Independent Power Producers. However, WWF-Malaysia was concern that the project might affect ecologically sensitive and thus obstructing the environmental conservation affixed within the principles of the Sabah Development Corridor (World Wildlife Foundation [WWF], 2008).

2.3.2 Coastal water pollution

"The introduction of substances or energy into the marine environment directly or indirectly by man which then harming the living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of seawater and reduction of amenities" is a definition of marine pollution quoted by the United Nations Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) (Lloyd, 1992). Aquatic pollution draws a lot of attention due to uncontrollable rate of industrialization and economic growth which substantially impaired the environment. The importance of coastal environment as a reservoir of persistent chemicals has been a discussion point among researchers and the implementation of bio-indicators as a monitoring strategy is proposed (Goldberg et al., 1978; Philips, 1980; Farrington et al., 1983; Duursma & Carroll, 1996). The coastal fronts is indeed a valuable asset to any countries worldwide as it offers ideal fishing grounds and a major subsidize for local fishermen.

Coastal aquaculture is a traditional practice in Southeast Asia particularly in countries such as Malaysia, Indonesia and Singapore which primarily host the industry along the Malacca Straits. In Malaysia, the coastal aquaculture hotspots are primarily located along the Malacca straits and within the coastal waters of Perlis, Kedah, Penang, Perak, Selangor, Negeri Sembilan and the West Coast of Johor. However, rise in coastal aquaculture industry also promotes negative environmental impacts such as copious discharge of organic matter, nutrient and faeces, changes in hydrologic regimes in enclosed waters, modification of natural coastal habitat such as mangrove for fish farming, modification of landscape, alteration of biodiversity and other pollutions (Chua et al., 1989; Wu, 1995; Tovar et al., 2000; Islam, 2005; Diana, 2009). Tovar et al. (2000) highlighted fish feed and drugs (to cure or prevent fish diseases) in most intensive fish culture systems proliferated water pollution, thus causing deterioration of local water quality conditions. According to Islam (2005), cage fish farm produced higher proportion of effluents in the form of feed waste (dependable on stocking density, feeding regime and feeding rate) to the surrounding waters. Excessive nutrients concentration (nitrate, nitrite, ammonium and reactive phosphate) produced by marine aquaculture increased phytoplankton biomass and chlorophyll-*a* concentration, thus stimulating local eutrophication and elevation of primary production capacity (Islam, 2005). Besides, enrichment of organic matter in the ecosystem may also lead to increase in oxygen consumption by decomposers. Other than aquaculture, Shahidul Islam and Tanaka (2004) reported impact of intense agricultural activities also led to surface water and groundwater pollutions (Dukes & Evans, 2006) through enrichment of nutrient elements such as ammonium and nitrate.

Dwight et al. (2002) reported that discharge of infectious and toxic chemical pollutants from urbanized areas into coastal waters significantly caused public health risks. Increasing population and development incidentally contribute greater amount of point and non-point source pollution into local waterways. Nevertheless, an association between precipitation frequency and the volume of storm water or runoff in the urban areas must be considered because it also determines the intensity of coastal water pollution. In the meantime, apart from urban pollution, land use activity also influences the water quality of surrounding watershed. Sooner or later, a wide range of pollutants from the activity will be transported to the coastal area through waterways.

2.4 Plankton

Plankton is a word derived from the Greek adjective (*planktos*) which defines as wanderer or drifter (Thurman & Burton, 1997). In general, plankton is defined as any drifting organisms including plants and animals that inhabit the pelagic zone of marine and freshwater water columns such as lake, sea and river (Davis, 1977). These organisms have the capability to swim against current (Lalli & Parsons, 1997) and also become a food source for various aquatic organisms such as fishes and whales. In terms of size, plankton are categorized into six divisions (Redden et al., 2009) (Table 2.1).

Table 2.1: Divisions of Plankton and its size.

Division	Size	Types of organisms
Megaplankton	exceed 20 cm in length	Large jellyfish and salps
Macroplankton	2 – 20 cm	Jellyfish, comb jellies, krill and arrow worms
Mesoplankton	0.2 – 2 mm	Copepods, cladocerans, small Salps, larvae of benthic organisms and fish
Microplankton	20 – 200 µm	Large phytoplankton (chain-forming diatoms, foraminiferans, ciliates and nauplii
Nanoplankton	2 – 20 µm	Small phytoplankton (single-celled diatoms), flagellates, small ciliates, radiolarians and Coccolithophorids
Picoplankton	0.2 – 2 µm	Bacterio-plankton and marine viruses

Source: Redden et al. (2009)

The distribution and abundance of plankton are primarily influenced by factors such as nutrient concentrations, the abundance of the upper consumers in the food web as well as the physical state of the water column. Environmental factor such as temperature affects vertical distribution of plankton directly and indirectly. The direct effect is on plankton mobility which forces it to move around the water column as well as adjusting its floatation rate in search for a favorable temperature. The indirect effect is by altering the level of viscosity and density of water (Sze, 1998).

2.4.1 Phytoplankton

Harris (1986) and Sze (1998) defined phytoplankton as a microscopic floating plant life of aquatic environment and mostly are non-motile species and thus depend vitally on water movements and sinking ability in both freshwater, brackish and marine environments (Round, 1981; Paerl et al., 2007). In addition, each phytoplankton species is characterized by its own unique form which reveals its great diversity through microscopic observation of water samples. Round (1981) categorized phytoplankton to groups of lower and non-flowering plant that presented in single or simple multicellular forms. Moreover, the size of phytoplankton ranged from the smallest form of eukaryotic and prokaryotic cells and capable of growing to the largest size visible to naked eyes (Harris, 1986). When present in abundant numbers, phytoplankton appears as a green discoloration of the water due to the presence of photosynthetically active pigments, such as chlorophyll, within their cells. However, the varying levels of chlorophylls and the presence of accessory pigments such as xanthophylls and phycobiliproteins may influence the actual color of phytoplankton species.

Being an autotrophic organism and living in the well-lit surface layer (euphotic zone) of any water bodies, phytoplankton consume nutrients and dissolved carbon dioxide (in the form of carbonic acid) in water and utilize energy obtained from solar radiation to produce complex organic molecules such as sugar or protein (Rissik & Suthers, 2009) and dissolved oxygen in a process known as photosynthesis. In an aquatic food chain, phytoplankton is classified as a primary producer as it occupies the base of a food web. Furthermore, most of the phytoplankton species are consumed by larger organisms such as zooplankton, crustaceans and small fishes which engage the upper trophic levels. In addition, phytoplankton is also consumed directly by large marine mammals especially the baleen whale.

Nutrients such as nitrogen and phosphorus are the core elements required by phytoplankton as building blocks for production of complex organic molecules as well as to sustain its existence (Rissik & Suthers, 2009). Naturally, nitrogen (in the form of ammonium, nitrite and nitrate) is the limiting nutrient in marine systems whereas phosphate is limited in freshwater systems (Rissik & Suthers, 2009). Silica and iron are also limiting nutrients for phytoplankton and derived from the natural weathering of land. Somehow, excessive input of nutrients especially from river and storm-water runoff, sewage discharge and groundwater have encouraged a rapid growth and reproduction of phytoplankton and for that reason causing a surplus in its population and biomass, a phenomena known as 'eutrophication'. Rissik et al. (2009)

pointed out that blooming-color of phytoplankton can be red, green, purple, yellow, brown, blue, milky white, or even colorless. Davis (1977) pointed out that seawater conditions, as in relation to temperature and salinity, significantly affect phytoplankton density and vertical distribution.

Round (1981) classified phytoplankton into six main phyla such as Bacillariophyta, Cryptophyta, Pyrrophyta, Cyanophyta, Haptophyta and Chrysophyta. Briefly, phylum Bacillariophyta (also known as diatom) is the major group of phytoplankton in the marine ecosystem. Most diatoms are often unicellular, can also exist in colonies and flourish in cold water. The difference between diatoms and other phytoplankton groups is based on the presence of frustules (a cell wall made of silica) which encased diatom cells. According to the study conducted by Ekwu and Sikoki (2006), the dominant marine diatom genera are *Thalassiosira*, *Skeletonema*, *Cyclotella*, *Chaetoceros*, *Bacteriastrum*, *Ditylum* and *Biddulphia*. Interestingly, several diatom species such as *Bacillaria paradox*, *Fragillaria* sp. and *Nitzschia closterium* were able to survive in both marine and brackish water (Round, 1965; Härnström et al., 2009). *Cyclotella choctawhatcheeana*, *Cylindrotheca closterium* and *Skeletonema costatum* were the diatom found in the marine water that received high nutrient enrichment mainly nitrogen and phosphorus. Therefore, a rapid growth and distribution of these species could be monitored to prevent eutrophication and might also be considered as bio-indicator for water quality degradation (Tilman et al., 1982; Vuorio et al., 2005).

Phylum Pyrrophyta (also known as Dinoflagellates) is a large group of flagellate protists which occurred in marine and freshwater environments. Most of dinoflagellates are marine eukaryotes and their population distribution is influenced mainly by temperature and salinity. Davis (1977) emphasized that dinoflagellates as one-celled organisms, preferring warm water and just a few species of them are photosynthetic. The presence of dinoflagellates is greater in lower salinity areas such as the coastal zone. Blooming population of dinoflagellates may result in a phenomenon known as red tide. The distressful harmful algal bloom is caused by the rapid growing population of some dinoflagellate species which produce neurotoxins, thus endangering all marine life in ocean and seafood consumers.

2.5 Water quality parameters as a tool for assessing ecosystem health

Water quality parameters are a combination of physical, chemical and biological environmental parameters which are essential in ecosystem health evaluation and prevalently applied in Environmental Impact Assessment (EIA). Din (1993) and Nasir (2001) stated several parameters such as color, water turbidity (a result of suspended solids), water temperature, salinity, electrical conductivity, dissolved oxygen and radioactivity are used as indicators in monitoring the marine environment. Nevertheless, chemical and biological parameters such as nutrient concentration, plankton assemblages and community structure of other aquatic organisms also facilitate the evaluation and interpretation of an aquatic ecosystem condition.

2.5.1 Water temperature

According to Davis (1977), the temperature of natural seawater ranges from -2°C to 30°C whereas deep waters have a range of -1°C to 4°C which uninfluenced by climatic conditions. Surface waters in higher latitudes are colder and become warmer as the latitude decreases towards the equator. In the meantime, ocean basins record a wide range in temperature in accordance to both horizontal and vertical directions. In the tropics, solar radiation irradiates the region for entire year and the water temperature of tropical oceans is relatively constant, that is 20°C throughout the year. Integration of intense radiation and persistent evaporation of seawater forms a very warm, heavy and damp tropical air.

Increment of water temperature would cause a linear decline of surface tension, ionization constant and latent heat of vaporization whereas viscosity, compressibility, solubility of dissolved oxygen and specific heat of water would decrease nonlinearly (Jack et al., 2009). Increasing water temperature also escalates thermal conductivity, vapor pressure, speed of sound in seawater and electrical conductivity. Changing water temperature may significantly affect biological and chemical processes of marine organisms such as photosynthesis and respiration rates and uptake of toxic substances in the coastal waters. Furthermore, alteration on the uptake of toxic substance affects behavioral pattern of organisms, thus leading to a decline in population as well as domination of invasive species.

2.5.2 Salinity

Salinity is defined as the total dissolved solids or dissolved salt content (such as sodium chloride, magnesium, calcium sulfates and bicarbonates) in one kilogram of seawater. In general, oceanic water has a uniform salinity (ranging from 33 to 37 with the mean about 34.5) due to circulation-induced mixing but deviations do occur as a result of geographic and vertical variations in the ocean basins. Geographically, salinity in coastal waters is primarily influenced by freshwater input from runoffs, thus advocating dilution factor (Kirst, 1989). On the other hand, areas with limited circulation also cause increment of salinity indirectly through evaporation. In vertical overview, a salinity range from 33 to 37 is recorded at the upper water layers and a range from 34 to 35 is recorded below the upper layers. Significantly, the center of most ocean basins records the highest salinity as a result of inadequate surface circulation. In latitudinal outlook, highest salinity occurs in subtropical regions due to less of atmospheric precipitation and somehow a gradual decline trend is projected towards the equator and higher latitudes as a result of persistent precipitation (Davis, 1977).

Dávila et al. (2002), in their study off the Chilean Austral coastal zone, emphasized the coastal zone as a make-up of two-layer structure. Principally, the top layer with offshore flow is characterized by temperature distribution, low density and low salinity (coastal runoff and high precipitation rate). In contrast, the bottom layer with inshore flow is composed of low temperature, high density and relatively high salinity. Hence, combination between top and bottom layers of coastal waters has yield out a sharp vertical salinity gradient.

Salinity, as one of the abiotic factors, affects the distribution and composition of marine organisms by regulating their growth and metabolic rate and causing osmotic stress (Kirst, 1989). The effect of salinity changes on organism's metabolic rate can be reflected by the varying optimum photosynthesis rate. Qasim et al. (1972), in their tropical phytoplankton study at the inshore waters of Cochin, southwest coast of India, pointed out that some phytoplankton species from dinoflagellates and diatoms showed a variation on photosynthesis rate as a result of a varying salinity level. Furthermore, a few dinoflagellate species showed greater photosynthesis rate at salinity level ranging from 6 to 25. Some phytoplankton species from diatom showed greater photosynthesis rate at salinity level ranging from 10 to 24. In terms of ecological distribution, Qasim et al. (1972) reported that greater fluctuation of diatom abundance occurred when the salinity was from 16 to 28. In contrast, a salinity level ranging from 25 to 32 promoted immense increment of dinoflagellate species abundance. In essence, phytoplankton species in coastal waters was resilient towards changing salinity level and preferred low salinity level for optimum photosynthesis rate. In addition, the ability of phytoplankton to tolerate lower salinity condition and, in the same time, showing optimum photosynthesis speculated that coastal waters are constantly enriched with nutrients, apart from anthropogenic inputs (Qasim et al., 1972).

2.5.3 Total suspended solids

Total suspended solids (TSS) are referred to non-filterable residue. Silts, clay, fine particles of organic and inorganic matter, soluble organic compounds, plankton