WATER QUALITY AND PERIPHYTIC ALGAE COMMUNITY OF PETANI RIVER BASIN, KEDAH

by

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LIST OF ABBREVIATIONS

Abbreviation	Caption
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOE	Department of Environment
dwt	Dry weight
FSI	Fine Sediment Index
FSW	Fine Sediment Weight
ISI	Important Species Index
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
WQI	Water Quality Index

KUALITI AIR DAN KOMUNITI ALGA PERIFITIK DI LEMBANGAN SUNGAI PETANI, KEDAH

ABSTRAK

Objektif kajian ini ialah untuk menentukan status kualiti air di Lembangan Sungai Petani berdasarkan kepada klasifikasi yang digunakan oleh Jabatan Alam Sekitar Malaysia dan membandingkannya dengan ketepatan penggunaan alga perifiton sebagai penunjuk biologi bagi kualiti air. Sampel air dan alga perifiton diambil dari 6 stesen persampelan A hingga F berdasarkan pengaliran air dari hulu ke hilir Sungai Petani yang mempunyai tahap pencemaran yang berbeza di sepanjang Lembangan Sungai Petani selama 12 bulan. Oksigen terlarut (DO), permintaan oksigen biokimia (BOD), permintaan oksigen kimia (COD), jumlah pepejal terampai (TSS), pH dan ammonium diukur untuk pengiraan Indeks Kualiti Air (WQI). Parameter seperti alkaliniti, nitrit, nitrat, ortofosfat, saliniti, dan jumlah pepejal terlarut (TDS) turut ditentukan untuk mendapatkan gambaran yang lebih tepat mengenai kualiti air di Sungai Petani. Stesen B mencatatkan nilai WQI yang tertinggi (60.49), diikuti oleh Stesen F (59.56), Stesen C (57.13), Stesen D (56.92), Stesen E (55.20) dan Stesen A (55.07). Secara amnya kualiti air sungai semakin merosot apabila air mengalir dari hulu ke muara, kecuali di Stesen F. Kualiti air sungai yang melalui kawasan perumahan (Stesen B) dan air di muara sungai (Stesen F) didapati lebih bersih berbanding air sungai yang melalui kawasan perindustrian dan pusat bandar (Stesen C, D dan E). Nutrien seperti nitrit, nitrat dan ammonium adalah tinggi di sungai yang melalui kawasan perindustrian (Stesen C), manakala ortofosfat adalah lebih tinggi di sungai yang melalui kawasan perumahan dan pertanian (Stesen A). TSS pula tinggi di stesen yang mengalami hakisan (Stesen A dan Stesen F). Kajian

ini mendapati air pasang besar mempunyai kesan yang lebih jelas terhadap parameter fisiko-kimia air berbanding ketika air pasang mati. Ketika air pasang besar, peningkatan dan penurunan kandungan fisiko-kimia air berubah dengan lebih ketara sepanjang kitaran pasang-surut air berbanding ketika air pasang mati. Klorofil *a* dan berat kering tanpa abu (AFDW) digunakan untuk pengiraan Indeks Autotrofik (AI), manakala berat sedimen halus (FSW) diukur untuk pengiraan Indeks Sedimen Halus (FSI). AI yang tinggi di Stesen C menunjukkan ianya didominasi oleh organisma heterotrofik dan mempunyai kualiti air yang rendah. Keputusan ini disokong oleh hasil analisis korelasi Pearson yang mendapati kepekatan nutrien mempunyai hubungan yang positif dengan AI. Pengiraan indeks kepelbagaian Simpson, Shannon-Weiner, Margalef dan Menhinick berdasarkan kepelbagaian dan kekayaan perifiton menunjukkan Stesen E dan Stesen F (berair payau) mempunyai kepelbagaian spesies alga yang tinggi. FSW juga didapati mempunyai kesan yang positif terhadap kepelbagaian spesies. Spesies seperti *Climacosphenia moniligera, Closterium* sp. dan *Mischococcus confervicola* hanya dijumpai di Stesen C. Oleh itu spesies tersebut mempunyai potensi digunakan sebagai penunjuk kualiti air yang mempunyai kandungan nutrien yang tinggi. Pengiraan indeks saprobik (SI) menunjukkan Stesen A (1.625) sebagai stesen paling tercemar. Keputusan ini adalah sama seperti keputusan yang diperolehi melalui pengiraan WQI sekaligus membuktikan keberkesanan perifiton sebagai penunjuk kualiti air.

WATER QUALITY AND PERIPHYTIC ALGAE COMMUNITY OF PETANI RIVER BASIN, KEDAH

ABSTRACT

This study was carried to determine the status of water quality in the Petani River Basin according to the classification used by the Malaysian Department of Environment (DOE) and to evaluate the reliability of periphyton algae as a biological indicator of water quality. Water samples and periphytic algae were collected from 6 sampling stations with varying level of pollution along the Petani River Basin. Dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), pH and ammonium were measured for the calculation of Water Quality Index (WQI). Parameters such as alkalinity, nitrite, nitrate, orthophosphate, salinity and total dissolved solids (TDS) were also determined. Station B (60.49) recorded the highest WQI, followed by Station F (59.56), Station C (57.13), Station D (56.92), Station E (55.20) and Station A (55.07). This showed that the water quality decreased as it flowed downstream except in Station F. Generally the water quality at Station B where it pass through residential areas and the water in the confluence (Station F) were cleaner as compared to water which flowed through industrial and town centre (Stations C, D, and E). Nutrients such as nitrite, nitrate and ammonium were high in river which flowed through industrial area (Station C), while orthophosphates was high in river which flow through residential and agricultural area (Station A). TSS was high at stations where erosion occurred (Stations A and F). It was found that spring tide has a bigger influence on water physico-chemical properties compared to during neap tide. During spring tide, the increase and decrease of water physico-chemical properties were more obvious throughout the tide cycle as compared to during neap tide. Chlorophyll *a* and ash-free dry weight (AFDW) were used to calculate autotrophic index (AI), while fine sediment weight (FSW) were determined for the calculation of FSI. High AI in Station C indicates that it was dominated by heterotrophic organisms and had a poor water quality. This was supported by the result of Pearson's correlation analysis which found that nutrient concentration had a positive relationship with AI. The calculation of Simpson, Shannon-Weiner, Margalef and Menhinick diversity indices had shown Station E and F (brackish) as having the highest species diversity. FSW was also observed to have a positive effect on species diversity. Species such as *Climacosphenia moniligera, Closterium* sp. and *Mischococcus confervicola* can only be found in Station C. Thus those species may have a good potential as indicators of nutrient enriched water. The calculation of saprobic index indicated that Station A (1.625) as the most polluted station. This was in agreement with the results obtained through the WQI, thus enhancing the reliability of periphyton as an indicator of water quality.

CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia has an annual rainfall of 3000 mm or 990 billion m^3 of which 566 billion m^3 are surface run-off, 64 billion m^3 become groundwater recharge and 360 billion m^3 return to the atmosphere through evapo-transpiration (Azhar, 2000). Being a nation with high water consumption, freshwater resources such as streams and rivers are of paramount importance to the development of the country. They contribute up to 98% of the total water used in Malaysia and the rest are from groundwater (Abdullah and Jusoh, 1997).

As the nation develops and increases in population, a serious water crisis such as pollution due to poor planning can cause environmental degradation and a decline in beneficial use of river (Madsen *et al.,* 2002). Therefore regardless of the abundance of water, there is simply a shortage to support the consumption of the population (Madsen *et al*., 2002). FitzHugh and Richter (2004) mentioned that quenching urban thirst of growing cities and balancing the thirst against all other freshwater needs is a major challenge.

The unequal distribution of freshwater resources around the world (Flemer and Champ, 2006) also makes things worse. This can be seen throughout the world where many countries are disputing over water resources. Currently there are disputes over the Nile Basin, the Mekong Basin and the Jordan Basin (Chan and Nitivattananon, 2006).

In Malaysia for instance, the increase water demand in Penang, has force it to become dependent on the water supply from the neighbouring state Kedah. It is expected that Penang will face water shortages by 2010 when its existing water production capacities will be outstripped by population and economic growth (Chan and Nitivattananon, 2006). If this condition persists, it is possible that freshwater may over the next several decades compete with petroleum as a limiting resource to socio-economic prosperity (Flemer and Champ, 2006). Some researchers also suggested that freshwater scarcity may even be the cause of political instability (Flemer and Champ, 2006).

In order to overcome this problem and increase the water supply, the government has build dams all over Malaysia, but the problem with building dams is its high cost. For example the Beris Dam in Kedah costs RM300 million and the Teluk Bahang Dam in Penang costs RM140 million to build (Chan and Nitivattananon, 2006). Apart from that, there are limited numbers of rivers where dams can be built. The Drainage and Irrigation Department (DID) estimated that there are about 255 river basins in Malaysia that have reached its water supply capacity (Keizrul, 2002) hence no more dams can be built in these rivers.

River pollution in cities and towns around the world are caused by anthropogenic influences as well as natural process. As the urban population continues to rise, the understanding of river-base flow and surface water quality for the urban area gains greater importance (Shepherd *et al*., 2006). The contamination of rivers will impair their use for drinking, industry, agriculture, recreation and other purposes (Sánchez *et al*., 2007).

In Malaysia, domestic sewage currently contributes to almost half of the organic pollutant load in the aquatic environment. It has been reported that the main pollution source of the Sarawak River was discharges from households (NREB, 2001; Ling *et al*., 2006). In Penang, 54% of the source of pollutant load to the rivers is effluent from Indah Water Konsortium (IWK) treatment plants (JAS, 2004; Harlina *et al*., 2006). From 120 river basins monitored in 2001, 60 basins (50%) were clean, 47 (39%) were slightly polluted and 13 (11%) were polluted (DOE, 2002). 51% of the pollution in these basins were from domestic sewage facilities, 39% from manufacturing industries, 7% from pig farms and 3% from agro-based industries (DOE, 2002). However the number of river basins which were clean in 2006 had improved. Out of 146 river basins monitored, 80 river basins (55%) were clean, 59 (40%) were slightly polluted and 7 (5%) were polluted (DOE, 2006).

At present the surface and groundwater of developed nations is experiencing elevated concentrations of nitrogen and phosphorus compared to about 50 years ago (Smith *et al.*, 2003; Flemer and Champ, 2006). Over enrichment by nitrogen and phosphorus has been known to encourage the growth of undesirable amount of aquatic plant growth. Some of the effects of over-enrichment includes hypoxia resulting in fish kills, shading out of sea grasses by periphyton and phytoplankton, loss of water clarity, reduction in biotic diversity, increase in algal species of poor food web quality and an increase in algal blooms (Flemer and Champ, 2006).

In Malaysia, most river water quality monitoring has been conducted in cities and states that are fully developed or economically prominent compared to smaller developing towns. This study focuses on the water quality of the Petani River that flows through the developing town of Sungai Petani, Kedah. The status of water quality was determined using the Water Quality Index and the river classification used by the Malaysian Department of Environment (DOE). The reliability of periphytic algal as a bioindicator of river pollution was also studied.

1.2 The Importance of Biological Monitoring

Biological monitoring methods are playing an increasingly important role in river quality monitoring, mainly due to the fact that the biota are continuous witnesses of the river's state of health and are collectively sensitive to the whole range of potential pollutants (Walley *et al*., 2001; Iliopoulou-Georgudaki *et al.*, 2003.). Apart from that, traditional approaches which depend on laboratory tests have several weaknesses including the failure to validate laboratory results under field conditions (McCormick and Cairns, 1994). So a lot of efforts have been made to characterize the cumulative impact of human activities on ecosystem more accurately by increasing the use of measures of ecological condition as an addition to chemical indicator (McCormick and Cairns, 1994).

If the full potential of biological monitoring is to be realised, much work needs to be done to improve existing methods and to develop new methods based on advanced data interpretation methods (Walley *et al*., 2001).

The usage of algae as a biological indicator has been suggested by various studies as a complement to the traditional method of monitoring (McCormick and Cairns, 1994; Knoben *et al*., 1995; Masseret *et al*., 1998; Hillebrand and Sommer, 2000; Pipan, 2000; Rauch *et al*., 2006). Biological monitoring using algae as an indicator can help provide unique information about the ecosystem which is potentially useful as an early warning sign of deteriorating condition and its possible causes (McCormick and Cairns, 1994).

1.3 Periphytic Algae

Algae are the simplest plant without roots, stem or leave and exist in variable sizes. There are microscopic algal cells which cause water to look green, while some of the algae are macroscopic with longer and branchy structures which make them visible to the naked eye. Usually micro algae can be seen in the form of green slime. The word ‘diatom’ is sometimes used to refer to singular cell algae that has fibrous silicate outer layer (Hammer, 1986).

Algal identification is carried out through microscopic observation (Hammer, 1986). According to Chapman and Chapman (1990), the most important criteria for the classification of algae are the differences in pigmentation, biochemical characteristic and the organelle structure such as flagellum.

The definition of ‘periphyton’ is normally used in scientific writing in America to describe the micro community that are attached and submerged underwater (Weitzel, 1979). According to Cooke (1956) and Sladeckova (1962), the first groups that used this definition were Russian scientists who referred periphyton as the assemblage of microorganism that grow or live on the surface of objects or artificial substrates that are submerged under water. Cooke (1956) also mentioned that in European and Asian writings, the definition of periphyton had been widened to cover all aquatic organisms that grow or live on submerged substrates.

Young (1945) defined periphyton as organisms that live on natural and artificial substrates, excluding benthos (Young, 1945; Weitzel, 1979).

Wetzel (1964) suggested that periphyton refers to all plants that grow on submerged substrates. The submerged substrates can be sediment, rock, thrash or rubbish and living organisms (Wetzel, 1964; Vollenweider, 1969; Weitzel, 1979).

Apart from the word periphyton, there is another word that can be used to represent this kind of assemblages. The German word 'Aufwuchs' was first used to describe organisms that grow or attach on certain substrates but do not grow into or through the substrates (Weitzel, 1979). Ruttner (1953) later defined 'Aufwuchs' as all organisms that are strongly attached on a substratum but not through it.

There are several qualifying terms that are used in referring to the different types of periphytic algal community associated with different type of substrates. They are epilithic (growing on rocks), epipelic (growing on mud or sediments), epiphytic (growing on plants), epizoic (growing on animal), epidendric (growing on wood) and epipsammic (growing on sand surfaces) (Weitzel, 1979).

1.3.1 Periphytic algae as Bioindicator

Periphyton is a complex microcosm composed of living, senescent and dead autotrophic (microalgae) and heterotrophic microorganisms (bacteria, fungi, protozoa and micrometazoa), and fine particulates, enveloped in a polysaccharide matrix of biological origin (Neckles *et al*., 1994; Masseret *et al.,* 1998).

Periphytic algae were chosen as a bioindicator in this study because it can reflect the environmental condition in the recent pass (Weitzel, 1979; Masseret *et al*., 1998). Its position which is at the interface between the substrate and the water combined with the fundamental role it plays in the various biogeochemical cycles and dynamics of the aquatic ecosystem (Amblard *et al*., 1990; Hansson, 1990; Masseret *et al*., 1998) enables periphyton to be an integrated source of information by serving as an indicator of both chemical and physical stresses in aquatic ecosystem (Weber and McFarland, 1981; Masseret *et al*., 1998). Apart from that, periphyton has been recognized as being among the best biological indicator (Prygiel and Coste, 1993; Stevenson and Lowe, 1986; Hürlimann and Schanz, 1993; Masseret *et al*., 1998). The sessile nature and fast growth rate of diatoms (Stevenson and Lowe, 1986) makes it useful in studying the impact of various forms of pollution such as the discharge of wastewater, treated sewage effluents, organic and inorganic nutrients (Hürlimann and Schanz, 1993; Masseret *et al*., 1998).

Periphyton has been included in pollution monitoring in several countries such as Canada (Vis *et al*., 1998), Western Australia (Cosgrove *et al*, 2004) and Florida in the USA (Notestein *et al*., 2003). Diatoms have been used to provide an integrated measure of the effects of a variety of effluents in the natural environment (Fjerdingstad, 1964; Patrick, 1973; Stevenson and Lowe, 1986; Lowe and Pan, 1996; Vis *et al.,* 1998). Currently, European countries are developing indices to monitor eutrophication (Kelly and Whitton, 1998) and so does Malaysia (Nather Khan, 1991; Wan Maznah and Mansor, 2000, 2002), while the U.S is incorporating algal sampling into their routine monitoring program (Rosen, 1995; Charles, 1996; Hill *et al*., 2000; Leland and Porter, 2000; Fore and Grafe, 2002).

Various ways were used to determine water quality using periphyton. There are two approaches that are usually used for evaluating the impact of pollution on the periphyton community. The first one is by studying changes in the population structure by measuring a representative of the biomass (Welch *et al*, 1992; Masseret *et al*., 1998; Yamada and Nakamura, 2002; Cosgrove *et al*., 2004). The second is through the species composition by measuring the species richness or diversity of the communities (Nather Khan, 1991; Cattaneo *et al*., 1995; Kelly and Whitton, 1995; Pan *et al*., 1996; Masseret *et al*., 1998; Winter and Duthie, 2000; Soininen and Niemelä, 2002; Potapova *et al*., 2005), calculating indices based on community composition such as saprobic indec (Walley *et al*., 2001; Matsché and Kreuzinger, 2004), diatom quality index (Sgro *et al*., 2007) and etc.

However there are some problems in using periphyton as an indicator. This is because its reaction to the various physico-chemical and environmental condition may vary depending on the level of disturbance (McCormick and Cairns, 1994; Fore and Grafe, 2002).

Apart from that, as a living organism, the sensitivity of algae may vary depending on various environmental factors such as chelating agents, nutrient concentration, abiotic and biotic parameters (McCormick and Cairns, 1994). It has been known that prior exposure to environmental pollution can alter the sensitivity of periphyton (Niederlehner and Cairns, 1993; McCormick and Cairns, 1994). Foster (1982a, b), Blanck and Wängberg (1988) also mentioned that periphyton may exhibit decreased sensitivity to a stressor due to chronic exposure.

The lack of information about periphyton responses to human-induced degradation also posed a problem as compared to other works on fish or invertebrates as a monitoring tool for biological assessment of lotic waters (Rosen, 1995; Whitton and Kelly, 1995; Davis *et al*., 1996; Hill *et al*., 2000; Fore and Grafe, 2002).

This study is aimed at increasing the information concerning the effects of various anthropogenic stressors on periphyton in the natural environment using natural substrate. This is important if autoecological indices were to be used routinely for monitoring purposes in the future. Apart from that, this study also helps to increase the knowledge on the reliability of using periphyton as an indicator of water quality and its consistency under varying field conditions.

1.4 Objectives

The objectives of this study are:

1. To determine the status of water quality in the Petani River Basin based on the classification used by the Department of Environment of Malaysia.
2. To study the reliability of periphytic algal composition and community structure as a bioindicator of water quality degradation.
3. To generate a checklist of periphyton species in the Sungai Petani River Basin.
4. To study the effect of water quality and habitat suitability for periphyton species in the Sungai Petani River Basin.

CHAPTER 2

LITERATURE REVIEW

2.1 Factors Affecting the Growth and Development of Periphyton

The growth and development of periphytic algal community depends a lot on abiotic factors (Table 2.1):

Table 2.1. Abiotic factors affecting the growth and development of periphytic algal community.

Factors	References
• Type of water bodies (eg. lake, stream or river); light availability (water turbidity and clarity); • Types of substrate, the depth where the substrate is found; • Water movement, current and water velocity; • pH, alkalinity and water hardness; • The amount of nutrient (phosphorus, nitrogen and carbon)	Bothwell, 1985; Lohman *et al.,* 1991; Pan and Lowe, 1994; Dodds *et al.,* 1997; Winter and Duthie 2000; Mosisch *et al.,* 2001; Stelzer and Lamberti, 2001; Notestein at al., 2003.
• Other dissolved nutrients (calcium, sulfur and silicon); • The presence of metal and trace metal (eg. ferum, cuprum, chromium, boron, vanadium and selenium)	Sigmon *et al.,* 1977; Thomas and Seibert, 1977; Pratt *et al.,* 1987; Pratt and Bowers, 1990; Scanferlato and Cairns, 1990; McCormick and Cairns, 1994; Tang *et al*., 2003; Boivin *et al*., 2006.
• Temperature, salinity, oxygen and carbon dioxide	Walsh, 1972; Weitzel, 1979; Kosinski, 1984; Herbst and Blinn, 1998; Segal *et al*., 2006; Shun *et al*., 2008.

2.1.1 Light

One of the factors that affects the growth of periphytic algae is the presence of light. Aufwuch and periphyton are defined as micro communities that grow in the zone where the penetration of light is possible (euphotic zone) (Weitzel, 1979). Any factors that influence the amount of light reaching the surface of substrate play an important role on the growth of periphytic algae (Weitzel, 1979; Meulemans, 1987; Paul and Duthie, 1989; Dodds, 1989; Kuhl and Jorgensen, 1994; Dodds *et al.,* 1999; Glud *et al.,* 1999; Guasch *et al.,* 2003).

A study by Evans and Stockner (1972) at Lake Winnipeg, Manitoba, found that most of the periphytic biomass accumulation occurs at a depth between 10 cm to 25 cm. The study also found that blue-green algae dominated the area at a depth of 0 cm to 10 cm. Species such as *Synedra ulna v. contracta* (Ehrenberg), *Gomphonema constrictum v. capitata* (Ehr.) Cleve, *Rhoicosphena curvata* (Kuetz.) Grunow and *Nitzschia* cf. *fonticola* (Grunow) were found at the depth between 5 cm to 25 cm, while *Navicula gracilis* (Ehrenberg) [= *N. tripunctata* (O. F. Muell.) Bory *v. tripunctata*] and *N. cryptocephala* (Kuetzing) were mostly found at a depth between 90 cm to 120 cm. Evans and Stockner (1972) concluded that the amount of light penetrating the water was an important factor that influences the growth and development of periphyton on natural or artificial substrates.

2.1.2 Substrate Suitability

Another factor that influences the growth of periphyton is the type and the availability of substrates. Blum (1956) stated that true river algae depend largely on rocky substrates and can mostly be found in fast flowing rivers. On sandy and shifting riverbeds where the turbidity was high, Nelson and Scott (1962) found that the presence of periphyton was low except on hard stable surfaces.

The abundance of periphyton in a river system depends largely on the type of substrates at that particular place. The growth of periphyton on a granite surface is higher compared to the growth on a limestone and sandy surface (Weitzel, 1979). McConnell and Sigler (1959) found out that the surface of small pebbles support higher chlorophyll content per unit area (m^2) compared to larger rocks on the riverbed.

Larger species of periphyton are normally found on stable objects compared to epiphytic species. Other researchers also found significant differences in the type of community on different types of substrate. The same species can be found on different substrate but at a different level of abundance (Weitzel, 1979). According to Round (1964), the condition and the characteristic of the sediment influence the epipelic algal community. Potapova *et al.* (2005) mentioned that some cyanobacteria such as *Calothrix parietina, Homoeothrix janthina* and the diatom *Coconeis neodiminuta* are often associated with sandy sediments.

Epiphytic algae and diatom attached themselves on substrates using secretion in the form of jelly, while other periphyton use stalks or gelatinous branches (Round, 1964). Therefore, the different strength of attachment in the form of jelly or gelatinous method influences the presence of a particular species on a certain substrate (Weitzel, 1979).

2.1.3 Water Movement

Movement of water such as velocity, wave, current and the circulation of water in a lake influence the growth and biomass of periphyton. The movement of water act as an inhibitor or as a catalyst for periphyton growth depending on its force and direction (Weitzel, 1979). Water movement is important because flowing water brings with it important nutrients that are needed for the growth and productivity of periphyton while flushing away the byproducts of its metabolic activities (Duffer, 1966; Blum, 1956; Hynes, 1972; McConnell and Sigler, 1959; Odum, 1956; Whitford, 1960; Weitzel, 1979). Biggs (1996) mentioned that a stable flow of water usually promotes the accumulation of algal biomass in streams. This similar pattern was also observed by Potapova *et al.,* (2005) during their study in the Boston metropolitan area. Streams that had more variable flow patterns or higher disturbance level associated with stream flashiness (rate of change in flows) would lower algal biomass and diversity and affect species composition (Biggs *et al.,* 1998). Flow variability in terms of discharges or stage variability, may affect algal assemblages at different temporal scales (Clausen and Biggs, 1997; Matthaei *et al.,* 2003; Potapova *et al.,* 2005).

The productivity of organism is influenced by water movement. Only diatoms that are attached using jelly or gelatinous stalks can endure and survive in places where the velocity of water is moderate or high (Patrick, 1948). High periphytic assemblages in rivers and streams can mostly be found in sheltered area and in ponds where the water is calm along the riverbanks. Apart from influencing the attachment ability of periphytic organism, water movement can also influence the solubility and the availability of dissolved substances such as oxygen, carbon dioxide and other nutrients. Water movement also influences the temperature, turbidity and transparency of water (Patrick, 1948; Weitzel, 1979).

Flowing water with high velocity becomes an inhibitor to the growth of periphyton due to its shearing effect even though there are a few species of filamentous algae that require an environment where the water velocity is high (Blum, 1956; Whirford, 1960; Weitzel, 1979). It was observed that when flood occurred and water velocity in streams increased, the periphyton on the various substrates was peeled away by stream flow (Yamada and Nakamura, 2002).

The type of substrates also plays an important role in determining the influence of water velocity on the growth of periphyton. Periphyton that grows on sandy surfaces are more vulnerable to erosion compared to periphyton that grows on the surface of a rock even if they are located at a place where the water moves slowly (Duffer and Dorris, 1966; Nelson and Scott, 1962; Neel, 1968; Weitzel, 1979). McConell and Sigler (1959) observed that productivity was high in places with slow moving water. This finding is similar to an earlier research by Butcher (1932) which showed that high biomass value was obtained at sites where the water flow was slow.

2.1.4 Dissolved Substances

The role played by dissolved substances is also important. Patrick (1948) discovered that most diatoms had a high abundance when calcium carbonate concentration was 3.0 mg/liter and above, while the concentration of silicate was at 0.5 mg/L and above. This is because apart from being a buffer for pH, calcium also reacts with toxic ion and control the concentration of sulfuric acid (Weitzel, 1979). Metals and trace elements cause different reactions when exposed to different types of algae species. There are some diatoms that can tolerate copper concentration between 1.5 mg/L to 2.1 mg/L even though at this level it is toxic to many algal species (Patrick, 1948; Weitzel, 1979). A study by Patrick *et. al.* (1975) also found that the presence of several trace elements changed the community structure from one that was dominated by diatoms to a community that was dominated by blue-green algae. They also found that diatom was dominant with higher species diversity when chromium concentration was between 40 µg/liter to 50 µg/liter. In contrast, a concentration of chromium between 95 µg/liter to 97 µg/liter lowered the diatoms diversity even though the abundance was still high. Boron also played an important part in determining the community structure of algal assemblages. A concentration of 1.0 µg/liter of boron caused a change from a community of diatom to a community of blue-green algae, while the presence of nickel at any concentration was toxic to diatoms but it was preferable for the growth of blue-green algae, such as *Stigeoclonium lubricum* (Dillw.) Kuetzing (Patrick *et. al.*, 1975; Weitzel, 1979). Potapova *et al.,* (2005) also mentioned that the concentration of dissolved solids would influence the assemblage's patterns.

Metals and trace elements are toxic to a lot of algae species. Generally diatoms are more vulnerable to the presence of trace elements compared to blue-green algae such as *Stigeoclonium lubricum* (Dillw.) Kuetzing. The effect of metals and trace elements on diatom can be seen from the reduced concentration of chlorophyll *a* (Weitzel, 1979). Apart from that, cell deformities have also been associated with contamination by heavy metals (McFarland *et al*., 1997). Studies have also found that extreme metal contamination from mining activities could decrease the number diatom taxa (Juttner *et al*., 1996; Medley and Clements, 1998; Stewart *et al*., 1999; Genter and Lehman, 2000; Verb and Vis, 2000; Fore and Grafe, 2002).

2.1.5 Nutrients

The increase of nutrients in streams and water body have been linked to the changes of autotrophic community composition, vegetative biomass and an increase of nuisance species (Wright and McDonnell, 1986a, 1986b; Notestein *et al*., 2003). This in turn, affects the community structure and alters the food web dynamic of a given system (Hershey *et al*., 1988; Peterson *et al*., 1993).

It was found that an increase in nutrient concentration would influence periphyton abundance (Notestein *et al*., 2003). An increase in nitrogen alone would stimulate periphyton growth (Stelzer and Lamberti, 2001) especially when light was not a limiting factor (Lohman *et al*., 1991; Mosisch *et al*., 2001). The addition of phosphorus whether solely or concurrently with nitrogen was also found to increase periphyton abundance (Bothwell, 1985; Pan and Lowe, 1994; Dodds *et al*., 1997; Winter and Duthie, 2000). Similar results were also obtained by Notestein *et al*., (2003) which suggested that phosphorus might be the primary nutrient limiting factor for periphyton growth in coastal stream in Florida.

McCormick *et al*., (2001) observed that two distinct periphyton assemblages developed in response to increase phosphorus loading. These assemblages were characterized by higher phosphorus content, lower N:P ratios and higher biomass-specific productivity compared to oligotrophic assemblages (McCormick *et al*., 2001). Intermediate phosphorus loads was found to change the dominance from cyanobacteria to filamentous chlorophytes, such as *Spirogyra,* while a high loading rates resulted in a direct shift from oligotrophic to eutrophic cyanobacteria (e.g. *Plectonema wollei*, *Oscillatoria princeps*) (McCormick *et al*., 2001). Similar results were also obtained by other studies where many were enriched simultaneously by both nitrogen and phosphorus (Howard-Williams, 1981; Hillebrand, 1983; McDougal *et al*., 1997; Havens *et al*., 1999).

2.1.6 Periphyton Predation and Competition

Apart from the abiotic environment, biotic interaction such as grazing and competition also plays an important part in the colonisation of periphyton on hard substrates in freshwater (Feminella and Hawkins, 1995; McCormick, 1996) and marine habitats (Hillebrand and Sommer, 1997; Hillebrand *et al*., 2000). Hillebrand and Kahlert (2002) observed that the presence of grazer can reduce periphyton biomass by 50% in Lake Erken. Other studies revealed that up to 90% of available algal biomass was consumed by grazers and this is especially true for periphyton found on hard substrate (Feminella and Hawkins, 1995; Hillebrand *et al*., 2000). Grazers such as snails (McClatchie *et al.*, 1982), crustaceans (Hargrave, 1970; Gerdol and Hughes, 1994) and annelids (Smith *et al.*, 1996) was found to have a big influence on biomass and community structure of periphyton.

Hillebrand and Kahlert (2002) also observed that the effects of macrograzer were lesser on periphyton that grows on sediment as compared to those that grows on hard substrate. In an earlier study, Hillebrand and Kahlert (2001) noted that strong grazing pressure of epilithic benthic algae were evidence in Väddö and Lake Erken.

Earlier study done by Cattaneo and Kalff (1986) found that smaller fauna such as oligochaete and cladocerans also had similar effects on algal biomass as macrograzers. Due to this, Sunbäck *et al.* (1996) and Epstein (1997a, b) proposed that micro and meiofauna are able to consume most of the primary production in sediments (Hillebrand and Kahlert, 2002). However, it is not clear whether small fauna can influence the algal biomass in a longer time scale (several weeks).

A close relationship between some invertebrate and periphyton were observed in Lake Iznik. An increase of nematodes resulted in the decrease of stalked and tube diatoms (Albay and Aykulu, 2002). They also found that Rotifers (mainly *Lophocharis* sp.) and Ciliates also have a negative impact on erect and *cocconeis* type diatoms. Rotifer also has a negative relation with prostrate diatoms. However Rotifer was found to have a positive relationship with Cyanophytes. Nematodes (mainly *Anonchus* sp. and *Microlaimus* sp.) on the other hand, have a negative relationship with Cyanophytes (Albay and Aykulu, 2002).

A study on the effects of snail grazing on periphyton found that grazing have a significant effect on the composition of periphyton communities (Marks and Lowe, 1989). It was observed that the relative biovolume of green algae increase to 93% from 64% on graze substrate (Marks and Lowe, 1989). Periphyton communities that were highly grazed would usually be dominated by prostrate species that adhere tightly to the substrate or by small understory species that were not grazed due to their small size (Hunter, 1980; Hunter and Russel-Hunter, 1983; Sumner and McIntire, 1982; Marks and Lowe, 1989). Grazing has been known to physiologically maintain periphyton communities in an earlier succession stage (Marks and Lowe, 1989), meaning that the development of the periphyton community into a mature state had been retarded due to grazing.

Competition for nutrient and habitat also effects periphyton growth. Brammner (1979) and Brammer and Wetzel (1984) observed that *Stratiotes* competes with phytoplankton for nutrients from the surrounding water. This competition had resulted in the decreased of phytoplankton density in the water where *Stratiotes* is dominant (Brammer, 1979; Brammer and Wetzel, 1984).

Submerged macrophytes have been found to compete with other autotrophic organisms such as algae and periphyton and limit their growth (Kufel and Ozimek, 1994; Von Donk and Van de Bund, 2002; Mulderij *et al*., 2005b). The macrophytes was also found to excrete allelophathic substances that inhibit phytoplankton growth (Gross, 2003; Mulderij *et al*., 2005b). It was reported that allelopathic activities of macrophyte such as *Chara* (Wium-Andersen *et al*., 1982; Blindow and Hootsmans, 1991; Mulderij *et al*., 2005a), *Ceratophyllum* (Jasser, 1995; Mjelde and Faafeng, 1997) and *Myriophyllum* (Jasser, 1995; Gross *et al*., 1996) could resulted in changes in phytoplankton composition and biomass (Mulderij *et al*., 2005b).

2.2 Periphytic Algal Attributes as Indicators of Aquatic Degradation

Even though physical and chemical variables are widely used in monitoring water quality due to its ability to detect changes in the environment in a quick and straightforward manner, it also has its disadvantages of not being able to reflect the changes in water quality on biological communities (Vis *et al.,* 1998). The mixture of organic and inorganic compounds in most urban effluent further complicates the monitoring process due to the high cost required for the analyses (Vis *et al.,* 1998). Therefore, the use of periphyton has several advantages compared to the traditional method of using physical and chemical variables to determine water quality. Among the advantages of using periphyton as an indicator are; they are easy to collect, taxonomically diverse and have a short regeneration time which means that it can react quickly to changes in stream water quality (Hill *et al.,* 2000; Wan Maznah and Mansor*,* 2000). Fore and Grafe (2002) also concluded that diatoms might represent a biological alternative to fish when assessing water quality in rivers or sites that were too deep to effectively sample fish or when endangered or protected species prohibited sampling. Apart from that, where cases of chemical and biological (faunal) information disagree about a site condition, diatoms can provide clues to resolve the conflict due to their sensitive nature to water chemistry (Fore and Grafe, 2002).

Various researches have showed that major changes in water quality can influence the characteristic of periphyton. Characteristics of periphyton such as biomass (Wuhrmann and Eichenberger, 1975; Watanabe *et al.,* 1988; Biggs, 1989), diversity indices (Weitzel and Bates, 1981; Stevenson, 1984; Stewart and Robertson, 1992; Vis, 1998; Hillebrand and Sommer, 2000), biotic indices (Descy and Coste, 1991; Kelly *et al.,* 1995) and taxonomic composition (Archibald, 1972; Rott, 1991) can be used as an indicator of water quality. Some studies have also found that algal community structure (Cattaneo *et al.,* 1995; Wan Maznah and Mansor, 2002) and periphyton productivity (Ho, 1976; Anton *et al.,* 1998) can also be used to determine water quality (Wan Maznah and Mansor, 2000; Wan Maznah, 2002).

The use of periphyton as a water quality indicator has been widely accepted. Researchers have developed several schemes that classified organisms according to the amount of organic pollutants associated with their occurrence. A system that classified water system as eutrophic, mesotrophic or oligotrophic was developed by using the correlation between the type of species that existed at different levels of pollution (Weitzel, 1979). The terms eutrophic, mesotrophic and oligotrophic refers to the level of nutrients that are high, moderate and low (Round, 1964). Eutrophication is defined as the process in which water bodies are made more eutrophic via an increase in their nutrient supply (Smith et al., 1999). Table 2.2 summarises the effects of eutrophication on stream ecosystems.

Table 2.2: Effects of eutrophication on stream ecosystems (from Smith *et al.*, 1999).

- Increased biomass and changes in species composition of suspended algae and periphyton.
- Reduced water clarity.
- Taste and odor problems.
- Blockage of intake screens and filters.
- Fouling of submerged lines and nets.
- Disruption of flocculation and chlorination processes at water treatment plants.
- Restriction of swimming and other water-based recreation.
- Harmful diel fluctuations in pH and in dissolved oxygen concentrations.
- Dense algal mats reduce habitat quality for macroinvertebrates and fish spawning.
- Increased probability of fish kills.

Many studies have been conducted to evaluate the effects of nutrient on the growth of periphytic organisms. Studies by Hutchinson (1967, 1975), Hynes (1972) and Nelson *et. al* (1973) found that nutrients such as nitrogen, phosphorus and carbon were important in determining the presence and the abundance of aquatic species. It has also been recognized that aquatic system or zone that has a different concentration or type of nutrients will create different aquatic communities (Weitzel, 1979).

The concept of using organisms as an indicator has been widely used to determine the level of pollution. Patrick and Hohn (1956) and Patrick and Reimer (1966) had discussed on developing and using indicator community to monitor pollution. Aquatic ecosystems was defined as "healthy", "semi-healthy", "polluted" and "severely polluted" based on the quantitative evaluation of the number of diatom species (Patrick, 1949; Patrick and Hohn, 1956; Patrick and Reimer, 1966). The scheme is based on the concept of 'indicator organisms' that live in different types of environment where it can be used to represent a general level of pollution, and the relative abundance of particular indicator species that are used must be significant.

Diatoms are good ecological indicators because they are found in abundance in most lotic ecosystem (Stevenson and Bahls, 1999). Since diatoms can be found in a wide range of ecological conditions, it can provide multiple indicators of environmental change.

There are also disadvantages of using periphyton as a bioindicator. Even though the changes in nutrient concentration in water had been linked to changes in periphyton community, its influence had been variable or inconsistent (Vis, 1998; Notestein *et al.,* 2003). For example, experiments on the effect of nutrient enrichment on algal density in freshwater has been contradictory. Marcus (1980) and Pringle (1990) reported an increase in algal density due to the increase in nutrient supply, but Miller *et al.* (1992) reported the opposite. Furthermore, some studies reported that nitrogen alone would stimulate periphyton growth (Stelzer and Lamberti, 2001) when light was not a limiting factor (Lohman *et al*., 1991; Mosisch *et al.,* 2001). Moreover, studies by Bothwell (1985), Pan and Lowe (1994) showed that the addition of phosphorus and nitrogen increased periphyton abundance. Dodds *et al*., (1997) and Winter and Duthie (2000) on the other hand, observed an increase in periphyton abundance when it was concurrently enriched with phosphorus and nitrogen.

Even though some researches found that the addition of phosphorus, and nitrogen plus phosphorus resulted in greater biomass, they also noticed that the addition of nitrate alone showed not much difference in periphyton biomass from the controls (Notestein *et al*., 2003). Further analysis, showed that the differences between the treatments containing phosphorus alone, phosphorus plus nitrogen, and nitrogen alone were not significant (Notestein *et al*., 2003). Thus, making the differentiation of the effects of phosphorus, phosphorus plus nitrogen and nitrogen difficult.

Sand-Jensen (1983) highlighted several reasons why it was not possible to accurately determine when and how physico-chemical parameters affected the growth of periphytic algae. The first reason was when periphyton growth patterns were examined in a fluctuating natural habitat, it was difficult to pinpoint a single regulating factor since there were many physico-chemical parameters that influenced periphyton growth. Sand-Jensen (1983) argued that the autotrophic and heterotrophic processes that happened internally within the boundary layer would change the chemical condition and could be different from the free water phase. The change in the chemical condition within the periphytic community depended on the rate of exchange with the free water process or the balance of opposing process within the periphytic layer. Another reason was that most measurements of physico-chemical only focused on the free-water phase above the periphytic community and not within the community where the condition was different. The growth rates of periphytic algae also were either difficult or impossible to measure directly (Sand-Jensen, 1983).

Apart from the variable response to nutrient enrichment, the viability of periphyton as an indicator is also under threat from the grazing activity of invertebrate and fishes. It was reported that the grazer would increase the grazing pressure to periphyton due to enhanced food availability and this situation could offset the effect of nutrient enrichment (Hillebrand *et al.,* 2000, 2002; Hillebrand and Kahlert, 2001; Hillebrand, 2002; Cosgrove *et al*., 2004).

The inconsistencies in the periphyton reaction to the changes in water quality are likely caused by natural variability associated with periphytic communities (Weitzel *et al,* 1979; Morin and Cattaneo, 1992; Vis, 1998) and the differences between systems under study (i.e. stream vs river, temperate vs tropical region). The complex interaction of physical, chemical and biological factors that influence periphytic communities makes it difficult to detect water quality related changes in periphyton (Vis, 1998). This can be seen in a study by Guasch *et al*., (2003) where apart from the river water quality and light, the physical structure and biotic activity in the dense biofilm also plays a significant role in determining the condition within the matrix. Their study shows that the responses of periphyton toward the concentration of organic and inorganic substances in the water are influenced by their physiological state and density (Guasch *et al*., 2003). The thickness of periphyton can causes the creation of marked gradients of light (Meulemans, 1987;