USE OF PHYTOPLANKTON ABUNDANCE AND SPECIES DIVERSITY FOR MONITORING COASTAL WATER QUALITY

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USE OF PHYTOPLANKTON ABUNDANCE AND SPECIES DIVERSITY FOR MONITORING COASTAL WATER QUALITY

by

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DEDICATION

To

My Father's soul,

My loving mother,

My wife

My brothers and sisters

&

My relatives

For their prayers, patience, devotion and encouragement

throughout the entire time spent in completing this thesis.

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ABSTRAK

Suatu kajian perbandingan kualiti air dan kelimpahan serta kepelbagaian fitoplankton telah dijalankan daripada Disember 2000 hingga November 2001 di empat lokasi di Pulau Pinang iaitu Teluk Aling, Batu Ferringhi, Kuala Juru dan Bayan Lepas. Objektif utama kajian ini ialah untuk menentukan korelasi di antara parameter-parameter kualiti air dengan kelimpahan serta kepelbagaian fitoplankton dan selanjutnya samada parameter-parameter tersebut dapat dikaitkan dengan ciri fitoplankton supaya dapat digunakan sebagai penunjuk perubahan kualiti air.

Kajian ini menunjukkan perubahan fiziko-kimia iaitu jumlah pepejal terampai (TSS), jumlah bahan organik terampai (TSO), keperluan oksigen biokimia (BOD) dan paras nutrien mempengaruhi perubahan kualiti air laut akibat aktiviti manusia. Sejumlah 63 genera yang tendiri daripada 133 spesies fitoplankton telah dicamkan daripada semua lokasi. Jumlah spesies tertinggi ialah diatom (103 spesies) diikuti oleh dinoflagelat (27 spesies) dan alga biruhijau (3 spesies). 7 spesies diatom, *Coscinodiscus asteromphalus*, *Odontella sinesis*, *Pleurosigma elongatum*, *Pleurosigma normanii*, *Rhizosolenia stolterforthii*, *Thalassionema frauenfeldii* dan *Thalassionema nitzschioides* di dapati mendominasi populasi yang dijumpai sepanjang kajian. Kuala Juru merekodkan kelimpahan dan biojisim tertinggi diikuti oleh Bayan Lepas. Batu Ferringhi merekodkan indeks kepelbagaian tertinggi diikuti oleh Teluk Aling. Parameter-parameter kualiti air serta kelimpahan dan kepelbagaian fitoplankton dipengaruhi oleh musim kering dan musim hujan serta paras pasang-surut.

Keputusan kajian ini menunjukkan bahawa biojisim, kelimpahan dan kepelbagaian spesies fitoplankton tidak boleh dijadikan ukuran yang baik untuk membuat ramalan perubahan kualiti air di tapak kajian. Keadaan kualiti air tidak dicerminkan didalam perubahan kepelbagaian spesies fitoplankton. Walaupun perubahan populasi fitoplankton dan biojisim dapat dikaitkan dengan perubahan kualiti air, tindakbalas fitoplankton terhadap perubahan keadaan persekitaran tidak difahami dengan jelas. Untuk semua lokasi, parameter-parameter kualiti air terpilih nampaknya tidak mencukupi untuk menerangkan perubahan didalam ciri-ciri fitoplankton. Faktor-faktor lain seperti pergerakan arus dan ombak mungkin memainkan peranan didalam perubahan kualiti air serta ciri-ciri fitoplankton dan mesti dikaitkan untuk memberi penjelasan yang lebih lanjut kepada kualiti persekitaran secara umum.

ABSTRACT

A comparative study on coastal water quality and phytoplankton abundance and diversity was conducted from December 2000 to November 2001 at four locations in Penang namely Teluk Aling, Batu Ferringhi, Kuala Juru and Bayan Lepas. The main objective of the study was to determine possible correlations between the water quality parameters and the phytoplankton abundance & diversity, and eventually to see if any of the parameters associated with the phytoplankton can be used as an indicator of the changes in water quality.

The study showed that changes in TSS, TSO, BOD and nutrient levels were significant in contributing to the changes in seawater quality resulting from human activities. A total of 133 phytoplankton species from 63 genera were identified from all the locations. The diatoms were the most diverse group with 103 species followed by the dinoflagellates (27) and the blue green algae (3). Seven species of diatoms, *Coscinodiscus asteromphalus*, *Odontella sinesis*, *Pleurosigma elongatum*, *Pleurosigma normanii*, *Rhizosolenia stolterforthii*, *Thalassionema frauenfeldii* and *Thalassionema nitzschioides* dominates the population found during this study. Kuala Juru recorded the highest phytoplankton abundance and biomass followed by Bayan Lepas, while Batu Ferringh recorded the highest values of phytoplankton species diversity followed by Teluk Aling. Both the water quality parameters and phytoplankton abundance and diversity were influenced by the dry and rainy seasons as well as the tidal levels.

The results of the study indicated that phytoplankton biomass, abundance and species diversity are not very good predictors for the changes in water quality for the study area.

The conditions of water quality were not reflected in the variation in phytoplankton species diversity. Although the variation in phytoplankton population and biomass can be related to the changes in water quality, the phytoplankton response to these environmental conditions is by no means fully understood. At all the locations, the selected water quality parameters do not seem to be adequate in describing the variation in phytoplankton characteristics. Other factors such as currents and wave movement may also contribute towards the variation in water quality and phytoplankton characteristics and these should also be considered to provide a refinement of the general picture of environmental quality for the area.

CHAPTER 1

Introduction

1.1 Background

The aquatic ecosystem is a major subdivision of the biosphere, and covers almost 71% of the earth's surface area. Land use is continuously changing (both under the influence of human activities and nature) resulting in various kinds of environmental impacts on the aquatic ecosystem. Particularly, these impacts have the potential to significantly affect the interface area between land and sea called the coastal zone ecosystem. Although coastal zone ecosystems represent only a small area of the world's oceans, they are of great ecological and economic importance (Matias *et al*., 2001). Now, the coastal zone ecosystem is being exploited for various development projects (ICZM, 1998), resulting in deterioration of habitats and resources.

Human activities are the most important factor of change in most of the world's coastal zone. However, the pressure of population growth, coupled with the demand for development, are jeopardising these regions. Changes in the biological, chemical and physical parameters (water quality) result from the different kinds of pollutants such as pesticides, heavy metals, oil, petroleum products, synthetic organics, radioactive isotopes and a large number of inorganic and organic compounds, etc (Ross, 1982; GESAMP, 1990). There is an increasing global concern about the fate persistent pollutants, particularly organic pollutants that are introduced into the marine environment through drainage, precipitation and run-off. A number of studies during the 1970s revealed extensive damage of some terrestrial ecosystem and in marine ecosystems ascribed to organic pollutants (Ratcliffe, 1965). There has been a growing concern globally in highlighting the hazards of organic pollutants and their impact on bio-diversity and human health. The pollutants originate from many sources of waste discharge, industrial wastes, municipal wastes, agriculture run-off, accidental spillage, etc. The greatest volume of wastes discharged to coastal waters is sewage, which is primarily organic in nature and subject to bacterial decay (Clark, 1986). Sewage pollution is manifested in the low dissolved oxygen levels and in high nutrient levels in these waters, which can lead to an imbalance of plant and animal communities through the food web (Johnston, 1976; Parnell, 2003).

In Malaysia, the rapid changes in the natural environment were mainly driven by the continued eco-social growth and industrialization whereby the coastal area is the most affected region. The coastal zone of Malaysia experiences the most intense human activity, where a large percentage of the population, ports, industries, tourism constructions as well as agriculture, aquaculture, fisheries, mineral and oil and gas exploitation, communication, transportation, recreation and sewage discharge result in many conflicting human activities in that region.

This wide range of activities may be contributing to the release of contaminants to the coastal zone. The release of contaminants occurs due to man-made sources, and to the natural (physical, chemical, biological and geological) processes. These process such rivers and atmospheric transport, coastal erosion and sediment transport (Shumilin and Chudaeva, 1991).

Coastal areas of Penang are the case of this study where it is directly exposed to the waste discharge of all sources of pollution such as domestic, industrial and agro-industrial, and animal wastes (Kadir, 1998). As a result, according to the Penang State Government (1997), Penang suffers from different sources of pollutants. For example, it is clear that the beaches are no more clean, except those which have been utilized for tourists attraction. Environmental quality in terms of the levels of water pollution in rivers and coastal waters has generally declined. In addition, most of the coastal waters of Penang are not safe for swimming because of the high bacterial levels and the high turbidity of the water.

The knowledge of water quality changes in coastal areas is an important component for monitoring and management activities concerned with land use to detect the natural seasonal changes in the coastal waters and to identify the changes from anthropogenic input. The water quality parameters (nutrients, chlorophyll-a, salinity, pH, biochemical oxygen demand, etc) provide an overview of the existing trends of the environment quality.

Environmental management is the main aim of environmental quality studies and many Asian countries have implemented numerous environmental laws and regulations containing provisions for the management of air and water quality (Rees, 1990).

Monitoring is one of the crucial steps and an essential component for proper environmental management and human health saving, so most of the countries in the world have monitoring programmes to assess the water quality in the coastal area and to estimate the rivers input. Since toxic materials can directly and indirectly affect individuals, communities and ecosystems (Stewart and Robertson, 1992), biological monitoring is better than other types of monitoring. It has a very valuable and interesting role to play in the monitoring of pollution (Spellerberg, 1991) and to obtain the information to indicate the water quality status. Biological communities reflect the overall ecological integrity and thus provide a broad measure of the stressors aggregate impact and an ecological measure of fluctuating environmental conditions.

Most of the organisms, either animal or plant, may be used as indicators of biological monitoring in the open sea and coastal area. They are affected by the changes in the water quality and the pollutants. The plankton population, abundance and species composition can be environmental indicators because of their sensitivity to environmental changes (APHA, 1992). But the routine biological monitoring of aquatic ecosystem is based largely on macroinvertebrates or phytoplankton (Weber, 1973; Kelly *et al.*, 1995) since the phytoplankton provide relatively unique information concerning ecosystem conditions compared with other commonly used animals (McCormick and Cairns, 1994).

To evaluate and predict the environmental impacts of land-use activities on the coastal area, it is efficient to focus on phytoplankton for two important reasons. Firstly, the composition and structure of phytoplankton communities (taxonomic analyses such as community composition) are fundamental indicators of ecosystem status. Secondly, phytoplankton are sensitive to environmental changes at small spatial scales.

Phytoplankton plays an important role as primary producers, forming the basis of the food chain. These assemblages exhibit excellent continuity through time and with changes in water quality.

Changes in phytoplankton species can occur under diverse circumstances including in response to a variety of irritants (Zmarly and Lewin, 1986). Marine phytoplankton assays are useful in the assessment of the toxicity of municipal, industrial and agricultural wastewater effluents (Greene *et al.*, 1975), so investigators used phytoplankton as indicators of water quality changes and pollution in their studies. Din and Brooks (1986) studied the responses of marine centric diatoms to the chemical wastes discharged. Walsh and Alexander (1980) used marine phytoplankton as indicator of pesticides and industrial wastes. Rai *et al*. (1981) used some algal species as indicators of heavy metals contamination because of their capability to accumulate and concentrate heavy metals.

Realizing the importance of the adverse impact of organic pollutants on aquatic biota, studies were taken to determine the present status of the water quality levels. In Malaysia, many researchers used phytoplankton for water quality monitoring and indicators of organic and inorganic pollution. For example, Nather Khan (1990) studied the biological assessment of water pollution in the Linggi River Basin (Malaysia) using diatom community structure and species distribution. Phang *et al*. (1997) used some marine phytoplankton as an indicator of heavy metals, while Wan Maznah (2001) studied the periphytic algal and physico-chemical parameters as indicators of water quality status of Penang River.

In view of this, coastal phytoplankton were thus selected as biological indicator for monitoring water quality changes and pollution study because very little research has been done on marine phytoplankton around Penang (Chua *et al*., 1977). Each of the projects or studies to be evaluated with focus on the extent to which the goals formally set have been achieved or not and may also be evaluated in terms of its effects or impact on the lives of specific individuals who were meant to benefit directly from it.

Our ability to protect the coastal environment depends on our ability to identify and predict the effects of human actions on biological systems, especially our ability to distinguish between natural and human-induced variation in biological condition. Thus, even though measures taken at places with little or no human influence (reference sites) may tell us something about natural variability from place to place. To find these signs in this study, sampling locations (four) were chosen which ranged from minimal to severe human disturbance.

Finally, this study covers different aspects of coastal water monitoring. The first part of the present research was the determination of the spatial variation of pollutants in inter-environment. The other part of the research attempted to understand the different factors that are responsible for the present contamination levels and then to correlate this information with chlorophyll-a, abundance and species diversity of phytoplankton.

1.2 Objectives

The main aim of this study is to look at the possibility of using phytoplankton as a biological indicator in coastal water quality monitoring.

Two main objectives of this biological monitoring are:

(1) To obtain quantitative information on the water quality and phytoplankton abundance and species diversity in the coastal waters of Penang; and

(2) To use phytoplankton abundance and species diversity as indicators of changes in coastal water quality.

CHAPTER 2

LITERATURE REVIEW

2.1 General Environmental Information of Penang

Peninsular Malaysia extends from latitude 1º 20’ N to 60º 40’ N and from longitude 99º 35’ E to 104º 20’ E, while Penang Island is located in the equatorial belt between latitudes 5º 7’ N and 5º 35’ N and longitudes 100º 9’ E and 100º 32’ E (Chan, 1991).

Penang State has a population of 1,064,166 at the 1991 Census (Rahim, 1998). It is the second smallest state of the thirteen states of Malaysia, comprising approximately 1,031 km^2. It is situated on the northwestern coast of Peninsular Malaysia, bounded to the North and East by the State of Kedah, to the South by the State of Perak and to the West by the Straits of Malacca and Sumatra, Indonesia (Figure 2.1). Penang State is made up of two separate physical entities: Penang Island covers an area of 293 square kilometers and Seberang Perai on the mainland covers an area of 738 square kilometers (ICZM, 1998).

Climate in Peninsular Malaysia is characterized by tropical monsoons, high temperature, high humidity and heavy rainfall (DOE, 1999). Penang also has a similar equatorial climate but with minor monsoonal characteristics. In Penang, the mean air temperature throughout the year is about 27ºC (Chan, 1991) with the averages for the mean monthly daily maximum and minimum being 31.4ºC and 23.5ºC respectively (Seck, 1993).

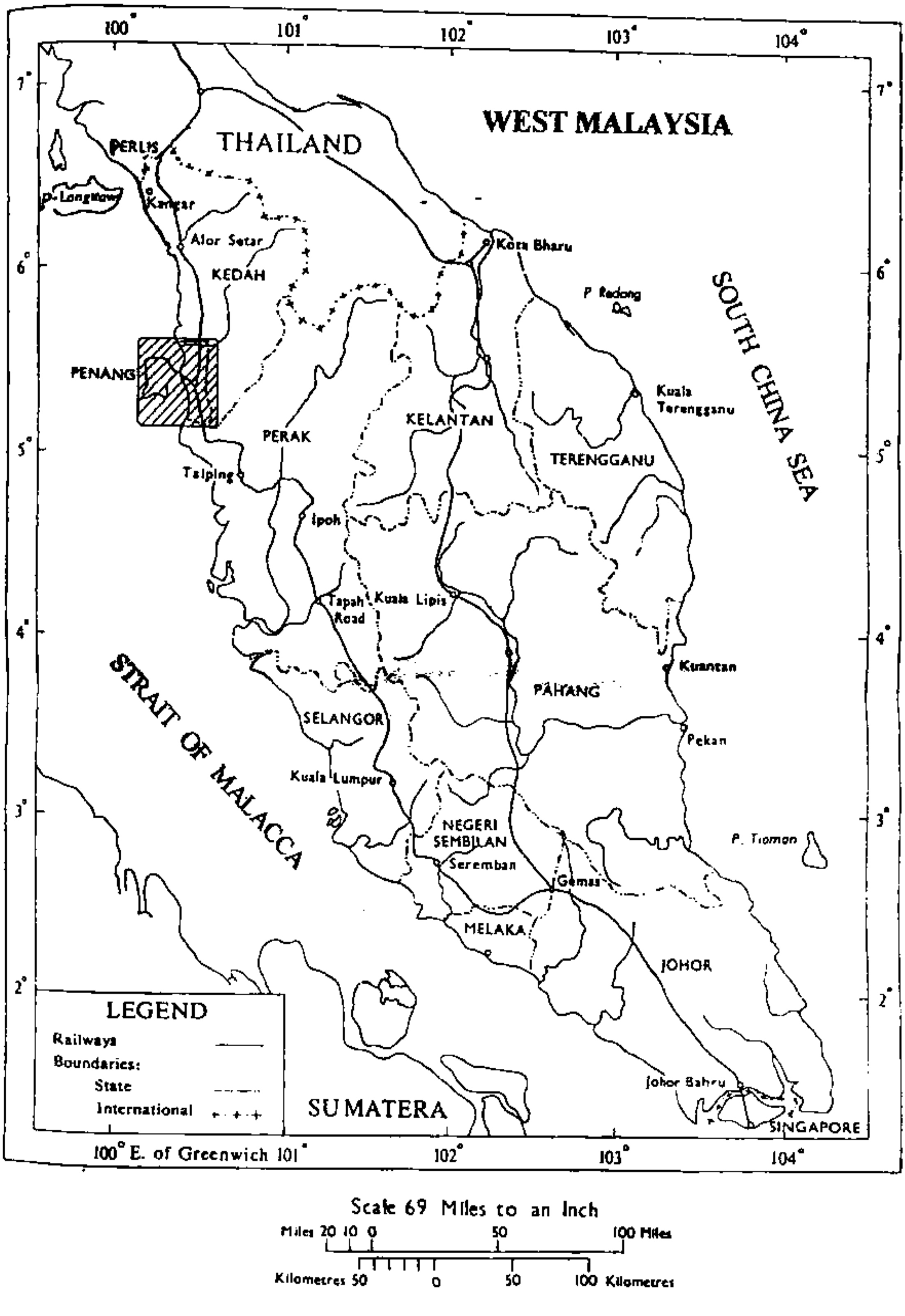

Figure 2.1 Map of Peninsular Malaysia showing the location of Penang.

The daily evaporation and relative humidity are related to the temperature and atmospheric pressure of the day and the monsoon season. The monthly total evaporation is 100-160 mm (Tan *et al*., 1985) and the highest value is recorded in dry season, especially in January. The relative humidity is generally high throughout the year especially during the months of heavy rainfall. High humidity values are recorded in Penang (Georgetown) during the wet inter-monsoon months, while the lower values ranging from 75 to 80% are normally recorded during the dry season (DOE, 1999).

The coastal area of Penang receives more than 220 cm of rain each year (Koh & Din, 1987; Nor *et al.*, 1995). In earlier studies by Chan (1991) and Wan Ruslan (2000), low rainfall was recorded on Penang Island in January while the high rainfall was recorded in October, However in this study, the lowest rainfall was found in February and the highest in October. The mean monthly rainfall data from December 2000 to December 2001 which was recorded by Malaysian Metrological Services (2002) for the Bayan Lepas Airport station indicates that the wet season during this study was from April to May, and from August to November 2001, while the dry season was from December 2000 to March 2001, and from June to July 2001 (Figure 2.2). Periods of dry and wet season are similar to the earlier rainfall data for Bayan Lepas from 1969 to 1980 as reported by Koh & Din (1987) and for the Sungai Juru basin from 1953 to 1990 (Nor *et al*., 1995).

The geological feature of Penang Island is mostly dominated by granite rocks in the hills towards the coast (Penang State Government, 1997). Two main types of beaches are distinguishable from the topographic maps: sandy beaches which are usually dominated by mangrove-fringed mud flats, and rocky beaches, which are limited areas.

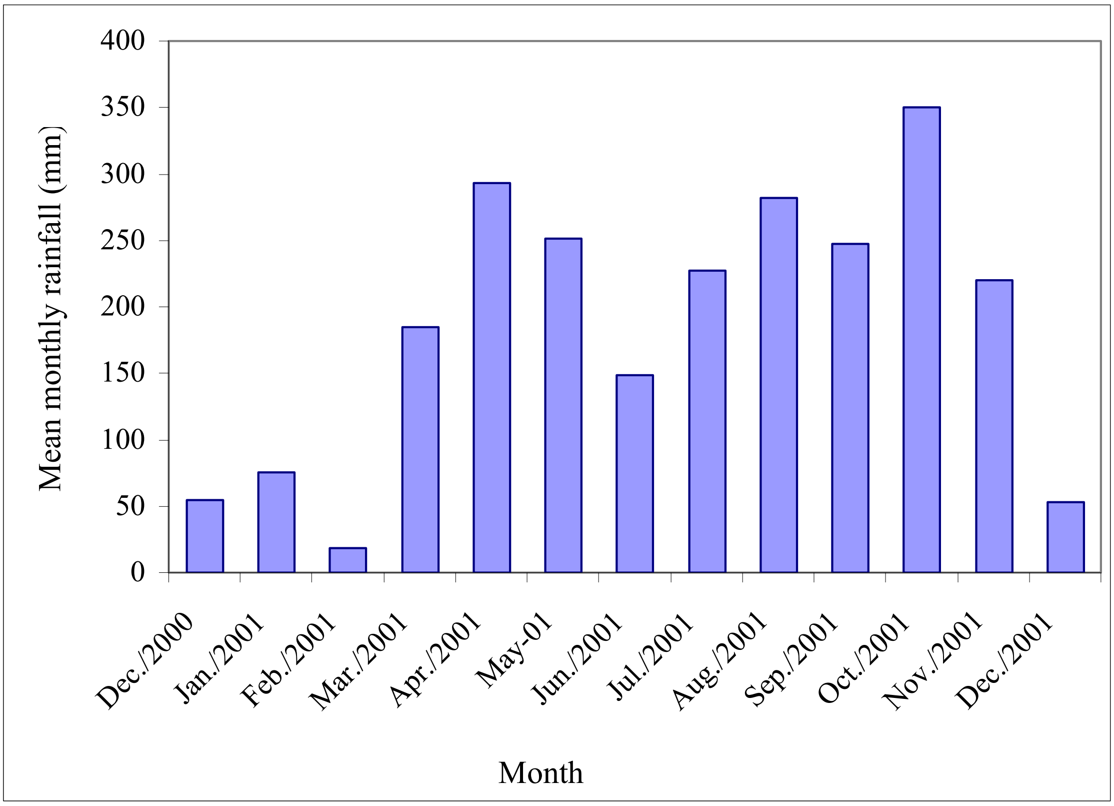

Figure 2.2 Mean monthly rainfalls for Bayan Lepas Airport station (December 2000 – December 2001).

2.2 Coastal Areas of Malaysia, Including Penang

Beer (1983) defined the coastal zone as the land that extends inland one kilometer from the high water mark on the foreshore and extending seaward up to the thirty meter depth line, and includes the waters, beds and banks of all the rivers, estuaries, inlets, creeks, bays or lakes subject to the ebb and flow of the tide. Coastal waters extend inland as far as tidal effects are experienced. Estuaries and deltaic river mouths are, therefore, parts of the coastal zone.

Malaysia consisting of Peninsular Malaysia, Sabah and Sarawak has a coastline of 4,800 km with about 418,000 km^2 of coastal shelf (down to 200 m) (Rabanal and Torno, 1983). The coastal plains along the east coast are narrower in width than the plains along the west coast and averages about 30 km, while the coastal plains in Sabah and Sarawak are about 50 km in width (Phang *et al.*, 1990). Peninsular Malaysia is boarded on the left (west) by the Straits of Malacca and on the right (east) by the South China Sea (Figure 2.3) (Ramachandran, 1993). The West Coast of Sabah and Sarawak also face the South China Sea while the East Coast of Sabah opens into the Sulu Sea and the northern part of the Celebes Sea.

Various bays, lagoons, estuaries and mangrove swamps characterize the Malaysian coastline. Off the coast are several groups of islands, many with fringing coral reefs. The mangrove swamps, mostly on the west coast of Peninsular Malaysia, play vital ecological roles because of their high level of primary productivity (Phang *et al.*, 1990).

Coastal sediments are extensively found along the coast of Peninsular Malaysia. The main types of coastal soils are sand soils, marine clay, peat and associated riverine alluvial soils (Isahak, 1992). The coastal beach system especially the sandy beach is home to hundreds of species of plants and animals that are dependent upon the beaches and near shore waters for all or part of their lives. In Penang, the shore and near shore ecosystem comprises the mangroves, estuaries, sandy and rocky beaches and mud flats (Din, 1995). The sandy beaches of Penang Island have long been a major tourist draw. It is no surprise that they have been over-zealously developed for the hotel and recreation industries. The rocky beaches on the other hand are less appreciated and have been left relatively undisturbed over the years perhaps due to the difficult access. Ecologically, however, they provide habitats for marine life as well as storm protection. Finally, the mud flats have been the mainstays of the cockle culture in Penang since the 1970's. Other than that, they play vital roles in recycling nutrients, assimilating pollutants and providing habitats for a variety of organisms such as mudskippers, crabs, etc (Penang State Government, 1997).

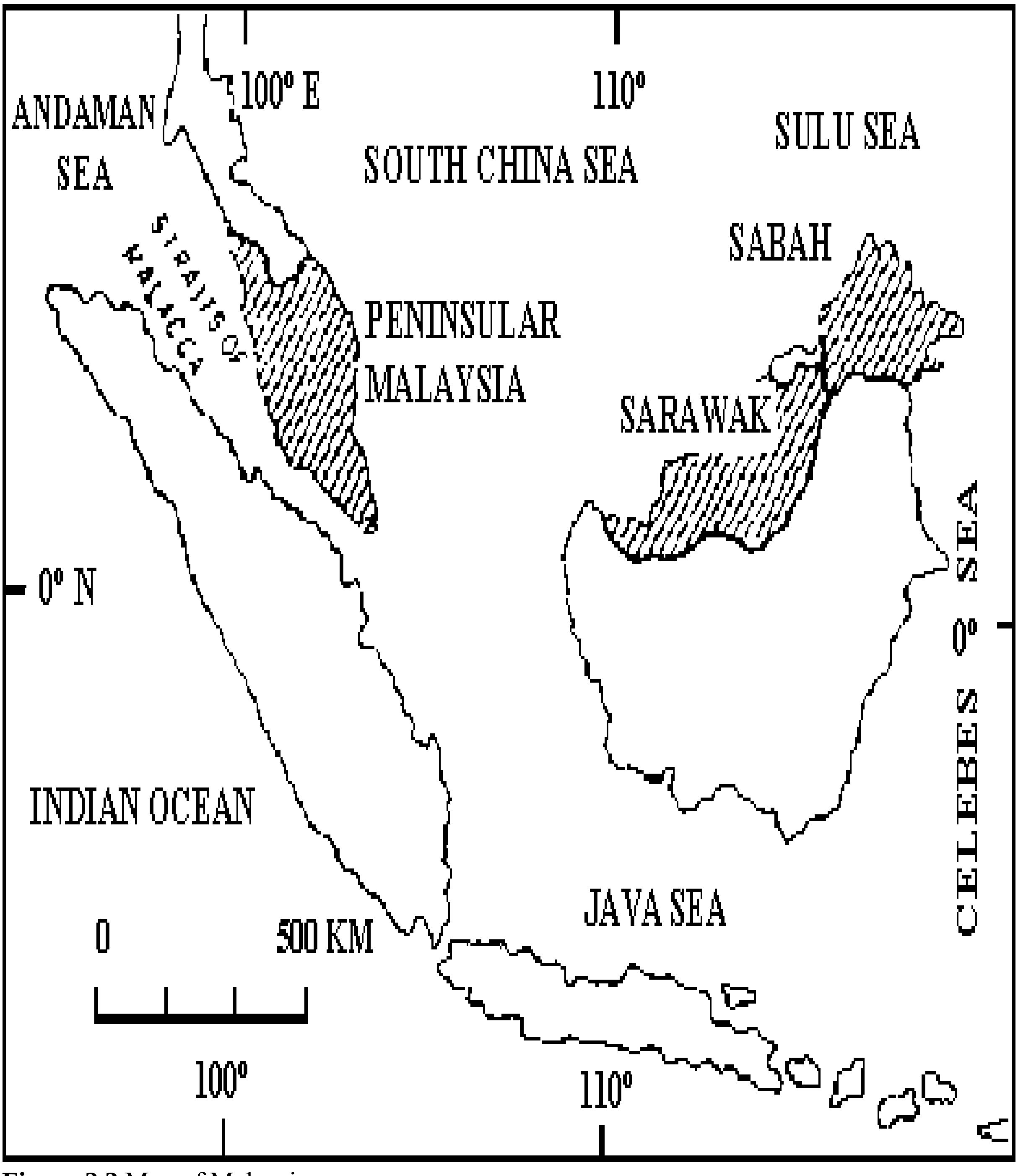

Figure 2.3 Map of Malaysia.

2.3 Coastal Tides and Currents

Tide is the periodic rise and fall of the sea surface, and the most commonly encountered type is that in which two high waters and two low waters occur each day (Bawden, 1983). As mentioned before, Peninsula Malaysia is bordered on the west by the Straits of Malacca (Figure 2.3). The tidal regimes are generated by tides in the Straits of Malacca and are driven primarily by the astronomical semidiurnal tide entering and leaving the Straits at the two north-south entrances (Koh *et al*., 1997). The range of tide is defined as the difference in height between the high and low tides that follow, thus this range varies periodically with the phases of the moon. Tides of maximum range, known as spring tides occur within a day or two of a new or a full moon, whereas those of minimum range, neap tides occur when the moon phase is near the first and the third quarters. The mean spring tide has amplitude of about 1 m and a maximum current speed of 1.05 m/s while the corresponding values for a mean neap tide are 0.25 m and 0.30 m/s, respectively. The semidiurnal tide has a tidal period of 12.45 hours (Koh *et al*., 1997). For Penang Strait, a mean tidal range of 200 cm was recorded during spring tide and a mean of 50 cm recorded during neap tide (Koh and Din, 1987).

The currents are generated mainly by tidal forcing, wind stress and bottom topography. Currents in the Straits of Malacca and the Straits of Penang affect the waters in Penang Island. The current speed and direction throughout the year in the Straits of Malacca are very much related to the stage of tide, winds and seasonal variations (SofianTan, 1999). It is northwest in direction (Keller, 1966), while for the Straits of Penang, the general flow pattern is in the north-south direction (Koh and Din, 1987) and the cumulative surface current speeds of 0.3 m/s or more was recorded at most places around Penang

(USM, 1995). The Indian Ocean and South China Sea influence the Malacca Strait and affect the currents around Penang. The current that passes through the South China Sea from the neighboring seas determine also the currents in the Straits of Malacca. For example, the current during the north monsoon from the South China Sea is originally moving from the Java Sea, and a southeast flow is a result of the Indian Ocean Current moving into the South China Sea and then passes into the Malacca Strait. Flood currents set to the southeast and ebb to the northwest in the strait (Keller, 1966).

2.4 Impact of Human Activities on the Coastal Zone

It is necessary to know the background concentrations of nutrients and other pollutants such as organic matter in the receiving waters in order to assess the environmental impact of human activities as well as the effect of nutrients and other pollutants in the coastal areas (Pillay, 1992).

The coastal areas are exposed to various development processes that alter the inputs of freshwater and sediments, the physical characteristics of the coastline and may result in the deterioration of marine and coastal habitats, resources, and on the human health. In Penang as for the whole of Malaysia, the population and the centers of economic activities encompassing urbanization, ecotourism industry, agriculture, fisheries, aquaculture, oil and gas exploitation, transportation and communication, recreation, etc are the major human activities in the coastal areas (ICZM, 1998). These human activities affect the coastal zone and may cause water pollution particularly from waste discharges.

The ICZM report (1998) mentioned that the shore and near shore ecosystems of Penang and its habitats are ‘heavily threatened’ or face some threat. The rocky beaches as habitats are unfortunately in pristine conditions. The ICZM (1998) quoting the Department of Environment (DOE) reported that, marine water quality around Penang is poor and that it exceeded the interim marine water quality standard in terms of suspended solids concentration, oil and grease, E. coli as well as heavy metals like mercury, lead and copper. It is clear that this system suffers from both land based and sea based pollution in the form of oils and sludge from marine discharges from the port activities, indiscriminate dumping of solid and liquid wastes and loading with organic and inorganic wastes including highly toxic, persistent and bioaccumulative organic chemicals (POPs), which include organochlorine pesticides.

Additionally, Ibrahim (1995) mentioned that at present, 27 % of the shorelines of Malaysia are experiencing erosion of various degrees of severity. The economic and social consequences of coastal erosion and the concern generated have increased several folds as the development in coastal areas intensifies. And the development along the coasts have and bound to cause serious pollution of seawater body which affect water quality and fishery productivity and high levels of siltation in the estuaries resulting from poor management of the projects and upland areas.

The discharge of excessive amount of human wastes into the coastal areas is one of the most widespread pollution problems (Sivalingam *et al*., 1983). The effects of wastes on the coastal areas of Malaysia can be concentrated on the impacts of three main sources of wastes namely domestic, industrial (including agro-based industries) and animal wastes. These are the main ways by which human intentionally or unintentionally contaminate the coastal environment. There are hundreds of pollutants whose effects are of actual or potential concern. Globally, pollutants from the sources mentioned earlier contribute towards 60 to 70% of the problem of marine pollution (Koe and Aziz, 1995).

Domestic sewage is biodegradable organic waste, which means that it can be decomposed in the presence of suitable bacteria species (Gorman, 1993). The sewage discharge outfall in Jelutong, Penang, Island has been discharging about 23 million litres of raw sewage per day (Tan *et al*., 1985). High bacterial count, high biochemical oxygen demand, high nutrient concentration, high suspended solids and eutrophication phenomena are some of the main effects on coastal water quality due to the discharge of domestic wastes (Koh *et al*., 1997). The domestic waste load could be inferred from the per capita suspended solids and per capita biochemical oxygen demand. For the approximately 310,000 population of the Juru River Basin, the waste load generation per capita per day is estimated to be 55 g for biochemical oxygen demand (BOD), 60 g for suspended solids (SS) and 7 g for ammoniacal-nitrogen (Nor *et al*., 1995). Commonly, the untreated sewage or even treated sewage discharge with high loadings is the most common sources of contamination resulting in the degradation of water quality due to the high organic and bacterial loads (DOE, 1999).

Industrial wastes have potential impacts on coastal waters e.g. turbidity as major pollution problem (Penang State Government, 1997). Many organic substances are toxic to marine life and cause oxygen depletion. Inorganic pollutants such as heavy metals are toxic to a variety of marine life. In the coastal areas of Batu Ferringhi on Penang Island, high concentrations of zinc, copper and lead were found in some algae species even as early as in the 1970s (Sivalingam, 1978). Choo *et al*. (1994); Thongra-ar *et al*. (1995)

and Phang *et al.* (1997) reported that the higher concentrations of heavy metals in marine waters of Peninsular Malaysia are because of industrial activities.

Aquaculture, which is rapidly expanding worldwide, if conducted on a large enough scale at a single site, can cause eutrophication, reduces visual amenity, and can interfere with other uses off the sea. Impacts of aquaculture activities on water quality are mainly in the form of a decline in dissolved oxygen and an increase in ammonia concentration (Fridley, 1995). These changes may induce alteration in phytoplankton composition (Nishimura, 1982 in ICES, 1988). Lin (1993) reported that the major constituents in the wastes of aquaculture activities are dissolved nutrients, organic solids, chemicals and bacteria. Cage farming in coastal areas involves the use of highly intensive stocking and feeding, which results in increased sedimentation, biochemical oxygen demand, and nutrient loading. In areas of low turbulence and high organic input, the sediment/water interface can also become anoxic. It has been observed that water under cage farms in turbulent locations can become depleted in oxygen for long periods (Gown and Bradbury, 1987).

2.4.1 Coastal Water Pollution

The United Nations Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) defined marine pollution 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 fishing, impairment of quality for use of seawater and reduction of amenities " (Lloyd, 1992).

It is clear that man's marine–related activities tend to be focused in shallow water near the coast, and the major source of contaminants to the sea is the continental landmass. The impact of man along the edges of ocean is therefore unambiguous, and in places substantial degradation of the environment is evident.

Environmental pollution including pollution of the aquatic environment is not a recent problem and has now become a serious concern on a global scale (Albaiges, 1989). It is drawing a lot of attention due to the increase in the rate of industrialization and economic growth that substantially appear to adversely impact on the environment. Many researchers have emphasized the importance of the coastal environment as a reservoir of persistent chemicals and advocated the need for introducing monitoring strategies employing bio-indicators (Goldberg *et al*., 1978; Phillips, 1980; Farrington *et al*., 1983; Duursma and Carroll, 1996).

Klein (1962) reported the various types of pollution according to four categories: Chemical, physical, physiological and biological. Many different chemicals ranging from simple inorganic ions to complex organic molecules that are discharged into the coastal waters are regarded as pollutants. Undesirable results from the discharge of inorganic materials include changes in the pH of the water (Krenkel, 1974) and other chemical properties. The variation in pH values in polluted areas perhaps are due to the non-stability of the buffer capacity of the carbonate system due to the introduction of either a large amount of acid or base or the fermentation of the organic matter (Khalil, 1989). Heavy metals and nutrients can be used as indicators of inorganic pollution. Suspended particulate acts as the main transport medium for chemical species. As man impinges on the coastal regions, his activities such as construction and agriculture efforts generally tend to increase erosion and therefore increase the amount of sediment in suspension (Choo, 1994).

More than 60,000 organic chemicals are presently used for various purposes and they finally end up in the marine environment (Ernst, 1984). The major consideration with respect to organic waste pollution is the depletion of dissolved oxygen and its resultant effect on the biota (Krenkel, 1974). The major organic chemical pollutants entering the marine environment are petroleum hydrocarbons, oil and grease, pesticides and their derivatives and detergents.

Colour, turbidity, temperature, salinity, conductivity, dissolved oxygen, radioactivity and suspended solids are some of water quality parameters which have been used as indicators of physical data which is vital for the proper management of the marine environment (Din, 1993 and Nasir, 2001). Suspended solids as an example, cause water turbidity and a disturbance of the balanced ecosystem, while accumulation of radioactive substances in food organisms produce human body changes (Dix, 1981).

Toxic chemicals can cause immediate or cumulative physiological changes in plants, animals and humans (Dix, 1981). The stress caused by certain pollutants may result in damages at the cellular or the organ level or may be at the whole organism level with possible lethal consequences (Walker *et al*., 1996). In Malaysia, several studies have been carried out to look at the influence of pollutants on the physiology of marine organisms. Din and Ahamad (1995) for example, studied the effects of pollution gradient on the growth physiology of the blood cockles from the Juru area.

Pathogenic effects are caused by microorganisms, where bacteria, virus and fungi are present in sufficient numbers to cause health hazard (Dix, 1981). Bacteria is one of the main indicators of biological pollution. High faecal coliform count is mainly due to domestic waste (Chua *et al*., 1997), as well as animal wastes (Choo, 1994; Law *et al*., 2001a) discharges.

2.4.2 Organic Pollution

Organic matter is present in seawater in particle size ranging from small organic molecules to big complex organic molecules and ranges from dissolved organic compounds to large aggregates of particulate organic matter. As has been stated earlier, under most normal conditions, input of pollutants in the natural systems is at a concentration that is low enough not to cause any significant problem. It is only when the concentrations increase to above the threshold levels that problem ensues and the magnitude of which is related to the level of concentration. In the case of organic matter however; the above statement is no longer necessary because pollution due to the input of organic matters is very complex, as it involves not only the de-oxygenation of water, but also the addition of suspended solids (Hynes, 1960).

The major source of organic pollution due to human activities are sewage and domestic wastes, agriculture discharge, food processing and manufacture and numerous industries involving the processing of natural materials such as textile and paper manufacture (Abel, 1996; Nor *et al*., 1995). The major concern in any consideration of organic pollution is the changing of the critical nutrient balances induced by the organic substances (Cairns *et al*., 1972), and an increase in algal biomass (Welch *et al*., 1992).

Bacteria and fungi decompose most of the organic matter, and the results of the breakdown of the complex organic molecules in the presence of oxygen are the simple inorganic substances such as phosphate and nitrate, carbon dioxide and water (Abel, 1996).

Fertilizer is one of the most important inputs in agriculture activities as it serves to maximize the yield and replenish the soil of its loss of nutrient elements such as nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) (Hui, 2001). Organochlorine pesticides as example of organic pollution have been used in Malaysia for more than fifty years, for agricultural and public health purposes (DOE, 1998). Now it is well proven that, these chlorinated pesticides are persistent, lipophilic, and hazardous to health and are suspected to have carcinogenic and or mutagenic effects (Ritter *et al*., 1995; WWF, 1998). The persistence and bioaccumulative nature in the food chain and specially due to highly lipophilic and toxicological characteristics of these compounds make it necessary to establish baseline data for the pollution of Malaysian environment with these pesticides and their degradation products to the commercially valuable and edible organisms of the coastal and marine ecosystem in view of public health concern as well as economic. Another report of case study done by Majid and Elizabeth (PRN, 2000) on the exposure of pesticide among estate workers of Perak, Penang and Kedah shows a number of adverse health effects though they did not identify which pesticides are responsible.

2.4.3 Nutrient Pollution

The coastal fronts have been noted to have high primary productivity due to the nutrient enrichment and thus offer ideal fishing grounds and contribute significant income for the fishermen and the country. Moreover, it is also known that the coastal fronts converge various floating materials and thus serve as ideal places of bioaccumulative and ecotoxicological concern regarding hazardous materials (Tanabe *et al*., 1991).

Nutrients are chemicals that are essential for the proper health and growth of plants. A total of 20 elements are required for phytoplankton growth. These are: C, H, O, N, P, S, K, Mg, Ca, Na, Fe, Mn, Cu, Zn, Mo, V, B, Cl, Co and Si ((Moss, 1980). The most common and major of these nutrients are the compounds of nitrogen and phosphorus (Nybakken, 1982; Yahya *et al*., 1989).

Nutrients exist in the natural environment (water, soil and air) at all times and some of them are recycled naturally by decaying living organisms. Aqueous life depends on the availability of dissolved nitrogen and phosphorus (Skinner and Turekian, 1973). Harris (1986) reported that in surface waters the pools of dissolved inorganic nitrogen (ammonium, nitrate, nitrite, molecular N_2 and DIN) are therefore very much dependent on biological uptake and regeneration. About 95 % of the N in the oceans is present as molecular N_2. The first three forms: dissolved nitrate (NO_3^-), nitrite (NO_2^-), and ammonium (NH_4^+) ions are the major sources of nitrogen, which are required by phytoplankton (Boney, 1989). Dissolved orthophosphate on the other hand is clearly one of the nutrient sources for phytoplankton as it is taken rapidly by phosphorus deficient cells until very low concentrations remain in the water (Rigler, 1966, Boney, 1989). In the freshwater environment, low availability of phosphate is one of the several factors which may cause a decline in primary productivity (Abel, 1996; Law *et al.*, 2001a), while the productivity in coastal waters is normally limited by the concentration of nitrogen compounds (Skinner and Turekian, 1973).

Nitrogen and phosphorus are normally low in seawater. The usual range of the N compounds in seawater are nitrate (1-500 μg NO_3-N dm^{-3}), nitrite (< 1-50 μg NO_2-N dm^{-3}) and ammonia (< 1-50 μg NH_4-N dm^{-3}), while the usual range for inorganic P compounds are present mainly as orthophosphate in seawater is 1-75 μg P dm^{-3} (Johnston, 1976).

Nowadays, nutrients are at times regarded almost as a nuisance (Salomons *et al.*, 1988) because the excess concentrations that enter the aquatic ecosystem in the form of sewage and industrial wastes or run-off from urban areas can dramatically increase the primary productivity of the ecosystem and this consequently may affect the marine water quality (Abel, 1996). The source of additional organic and inorganic phosphate is mainly through discharges of domestic sewage, partly supplied by human waste and mainly from the use of phosphate-rich detergents and fertilizers (Abel, 1996).

Inorganic compounds such as ammonium are used preferentially by plants, and produced by bacterial breakdown of organic matter and animal excretion. At optimal concentration this nutrient concentration stimulated excess algal growth in unpolluted marine waters, ammonium concentrations are low and variable, while nitrate that is an important source of nitrogen is present in large quantities, while nitrite is present in much lower quantities (Boney, 1989). In polluted waters, it is known that high concentrations of nitrogen, particularly in the form of NH_4^+, NO_2^- and NO_3^-, can be toxic to many varieties of aquatic organisms, and can constitute a human health hazard.

In Malaysia, several studies have indicated that the Malacca Straits is contaminated by nitrogen discharged from land-based activities, whereby high ammonium, nitrate and nitrite values were recorded in near-shore waters area from the wastewater discharge (Law *et al.*, 2001b). Chua *et al.* (1997) reported that the average nitrate concentrations in the open water of the Malacca Straits varied from 0.12 to 0.98 mg NO_3-N/L, and inorganic phosphate concentrations varied from 0.17 to 0.42 mg PO_4-P/L near the surface. Law *et al.* (2001a & b) reported that the mean concentrations of nitrate, nitrite and ammonium in the surface seawater are 0.827, 0.167 and 2.248 µg-at N/L respectively, and the mean concentration of phosphate is 0.242 µg-at P/L.

The external concentrations of nutrients are subject to wide variations in space and time. Moreover, they are present in differing amounts relative to the requirements of the healthy, active cell. Algal responses to nutrient enrichment include both nutrient uptake and cell growth. Phytoplankton can assimilate nutrients at rates far exceeding their requirements for steady state growth assimilation (Parnell, 2003). As such, the growth of phytoplankton may be limited, or in some cases, inhibited by the availability of particular nutrients. In fact, the variations in the chemical composition of natural waters might play an important role in regulating the abundance, composition, the geographical and temporal distribution on phytoplankton (Reynolds, 1984). Excess amount of nutrients (phosphorus and nitrogen) that are discharged into the coastal areas have been shown to cause eutrophication and this would lead to various changes in the algal community structures (Riegman, 1995 and Parnell, 2003), such as rapid growth of