

2.0 LITERATURE REVIEW

2.1 Tasek Bera ecosystem and biological diversity

Tasek Bera is unusually rich in flora and fauna. Habitat diversity coupled with relative isolation has produced a very diverse ecosystem, with very high degree of specialisation (Lim et al., 1982). The high diversity is attributed to the combination of the following main habitats:

- i) limnetic or open water regions (1% of total wetland area) which are fringed by stands of *Utricularia* in the surface water. It is the least extensive of the swamp.
- ii) littoral Lepironia reed and Pandanus stands forming part of the littoral region (32% of wetland area).
- iii) the Eugenia swamp-forest stands that form major part of the littoral region (67% of wetland area). Trees rarely exceed 30 m in height and usually have many epiphytic bryophytes, ferns and orchids.
- iv) lowland dipterocarp forest adjoining the wetlands system is characterised by palms, forest trees such as *Dipterocarpus* spp. and *Shorea* spp. and the buttressed species including *Koompassia* spp.

Ninety five species of fish, representing 22 families were recorded in the area (Mizuno and Furtado, 1982). All of these, except *Trichogaster pectoralis*, are indigenous to Malaysia (Johnson, 1967). Two threatened species include *Sclceropages formosus* (Asian Arowana) and *Probarbus jullieni* (Ikan Temoleh) which are listed as category 'K' (insufficiently known) (IUCN, 1988).

Furtado and Mori (1982) recorded about 200 species of birds. Two species, Crested Fireback (*Lophura ignita*) and Masked finfoot (*Heliopais personata*) are listed as threatened (Collar and Andrew, 1988) while another two, Malayan Night Heron (Gorsachius melanophus) and Crestless Fireback (Lophura erythrophthalma) are listed as 'near threatened'

Although lacking a full list for the mammals of Tasek Bera, Nathan Khan et al. (1991) reported several threatened species of wildlife including Clouded leopard (Neofelis nebulosa), Leopard (Panthera pardus), Tiger (Panthera tigris), Asian elephant (Elephas maximus), Malayan tapir (Tapirus indicus) and Gaur (Bos gaurus). In addition, the freshwater lakes and swamp also supports a wide array of reptiles and amphibians. One of them is the endangered Malayan False gharial (Tomistoma schlegelii) which is very rare and localised. However, the diversity of the invertebrates in Tasek Bera is relatively low due to the acidic pH, except for the Odonata species (33 species recorded) which favours acidic conditions.

2.2 Environmental conditions of Tasek Bera

2.2.1 Rainfall

Annual rainfall for Tasek Bera measured at Dunlop Estate, Bahau in 1970 was 1955 mm and 2700 mm in 1971. The rainfall in 1971 showed an atypical pattern due to abnormally heavy rains in January. Wet months are from April to May and September to January, while dry periods extend from February to March and June to August. However, the regularity of these seasons, as well as the rainfall, was not periodic and definite. Therefore, in some years there may be only one extended wet season followed by an extended dry season. Based on available data and observations, the rainfall within the Tasek Bera watershed and its vicinity is patchy and sporadic due to considerable influence by microclimatic and local conditions (Lim et al., 1982).

2.2.2 Physical properties

2.2.2.1 Transparency

Transparency was measured using a Secchi disc for a period of three years (1970 to 1973) at one of the stations at Tasek Bera (Ikusima et al., 1982). Transparency ranged from 1.5 to 2.5 m with a maximum of 2.67 m (September 1971) and minimum of 1.08 m (April 1971). In addition, transparency at Tasek Bera fluctuated daily with the fluctuation of water level which in turn is related to the amount of rainfall. A positive correlation between the water level and transparency was reported (coefficient of correlation = 0.60). Low transparency was generally observed at low water levels during the dry season or at extreme high water levels during the wet months. Increase in density of phytoplankton and decrease in water renewal due to a reduction in water flow and velocity of the streams are among the causes for increased turbidity. Other factors include increase of particulate materials especially inorganic particles such as clay, in the run off water from the forest floor of the watershed, agitation of organic particles and debris attached to the macrophytes by strong water currents and the action of raindrops.

Lind (1979) noted several factors, such as the clearness of the day, position of the sun and roughness of the water are all significant considerations and should be recorded along with the water quality data in weather conditions. Therefore, it is important for an observer to establish a set of operation conditions. This include always taking Secchi depth readings with or without sunglasses, with the sun to one's back or between 9 am to 3 pm. Secchi depth gives a quick relative measure of turbidity which affects light penetration and therefore the growing conditions for macrophytes, phytoplankton and benthos (Hart, 1974).

Turbidity, a measure of the degree of scattering light, is related basically to the amount of particulate matter suspended in water. These particles, also known as suspended solids, usually consist of soil, sand, mud, algae, fecal matter and other organic particles. Turbidity levels may vary markedly over time.

Reynolds (1984) discussed the use of Secchi disk readings as an auxillary measure to characterise light attenuation in natural waters, hence the optical properties of lakes. However, in the absence of more detailed photometric information, broad deductions regarding the photosynthetic environment may be possible but should be applied with considerable caution (Vollenweider, 1974; Edmonson, 1980). The Secchi disc had a major limitation in being more sensitive to scatter and less to irradiance than selenium photometer cells. Therefore, it is not measuring the same effect. Reynolds (1984) also stressed that the depth of disappearance of the alternate black-and-white quadrants in the disc varies with the observer.

2.2.2.2 Temperature

The mean air temperature recorded during the IBP project was 29.5°C (Ikusima et al., 1982). The mean water temperature was 26.3°C. Water temperature showed a distinct seasonal fluctuation related to the wet and dry seasons. Lower water temperatures occurred in the wet monsoon seasons (September to January and April to May), while the higher temperatures occurred in the dry seasons (February to March and June to September).

2.2.2.3 Water level fluctuations

Ikusima et al. (1982) reported that Tasek Bera drained into Sungai Bera through a main channel. This narrow outlet was unable to cope with surface flow especially during the northeast monsoon (September to January), causing marked fluctuations in the water level. When Sungai Bera and Sungai Pahang were flooded, a reverse flow of water into Tasek Bera through several channels near the main outlet at Tanjung Kuin, had been reported. Therefore, the water level rose between one to five metres during the northeast monsoon. However, the average depth of the littoral zone was 0.8 m while the limnetic region was 2.0 m, with an average depth of 2.5 m in the channels in the swamp-forest and a miximum of 7.0 m in the main channel near the outlet.

Water level was observed as closely associated with rainfall. The mean, minimum and maximum water level measured from 1971 to 1982 were 1.53 m, 0.66 m (9 August 1971) and 5.72 m (2 January 1971) respectively.

2.2.3 Chemical properties

2.2.3.1 Dissolved oxygen and carbon dioxide

The average dissolved oxygen concentration at Tasek Bera from 1970 to 1972 was 1.90 mgL⁻¹ with a maximum of 4.43 mgL⁻¹ (April 1971) and a minimum of 0.84 mgL⁻¹ (August 1971) (Ikusima et al., 1982). Low oxygen levels are usually associated with low primary production, oxygen uptake by humic colouring matter undergoing oxidation, bleaching reactions, presumably by ultraviolet radiation that causes photoxidation or a high chemical oxygen demand (COD) by suspended organic matter which was abundant. A high concentration was observed in

September to November (monsoon season) while a low concentration occurred in January to April and August, indicating seasonal trends of oxygen concentration.

A decrease in total carbon dioxide during the day is due to the uptake of CO_2 as a carbon source during photosynthetic activity of algae and macrophytes. During the night, it is replenished by respiratory activity. The proportion by weight of free carbon dioxide to the total carbon dioxide is high because the waters of Tasek Bera have low pH values.

According to Allan (1995), phytosynthesis and respiration are the two important biological processes that alter the concentration of oxygen and carbon dioxide. In highly productive waters, such as slow-moving rivers with abundant macrophytes, oxygen is elevated and carbon dioxide is reduced during daytime, while the reverse occurs at night. Such changes are evidence of strong biological control over the concentration of these dissolved gases. In the absence of this biological activity, shifts in temperature between day and night would cause oxygen to exhibit just the opposite pattern.

2.2.3.2 pH

The pH at Tasek Bera during the IBP project had an average of 5.33 with a minimum of 4.57 and a maximum of 6.83 (Ikusima et al., 1982). No significant variation of pH was observed with reference to depth, time in a day or between stations.

Extreme pH values, usually below five or above nine, are harmful to most organisms, and so the buffering capacity of water is crucial to the maintenance of life (Allan, 1995). pH is a measure of the concentration of hydrogen ions, hence the strength and amount of acid present. The main source of hydrogen ions in natural

waters is carbonic acid, resulting in a pH of 5.7. Rain-water normally is acidic due to its carbon dioxide content. Normally, these acids are neutralized as rainwater passes through soil. However, in catchments of hard rocks, little buffering capacity and high surface water inputs, streamwater will be acidic even if pollution is absent. Organic acids also contribute to low pH values. Where decaying plant matter is abundant, particularly in swamps, bogs and peaty areas, humic acid result in 'brown' or 'black' waters, and a pH range of four to five.

2.2.3.3 Conductivity

Conductivity indicates the total content of electrolytes present and is usually taken as an index of dissolved salts. The conductivity of the water recorded during the period of 1970 to 1972 was generally low, averaging at 14.2 µmhos.cm⁻¹ with a minimum of 10.5 µmhos.cm⁻¹ and a maximum of 23.0 µmhos.cm⁻¹ (Ikusima *et al.*, 1982). No marked difference on conductivity measurements was observed. However, fluctuations in conductivity were apparently related to the onset of monsoon and dry seasons. High conductivity measurements were recorded in September to October and December to January (northeast monsoon), April to May (southeast monsoon) and in June to August (dry season). This is probably due to the influx of nutrients from the watershed during heavy rains in the monsoon season flood that causes reverse flow and nutrient influx from downstream in the December to January period. The other reason could be due to the decomposition and mineralisation of allochthonous organic matter in the dry season and the concentration of nutrients by evapotranspiration in the drier months.

The moisture-aeration regime also influences the concentrations of inorganic forms of nitrogen. Anvimelech (1971) and Klopatek (1975) pointed out that high NH₄ and NO₃ concentrations in aerated zones created by water level fluctuations is caused by higher rates of organic N mineralization and oxidation. van Cleemput *et al.* (1975) also stated that NO₃ concentrations may increase during periods of low water as denitrification process is inhibited in aerobic conditions.

The main microbial process that modifies the chemical composition of nitrogen in incoming waters is denitrification. Among the factors that determine the rate of NO₃ removal from surface waters are the amount of water-soluble carbon (Burford and Bremner, 1975), soil pH, redox potential, moisture status and temperature (Anvimelech, 1971; van Cleemput et al. 1975).

Pearsall (1932) conducted a series of field studies on the composition of the phytoplankton in relation to dissolved substances in lakes. He reported a conclusion that diatoms increased when the water was richest in silica, the development of chrysophytes particularly the *Dinobryon* was favoured at low silica levels and high ratios of nitrogen to phosphorus, desmids were associated with waters of low calcium and a low nitrogen and phosphorus ratio and the cyanobacteria increased in correlation to high concentration of organic nitrogen. Subsequent studies have reinforced Pearsall's contention that phosphorus, nitrogen and silica (in the case of diatoms) are nutrients whose typically low concentrations in the water are most likely to become limiting.

However, it has not been fully resolved the extent to which competitive interactions along natural N:P gradients significantly influence the species composition of phytoplankton communities, as compared to either nutrient being limiting. Reynolds (1979) reported his observations in the phosphorus-rich Shropshire moores that seasonally falling nitrogen or reducing N:P ratio is followed by dominance by *Anabaena* or *Aphanizomenon*. Nevertheless, Chlorococcales dominate when supply of nitrate or ammonium remains relatively high. He interpreted the difference in terms of competition for nitrogen along the N:P gradient. However, quite a different algal assemblage is observed when phosphorus supply is critical (N:P high) whereby colonial chlorophytes such as *Sphaerocyctis* or Chrysophyceae like *Dinobryon* typically dominate. It is presumed that the development is influenced primarily by the outcome of competition for available phosphorus, independent of the nitrogen concentration.

2.2.3.4 Phosphate and nitrogen

The mean phosphate-phosphorus (PO₄-P) concentrations in Tasek Bera was 0.0240 mgL⁻¹ while the minimum was 0.0000 mgL⁻¹ (May 1970 and between September and November 1970) and maximum 0.1050 mgL⁻¹ (September 1970) respectively (Ikusima et al., 1982). A seasonal fluctuation in the phosphate-phosphorus concentrations showed that it is abundant in the monsoon seasons (April to May and September to December) as well as the dry seasons (February to March and June to August). In fact, phosphate concentrations were maximal either at the onset of rains (May to September) or in the dry months (July). This suggests that phosphate concentrations are dependent on nutrient enrichment from the watershed in the monsoons and on mineralisation of decomposing organic matter in the dry

seasons. Undetectable concentrations of PO₄-P indicate that phosphate consumption overrides replenishment. However, exceptional maximum value recorded in the wet months was due to remineralisation after the dry season and burning of the littoral *Lepironia* and *Pandanus* by the Semelai aborigines.

Organic and ammonium-nitrogen are the dominant forms of nitrogen found in Tasek Bera. Biological nitrogen sources are in the form of leachates directly from aquatic macrophytes (Nye, 1961), leachates from allochthonous and autotochthonus organic material decomposing in the water (Hynes, 1969) and terrestrial as well as aquatic nitrogen-fixing bacteria and algae.

The mean ammonium-nitrogen concentration at Tasek Bera was 0.304 mgL⁻¹ while the minimum and maximum were 0.000 mgL⁻¹ and 0.767 mgL⁻¹ respectively (Ikusima *et al.*, 1982). A seasonal fluctuation was reported, with high concentration during the dry periods (February to March and July to September) and low during the monsoons (except for May due to the southwest monsoon). This suggests that the oxidation of nitrogen from the nitrate to ammonium state was enhanced by the reduction processes predominating during the dry seasons, and enrichment from the watershed during the southwest monsoon.

The mean nitrate-nitrogen concentrations at Tasek Bera was 0.107 mgL⁻¹, while the minimum and maximum are 0.010 mgL⁻¹ and 0.290 mgL⁻¹ respectively (Ikusima et al., 1982). A seasonal fluctuation was observed, with higher concentration in the dry seasons (February to March and June to September) and low concentration during the northeast monsoon (September to November). This might be caused by dilution during initial monsoon rainfall, nitrate enrichment due to the decomposition and remineralisation of allochthonous organic materials. Therefore, the main source of nitrate appears to be biological. The abundant soil

bacteria and fungal spores washed into the swamp from the watershed are likely to be related to this nitrate enrichment.

2.2.4 Primary production

Primary production is an important component in Tasek Bera since it is a swamp with more than 75% of the area covered by vegetation (Ikusima and Furtado, 1982). Primary production can be divided into algal production and macrophyte production (subdivided into non-emergents and emergents).

2.2.4.1 Classification of algal primary producers

Mizuno and Mori (1970) listed algal species belonging to the following groups: Cyanophyta (five species), Pyrrophyta (one species), Bacillarophyta (19 species), Chrysophyta (one species), Euglenophyta (one species), Chlorophyta (54 species). A total of 328 species has been recorded to date in Tasek Bera by several researchers, as listed in Appendix 20 (Ikusima and Furtado, 1982). These consisted of 23 species including five unidentified species belonging to the Cyanophyta, five Pyrrophyta, 61 including eight unidentified species of Baccillariophyta, seven Chrysophyta, 24 including three unidentified species of Euglenophyta, 293 including 14 unidentited species of Chlorophyta, two species of Charophyta and three species of Rhodophyta. The Chlorophyta, Bacillariophyta and Cyanophyta are very common in Tasek Bera. Chlorophyta is the most dominant with the Zygnematales being the most abundant and diverse in term of species.

The algae of Tasek Bera occur as free floating, loosely entangled or attached forms among the aquatic macrophytes such as Lepironia articulata and Utricularia spp. Phytoplanktonic algae are common in static pools, among the reeds and submerged aquatic macrophytes but are rare in the open waters where there is current and in the stream channels especially in the swamp-forest. In Tasek Bera, the genera represented by the most number of species are Staurastrum, Cosmarium and Euastrum. Amongst the phytoplankton, diatoms such as Tabellaria fenestrata, Eunotia gracilis, Eunotia lunaris, Eunotia robusta, Frustularia rhomboides and Pinnularia major are common. Desmids such as Cosmarium moniliforme, Closterium dianae, Closterium gracile, Closterium libellula, Hyalotheca disssiliens, Hyalotheca undulata, Micrasterias foliacea were most common. Several species of desmids that are unique to Tasek Bera include Triploceras splendens Prowse, Micrasterias foliaceae Bail. var. spinosa Prowse, Micrasterias alata Wall. f. tumida Prowse and Xanthidium superbum Elfv var. centricornis Prowse.

Ratnasabapathy et al. (1982) noted that the algae of Tasek Bera is dominated by desmids (Chlorophyta) with an abundance and diversity not found anywhere else in Malaysia. More recent studies were also done by Phang and Murugadas (1997) in Tasek Bera. A total of 66 species with 27 species of Bacillariophyta, 26 species of Chlorophyta, two species of Chrysophyta, four species of Cyanophyta, six species of Euglenophyta and one species of Pyrrophyta were recorded (Appendix 21). Chlorophyta, followed by Bacillariophyta dominated three out of the five stations studied. The species most commonly found were Dinobryon sertularia, Trachelomonas volvocina, Tabellaria fenestrata, Frustulia rhomboides and Staurastrum arachnea.

Williamson (1998) reported several genera of desmids in Tasek Bera, some of which were previously recorded by Ikusima and Furtado (1982). Among them are Closterium, Pleurotaenium, Triploceras, Ichthyocercus, Euastrum, Micrasterias, Actinotaenium, Cosmarium, Xanthidium, Staurodesmus, Bambusina and Desmidium (Appendix 22).

The taxonomic identification of diatoms for the Federated Malay States (and Siam) was among the first recorded of studies in freshwater algae in Malaysia (Patrick, 1936). The study consisted of identification of diatoms found in intestines of tadpoles collected mainly from Perak and Kedah. 185 forms were identified, including four new species, Achnanthes asymetrica, Navicula frustuloides, N. multistriata and Pinnularia patricki. This was followed by investigation by Prowse (1957) on desmids of Malaya. These initial studies had recorded a total of 200 taxa, sampled mainly from acidic waters and habitats with high densities of submerged weeds (Anton, 1991). Studies were also extended to other groups of algae such as the Euglenophyta (Prowse, 1958) and the dinoflagellates of the Chrysophyta (Prowse, 1960; Prowse, 1962). In addition to taxonomic investigations of individual species of groups, phycological studies in Malaysia also included descriptions of algae from specific localities such as Gunung Jerai (Kedah Peak) (Ratnasabapathy, 1972), Tasek Bera, Pahang (Mizuno and Mori, 1970) and the Ulu Endau rivers in Johore (Phang and Leong, 1978; Wah et al, 1987).

Mansor and Muthaiya (1993) conducted a study on the algal species composition in almost undisturbed streams of Sayap-Kinabalu Park in Sabah. Generally, the streams studied, Sungai Wariu, Sungai Minodtuhan and Sungai Kemantis, are relatively low in algal composition. Only three divisions of algae, namely, Chlorophyta, Bacillariophyta and Cyanophyta, were recorded. Five genera

from Chlorophyta (green algae) include Spirogyra, Cosmarium, Closterium, Scenedesmus and Euastrum. Eight genera of Bacillariophyta (diatom) recorded were Navicula, Synedra, Diatoma, Nitzschia, Fragilaria, Gomphonema, Tabellaria and Cymbella. Only one genus Oscillatoria from Cyanophyta was recorded.

Anton (1991) listed the number of species from three major freshwater algal groups found in Malaysia (Table 1).

Table 1. Number of freshwater algal species identified in Malaysia

| Desmids | 245 |
|------------|-----|
| Diatoms | 281 |
| Eugleninae | 125 |

In Malaysia, only limited studies had looked into factors that control growth and productivity of algae in different habitats. Ecological studies were restricted to descriptions of phytoplankton composition and productivity rates in relation to limnological parameters in fishponds (Fish, 1960), swamp lakes (Fatimah et al., 1984), reservoirs (Ho 1970; Arumugam and Furtado 1980; Anton and Abdullah 1982), rice fields (Sands 1934; Johnson 1970) and rivers (Ho 1973; Anton 1981; Nather Khan et al. 1986; Anton and Wan Othman 1990).

2.2.4.2 Population density and standing crop

The phytoplankton had an average density of 343.1 cells.L⁻¹ with a minimum of 11.8 cells.L⁻¹ and a maximum of 6903.9 cells.L⁻¹ (Ikusima and Furtado, 1982). At least one peak abundance of phytoplankton was observed in the early northeast monsoon (September to December 1971) at all the sampling stations. The Chlorophyta which dominated the phytoplankton community and to a lesser extent, the Bacillariophyta, contributed to this abundance. The dominant peak in phytoplankton abundance could be due to increasing nutrients through influx from the watershed that favoured the temporal development of certain taxa, the presence of abundant surface aquatic macrophytes for algal epiphytes and the translocation of phytoplankton from the littoral and sublittoral, especially the *Utricularia*, to the limnetic by water flow caused by the monsoonal rain.

In terms of species diversity and density, Chlorophyta was reported as very rich while Bacillariophyta was rich (Ikusima and Furtado, 1982). The Cyanophyta was poor while the Rhodophyta, Pyrrophyta and Euglenophyta were very poor. The Chrysophyta was very rarely encountered. Fluctuations in the diversity of phytoplankton species in dominated by the Chlorophyta as it forms at least 60% of the average species composition. The Bacillariophyta and Cyanophyta are less important while the Rhodophyta, Pyrrophyta and Euglenophyta are not important in contributing to these fluctuations.

2.2.4.3 The chlorophyll content of phytoplankton

Chlorophyll was determined using the method of Strickland and Parsons (1968). In the modified limnetic and forested limnetic regions, the average chlorophyll content was 1.32 mg chl.-a.m⁻³ with a maximum of 1.94 mg chl.-a.m⁻³ and minimum of 0.70 mg chl.-a.m⁻³ (Ikusima and Furtado, 1982). In the littoral Lepironia region, the average chlorophyll content was 2.39 mg chl.-a.m-3 with a maximum of 3.74 mg chl.-a.m⁻³ and minimum of 1.25 mg chl.-a.m⁻³. It was observed that the chlorophyll content was consistently higher in the littoral due to contamination from the attached algae, which were released from the stems and leaves of macrophytes when the water was agitated during sampling. It was reported that chlorophyll content had increased when phosphate and other nutrients were added. For instance, with the addition of nutrients (KH₂PO₄ 20 mgL⁻¹, (NH₄)₂SO₄ 20 mgL-1, CaCl2.2H2O 10 mgL-1, MgSO4 10 mgL-1) into the lake water of Tasek Bera, the chlorophyll amounts of the seston reached values of 54.5 mg chl.-a.m⁻³ after 33 days incubation, while the controls had values of 3.86 mg chl-a.m⁻³. Addition of nutrients caused a remarkable change in algal composition when compared with the control particularly in the Chlorophyta, which tended to increase.

2.2.4.4 Photosynthetic production

Photosynthetic production was determined *in situ* and in tanks using the ¹⁴C method (Ikusima and Furtado, 1982). The gross photosynthetic production ranged from 0.70 to 0.25 mg CL⁻¹day⁻¹ in the limnetic region and 0.19 mg CL⁻¹day⁻¹ in the stream channels. However, net production was greatly reduced, ranging between 0.02 and 0.07 mg CL⁻¹day⁻¹ in the limnetic region and 0.01 mg CL⁻¹day⁻¹ in the stream channel.

Reynolds (1984) also criticized the bottle experiments as a quantitative index of photosynthetic production because they remove from the phytoplankton cells the vertical movement within the light field that most cells would experience in the natural environment. However, he noted that measurements of photosynthesis in closed bottles exposed at selected depths in the water column yield consistent generalized results which provide a convenient starting point for an analysis of photosynthetic behaviour.

2.3 The distribution patterns of freshwater phytoplankton

Reynolds (1984) pointed out the importance in understanding the patterns of distribution and the scales of spatial and temporal heterogeneity within the fluid environment. This includes some of the phenomena that contribute to their existence in order to gain a better insight to the life of planktonic organisms and the functioning of a pelagic ecosystem. In fact, these various fluctuations characterise the habitats of freshwater phytoplankton to a greater or lesser extent.

2.3.1 Spatial distribution

2.3.1.1 Vertical distribution

Discontinuities in spatial distribution of phytoplankton that persist for hours or days are probably best known in the vertical plane. Reynolds (1984) reported that specific vertical distribution vary substantially with depth, with time and in relation to physical segregation of the water column. He emphasised that water masses of different mean densities in lakes have their own characteristics of motion and may become segregated vertically. The input of radiation into the surface layers and the increases in temperature and reduction in density that follows result in the formation

of density gradients as well as thermal stratification. Therefore, the water body is divided into the epilimnion on the upper surface and hypolimnion at the bottom. The steep density gradient between them is known as the metalimnion which usually corresponds to the band of steepest temperature gradient, the thermocline.

Reynolds (1984) explained that the water columns of thermally-stratified lakes permit considerable environmental differentiation and the establishment of striking gradients in resources. The warmer, well-illuminated epilimnion is more conducive to algal growth as compared to the cold, darker hypolimnion. However, phytoplankton growth depletes the epilimnetic nutrients at a faster rate than they can be replenished. Therefore, the epilimnion becomes progressively more depleted of nutrients as cells die or sediment into the hypolimnion, or are consumed by animals whose faecal pellets sink rapidly. Decomposition processes in the hypolimnion consume oxygen. Thus, in shallow, productive lakes, the hypolimnia often become anoxic. In this condition where redox potential is low, processes such as reduction of nitrate to ammonia and release of phosphate from the sediments into the water are accentuated. Therefore, the lake becomes steadily segregated into a nutrient-limited epilimnion and a light-limited but nutrient-rich hypolimnion.

2.3.1.2 Horizontal distribution

Reynolds (1984) stated that patchiness in the horizontal distribution of phytoplankton occurs frequently. It is necessary to relate the sizes and longevities of patches both to the processes which contribute to their formation and survival as well as the generation times of phytoplankton. At the level of absence and presence of a particle in a given parcel of water, discontinuities are inevitable at the finest scales of milimetres. However, the trajectories of the various individual parcels

determine the pattern of distribution at higher scales. Therefore, if the parcels are part of a more widespread and identifiable flow pattern, patchiness at the smaller scale may appear either integrated within or further differentiated between larger or more stable patches. He also pointed out that the incidence of patchiness is predictable in terms of basin size, apart from the vertical behaviour of the dominant species and the immediate history of wind action on that lake. However, it is apparent that the responses of plankton vary according to the scale and type of the imposed flow pattern. For instance, large-scale patchiness, in terms of kilometres, reflects the responses of populations to diffusivity. At progressively smaller scales, in terms of metres, patchiness is attributed to a behavioural response to flow patterns which alter over smaller intervals of space and time.

2.3.2 Temporal distribution

Seasonal changes in the abundance and composition of phytoplankton may be observed to occur on temporal scales measured in weeks or months, during which mean specific population densities may increase or decrease through six to nine orders of magnitude, for instance from 10³ to 10⁶ cells.mL³.

2.4 Factors controlling the growth of phytoplankton

2.4.1 Physical factors

2.4.1.1 Temperature

According to Moss (1980), temperature differences that develop down the water column divide the lake into layers or stratification that does not readily mix. Therefore, a transitional zone called the metalimnion is found between the upper layer, epilimnion, and the lower layer, the hypolimnion. In this zone, a temperature

gradient, the thermocline of up to 1°Cm⁻¹ or more can be detected. This structure is referred to as direct stratification and is often recorded in lakes in warmer climates. In the tropics, temperature ranges between epilimnion and hypolimnion is from around 29 °C to 25°C.

Temperature is an important factor in determining growth of phytoplankton. Reynolds (1984) noted that many cellular processes are temperature dependent, their rates accelerating with increasing temperature, to maximal values occurring between 25°C and 40°C. In terms of real temperatures, rates typically increase according to non-linear, exponential functions. Such progression are generally described by Q_{10} values, that is the factor by which the rate increases per 10° C rise in temperature.

2.4.1.2 Light

Moss (1980) defined the euphotic depth as the depth in the water column at which the energy absorbed in photosynthesis (gross photosynthesis) in an algal cell just balances the maintenance energy needs of the cell (respiration). Thus, net photosynthesis is zero. The layer of water above it is referred to as the euphotic zone (z_{eu}) . In general, the euphotic depth corresponded with that at which 1% of the surface light still remains. A crude measure of the depth of the euphotic zone may be obtained by dangling a Secchi disc into the water and recording the depth (z_{v}) at which it just disappears to an observer at the surface. This depth is a measure of the transparency of the water. Although it varies according to the observer and surface conditions, it has an approximate relationship to the depth of the euphotic zone : $z_{eu} = 1.2-2.7$ (mean 1.7) z_{v} .

2.4.1.3 Dissolved oxygen

Oxygen is involved in many important chemical and biological reactions. Dissolved oxygen, a variable frequently measured by limnologists, is continually consumed during respiration by both plants and animals but is produced by plant photosynthesis only when sufficient light and nutrients are available. Cold well-oxygenated water contain less than 5% of the oxygen contained in the similar volume of air. The amount rapidly decreases as water temperature increases. This is due to the combination of a relatively low partial pressure of oxygen in the atmosphere (0.21 atm) and its low solubility. Dissolved oxygen is high in the epilimnion and low in the hypolimnion. Organic matter from natural resources or domestic and industrial wastes may result in serious depletion of dissolved oxygen. This will cause most aquatic organisms to perish or be replaced by a few specialised organisms tolerant of low oxygen levels (Horne and Goldman, 1994).

Reynolds (1984) also noted that since oxygen is abundant in a natural stream, many aquatic organisms are very sensitive to the lack of it. According to Horne and Goldman (1994), oversaturation of lake or stream water with oxygen indicates high levels of photosynthesis while undersaturation indicates organic pollution or natural respiration. The short- and long-term variations iin dissolved oxygen of lakes and rivers are a good measure of their trophic states. For instance, oligotrophic waters show little variation from saturation, while eutrophic ones may range from constant anoxia in the hypolimnion to supersaturation in the epilimnion.

2.4.1.4 Carbon dioxide

Carbon dioxide concentration in water often shows an inverse relationship to oxygen (Reynolds, 1984). A product of respiration by both plants and animals,

carbon dioxide provides the major carbon source for photosynthesis. Carbon dioxide has a solubility of more than 30 times that of oxygen and dissolves in water to produce carbonic acid. The most important environmental factor regulating the concentration of carbon dioxide is temperature although the levels also depend on photosynthesis of plants, respiration of all organisms, aeration of the water and any chemical oxidations that occur.

2.4.1.5 pH

Reynolds (1984) pointed out that pH also has considerable influence on the flora of water. Swale (1968) and Reynolds & Allen (1968) documented a remarkable case of change in the plankton flora in response to pH fluctuation. The plankton of Oak Mere, a small acidic lake (pH 4.5), was dominated by various Chlorophytes (Ankistrodesmus, Lagerheimia, Closterium and Chlorella sp.) until after the introduction of base-rich borehole water which raised the pH to 6.5, when Asterionella, Pediastrum, Anabaena and Microcystis became the dominant forms.

2.4.2 Photosynthetic activities

According to Reynolds (1984), photosynthetic rate in phytoplankton is usually measured either from the uptake of dissolved ¹⁴C-labelled carbon dioxide into algal particles or from the net change in the dissolved oxygen concentration of the suspending medium by the Winkler's method or using oxygen electrodes. Suspensions of natural algae are exposed to the natural underwater light field in small closed light vessels

The oxygen method requires the use of parallel darkened controls where photosynthesis is inhibited in order to correct the net change in oxygen concentration for respiratory consumption. However, it is inaccurate to assume that ¹⁴C incorporated by the algal cells represent gross photosynthesis because some of that taken up may subsequently be recycled into the medium. In addition, it is also incorrect to assume that losses of oxygen via respiration are identical in light and darkened bottles. Another shortcoming for both methods are that the external concentration of carbon dioxide is altered by photosynthetic uptake, thus altering the enclosed micro-environment significantly from the natural environment it is designed to imitate. This effect can be reduced by allowing the shortest exposure time possible.

Another disadvantage of bottle experiments as a quantitative index of photosynthetic production is that they remove from the phytoplankton cells the dimension of vertical movement within the light field that most cells would experience in the natural environment. Nevertheless, measurements of photosynthesis in closed bottles exposed at selected depths in the water yield consistent generalised results, hence providing a convenient starting point for an analysis of photosynthetic behaviour (Reynolds, 1984).

Moss (1980) reported that in enclosure methods used to measure the primary productivity, net primary productivity cannot be calculated because the respiration estimates includes the activities of organisms such as bacteria associated with the photosynthesisers. A characteristic curve of gross photosynthesis with the depth is frequently obtained when samples of water from a well-mixed water column are placed in bottles, resuspended at a series of depths in the water column and the photosynthesis rates measured by the oxygen release method. It often has a low value at the surface and may be due to inhibition of photosynthesis by ultra-violet

light and a peak at some depth below the surface. Then, the curve of photosynthesis with depth declines more or less exponentially below the peak.

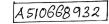
Saravanamuthu and Lim (1982) measured the primary production of phytoplankton in the Taman Jaya pond (Petaling Jaya, Malaysia) using the light and dark bottle technique (Vollenweider, 1974). Chlorophyll-a was extracted and determined as in Strickland and Parsons (1968). They found that the correlation between algal population based on primary production and the nutrient status lacking in significance. In fact, orthophosphates, nitrates and CO₂ that was utilised by the phytoplankton during primary production were not limiting factors. Nevertheless, it was stated that the rapid turnover of the water in the pond contributed to this situation. However, primary production was observed to decrease with depth. Saravanamuthu and Lim (1982) implied that light has a limiting effect on the primary production because lower values were noted during overcast conditions.

In addition, no correlation was observed between chlorophyll-a levels as standing crop with total plankton nor net photosynthesis. The explanation behind this is that only chlorophyll-a was extracted from a mixed assemblage of phytoplankton such as Cryptophyta that contain mainly carotenoids and xanthophylls and blue-green algae with phycocyanin as the photosynthethic pigment. The exclusion of these pigments accounted for the lack of correlation as noted. Therefore, it is inferred that chlorophyll-a analysis is unreliable for estimating primary productivity under eutrophic conditions.

2.4.3 Nutrient requirements

Moss (1980) reported that phytoplankters require about 20 elements for growth. However, only C,N and P are likely to limit growth rates in general. Since all three are present in the water at lower concentration that are required in the cell, active energy-requiring uptake mechanisms involving transport enzymes are needed to concentrate them into the cells. In general, the phytoplankton in an infertile lake is likely to be of small organisms with high surface to volume ratios. Unicells are more likely to dominate than colonies or filaments. They are readily grazed so that nutrients can be rapidly recycled by excretion from the grazers before the cells are lost to the sediment and their nutrients removed from use. In slightly acid waters low in alkalinity and Ca, a large variety of desmids such as unicellular and Staurastrum species, some colonial green algae including Sphaerocystis and diatoms like Tabellaria tend to dominate. Waters of intermediate fertility will be dominated by dinoflagellates (Peridinium and Ceratium), diatoms (Cyclotella, Stephanodiscus, Asterionella formosa), desmids limited to the genera Staurastrum, Closterium and Cosmarium and other green algae (Scenedesmus and Pediastrum). On the other hand, fertile waters may be able to sustain greater proportions of larger organisms. The organisms may invest more energy in devices to avoid grazing since nutrient uptake is unlikely to be a problem. Euglenophyta dominated small ponds heavily fertilised with organic matter. The Euglenophyta seemed to be confined to ammonium, which is a major breakdown product of organic decomposition, as nitrogen source.

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. 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 of phytoplankton (Reynolds, 1984).

2.4.3.1 Nutrient uptake and growth rates of phytoplankton

Reynolds (1984) noted that the nutrients required by phytoplankton are divided into macronutrients, namely elements required in considerable amounts for the proper functioning of cells and micronutrients, elements required in trace levels. The elements H, N, P, S, K, Mg, Ca, Na and Cl are grouped as macronutrients while micronutrients includes Fe, Mn, Cu, Zn, B, Si, Mo, V and Co. Before they can be assembled into the structures of the living cell, various nutrients must be obtained from the external medium in the chemical forms which they naturally occur. Phosphorus is essential to the function and growth of plants because it is a component of nucleic acids and of adenosine triphosphate which forms the basis of enzyme synthesis and intracellular energy transfer system. Nitrogen is essential in the synthesis of amino-acids and proteins of the phytoplankton. It constitutes about one-eighth to one-sixth by weight.

Uptake by autotrophic organisms is limited to sources that are soluble and diffusable in order to pass through the semi-permeable membrane into the cell. Therefore, many soluble complexes and insoluble polymers are unavailable.

2.4.3.2 Phosphorus availability

Dissolved phosphates are derived from weathering of phosphatic minerals such as apatite found in the catchment soils and are generally present in aqueous concentration within the range of 0.1 - 1,000 µg P L⁻¹. In water, phosphorus usually occurs in oxidised state, either as inorganic orthophosphate ions (HPO₂⁻⁴, H₂PO₄⁻) or in organic, largely biogenic compounds. Apart from that, it is also found in living microorganisms and dead detritus. Only some of these forms are immediately available for plant and algal growth while others may become so through microbial activity in the water (Reynolds, 1984).

As phosphorus is often present in low concentrations in lakes, it is a common growth limiting factor for phytoplankton. Most phosphorus is held in a biologically unavailable form by particles in the lake water. Moreover, plant roots and the soils of the watershed retain phosphorus much more than nitrogen. However, the quantities of phosphorus needed by living plants and animals are much smaller than for carbon, silicon or nitrogen because it consist of only 0.3% of body weight (Horne and Goldman, 1994).

Dissolved orthophosphate is clearly the major source of phosphorus for phytoplankton as it is taken up rapidly by phosphorus-deficient cells until very low concentrations (less than $1 \mu g \ P \ L^{-1}$) remain in the water (Rigler,1966). Therefore, the sum of all the forms of phosphorus or total phosphorus is a reasonable measure of the fertility of water. A rather infertile lake may have only about $1 \mu g \ P_{tot} L^{-1}$ while the most fertile may have $1000 \mu g \ P_{tot} L^{-1}$.

2.4.3.3 Nitrogen availability

Several commonly occurring sources of nitrogen that are potentially available to phytoplankton include nitrate, nitrite and ammonium ions as well as certain dissolved nitrogenous compounds, such as urea and free amino-acid peptides. According to Moss (1980), elemental nitrogen is relatively unreactive and

unavailable despite the huge atmospheric supply. Nitrogen is converted to available compounds such as nitrate and ammonium by atmospheric lightning sparks and by nitrogen fixers. These compounds are very soluble and therefore readily transported into waterways.

Inorganic nitrates which are extremely soluble may be abundant in the order of mgL⁻¹ in waters receiving substantial inputs of leachates from agricultural soils, ground water or treated sewage effluent. Without such inputs, maximal concentration may be one or two orders of magnitude lower which is between 10 to 1000 μgNL⁻¹ (Reynolds, 1984). According to Prowse and Talling (1958), freshwaters characteristically deficient in nitrate probably include many tropical continental systems draining forest or well-leached savannah soils.

Ammonium is typically present in unpolluted surface waters at concentrations of less than 150 µgNL⁻¹. McCarthy (1980) reported that the principle source of ammonium ions derives from bacterially-mediated degradation of organic matter and from direct animal excretion. In addition, low concentrations do not always imply ammonium deficiency because the ion can be continually regenerated in aquatic communities. Alternately, direct sedimentation of phytoplankton and of the faecal pellets of animals feeding on them transport nitrogen out of the upper water layers of lakes. Therefore, Owens and Esaias (1976) noted that nitrogen does appear to be the major nutrient limiting primary production in many tropical freshwater lakes and in the open oceans.

Horne and Goldman (1994) reported that nitrates is the most common form of combined inorganic nitrogen in lakes and streams. Its concentration and supply is closely connected with land use practices on the watershed. Nitrate ions move easily through soils and are quickly lost from the land. This differs with phosphate or

ammonium ions, which are retained by the soil. Natural changes in the vegetation of the drainage basin due to fires, floods, or artificial clearing increase the nitrate levels in streams. In addition, nitrogen derived from waste discharges from agricultural fertilisers and waste discharges from cities greatly increase nitrate levels in streams and lakes. However, it is possible to remove nitrate by denitrification if streams are diverted through wetlands.

2.4.3.4 The cycle of phosphorus and nitrogen in freshwater wetlands

According to Moss (1980), phosphorus enters the cycle from the catchment area or by release from the sediment. It leaves the cycle when it is washed through the outflows, or it is incorporated permanently into sediments as detritus or precipitates. Two major means of regeneration of inorganic phosphate are by zooplankton and by microorganisms. Organic phosphorus must be metabolized first by bacteria as they may not be available directly to the phytoplankton. Zooplankton may also be main agents of loss of phosphorus to the sediments through sedimentation of their faeces and cycle phosphorus with a longer turnover time.

Horne and Goldman (1994) noted that the phosphate cycle in lakes involves organic and inorganic phosphorus in both soluble and particulate forms as well as intermediates between the different fractions. Among all the phosphorus compounds present in lakes, phytoplankton can use only soluble phosphate (PO₄) for growth. Phosphorus taken up by algae, are continually recycled back to phytoplankton via excretion from fish, zooplankton and bacterial activity. In the watershed, PO₄ is readily immobilised in the soil and even those from fertilisers soon become unavailable for plant growth. Therefore, PO₄ does not move easily with ground

water to recharge surface streams. In general, phytoplankton in wet climates tend to be growth-limited by phosphorus rather than nitrogen.

Moss (1980) also noted that ammonium, nitrite, nitrate and molecular N_2 makes up the four main inorganic pools. The first three forms are available for uptake by most phytoplankters and can be simultaneously absorbed. Some species, especially the Euglenophyta seem capable to absorb only ammonium. Other plankters may often prefer absorbing ammonium since it is energetically less costly to process in the cell. In lakes where the loading of phosphorus is large, the rate of supply of inorganic nitrogen compounds may limit the growth of phytoplankton.

According to Horne and Goldman (1994), the availability of various nitrogen compounds influences the types, abundance, and nutritional value of aquatic animals and plants. Nitrogen, being the fourth most common cellular element, constitutes about 5% of living matters by dry weight. Nevertheless, nitrate and ammonia are not always present in adequate amounts in natural waters and may limit plant growth. Nitrogen limitation is reported to be common in lakes in warm climates and where phosphorus and silicon are naturally present in relatively large quantities of where pollution has increased phosphorus relative to nitrogen.

The major forms of nitrogen available to bacteria, fungi and plants in both the aquatic and terrestrial ecosystems are nitrate and ammonia. In lakes at the eutrophic or oligotrophic ends on the trophic spectrum, it is common for nitrogen to be the nutrient element that most limits plant growth. Nitrate is usually not toxic in the quantities found in lakes and rivers, up to 10 mgL⁻¹ NO₃-N, the human drinking water standard. Major sources of nitrates in streams and lakes are runoff from agriculture and sewage discharge from cities. Nitrate is the most common form of nitrogen and is the form most used by phytoplankton.

Horne and Goldman (1994) also noted that ammonia is much more reactive than nitrate due to its higher chemical energy and is present in aquatic systems mainly as the ion NH₄* (ammonium). Ammonia differs from nitrate in terms of toxicity and mobility. This is because ammonia has high toxicity and ammonium ions are retained by most soils. Toetz (1971) reported that ammonium ion is rapidly taken up by phytoplankton and other aquatic plants. Despite its rapid uptake by algae, ammonia persists in small quantities because it is also the major excretory product of aquatic animals. According to Horne and Goldman (1994), ammonia in most lakes and streams is generally well below 0.1 mgL⁻¹. Most toxic effects of ammonia on animals are due to pollution, generally sewage outfalls that contain 10 to 30 mgL⁻¹ NH₄-N before dilution by receiving water. In lakes and rivers, at least a few days are required before this ammonia is removed by plant growth or transformed to nitrate.

2.5 Periodicity and seasonal changes in phytoplankton composition

Reynolds (1984) reported that the composition of phytoplankton communities and the relative abundances of component species experience continuous changes and on varying degrees. In general, it is observed that the variations in the abundance and species composition of phytoplankton that occur in a given lake through a given twelve-month period are often broadly repeated the following year which constitutes one of the most outstanding examples of pattern conformation in freshwater communities. In addition, it is often the case that the phytoplankton biomass obtains high levels and falls to low ones at approximately the same times in successive years, usually the same species will be prominent at the corresponding stages. However, of greater significance is that the annual cycles of

biomass fluctuation and the sequence of representative assemblages are often widely repeated in geographically remote lakes. This means the sequential patterns are common to the whole series of water-bodies sharing properties of morphometry and trophic status.

2.5.1 Seasonal succession

Moss (1980) noted that the plankton community changes on a long term basis with a seasonal periodicity of different species being reflected week to week or month to month. This change is brought about by changes in the water caused by climate through its effects on temperature, rainfall and nutrient loading and internal chemical changes as the community reacts to the external factors. Almost all phytoplankton species that increase their population some time during the year are ever present in the water as small residual populations and some species may form resting stages in the surface sediment.

The great reserve of varied forms had each been best fitted to exploit a particular set of conditions in the water whereby its population will increase. However, its population will be unable to compete in other conditions which leads to a decline in population. In turn, the changing water mass throughout the year selects the better fitted species for a particular time. This results in a progression of overlapping, large populations against a background of small, declining populations. In addition, if changes in weather are a major driving force in determining seasonal periodicity, the least marked periodicity must be expected in lakes at the Equator.

2.5.2 Adaptive characteristics and class succession patterns

Tubbing et al. (1995) noted a strong relationship between the presence of toxicants and the decline of species in River Meuse, Netherlands, which is described as a typical nutrient rich lowland river with relatively high plankton activity. Chlorophyll-a concentration was observed to be relatively low despite very high concentrations of phosphate and ammonium. Correlation of high zooplankton densities with declining phytoplankton concentration were noted in some months. Water samples collected from locations with a high content of organic substances showed low phytoplankton growth rate, thus supporting the opinion of a strong correlation between the presence of toxicants and the inhibition of plankton productivity.

According to Palmer (1969), organic pollution is likely to influence the algal flora more than other factors in the aquatic environment including light, intensity, pH, DO, temperature, rate of flow or other types of pollutant. He reported the top eight genera of algae tolerating high organic pollution to be Euglena, Oscillatoria, Chlamydomonas, Scenedesmus, Chlorella, Nitzschia, Navicula and Stigeoclonium while the top five genus are Euglena viridis, Nitzschia palea (Figure 2), Oscillatoria limosa, Scenedesmus quadricauda (Figure 3) and Oscillatoria tenuis. In addition, algal pollution indices, one based upon genus (Table 2) and the other on species (Table 3) were developed for use in rating water samples for high or low organic pollution. However, the species index is more reliable because it deals with more specific taxonomic units.

When analysing the water sample, all of the 20 genera or species of algae are recorded. If there are 50 or more individuals per millimeter, the algae is indicated as 'present'. The pollution index factors of the algae present are then totalled. A score

of 20 or more for a sample is taken as evidence of high organic pollution while a score of 15 to 19 is taken as probable evidence of high organic pollution. Lower scores would indicate that the organic pollution of the sample is not high, that the sample is not representative, or that some substance or factor which is interfering with algal persistence is present or active (Table 4). Examples of phytoplankton that are pollutant tolerant are shown from Figure 4 to Figure 8.

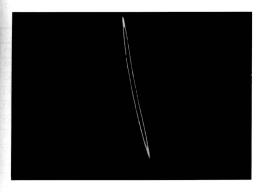


Figure 2. Pollutant tolerant phytoplankton in Tasek Bera : Nitzschia palea (4.0μm)



Figure 3. Pollutant tolerant phytoplankton in Tasek Bera : Scenedesmus quadricauda (0.8µm)

Table 2. Algal genus pollution index

| Genus | Pollution index |
|----------------|-----------------|
| Anacystis | 1 |
| Ankistrodesmus | 2 |
| Chlamydomonas | 4 |
| Chlorella | 3 |
| Closterium | 1 |
| Cyclotella | 1 |
| Euglena | .5 |
| Gomphonema | 1 |
| Lepocinclis | 1 |
| Melosira | 1 |
| Micractinium | 1 |
| Navicula | 3 |
| Nitzschia | 3 |
| Oscillatoria | 5 |
| Pandorina | 1 |
| Phacus | 2 |
| Phormidium | 1 |
| Scenedesmus | 4 |
| Stigeoclonium | 2 |
| Synedra | 2 |

Note:

Algal pollution index was developed for use in rating water samples for high or low organic pollution. Increasing number indicates increasing level of organic pollution.

Table 3. Algal species pollution index

| Species | Pollution index |
|-------------------------|-----------------|
| Ankistrodesmus falcatus | 3 |
| Arthrospira jenneti | 2 |
| Chlorella vulgaris | 2 |
| Cyclotella meneghiniana | 2 |
| Euglena gracilis | 1 |
| Euglena viridis | 6 |
| Gomphonema parculum | 1 |
| Melosira varians | 2 |
| Navicula cryptocephala | 1 |
| Nitzschia acicularis | 1 |
| Nitzschia palea | 5 |
| Oscillatoria chlorina | 2 |
| Oscillatoria limosa | 4 |
| Oscillatoria princeps | 1 |
| Oscillatoria putrida | 1 |
| Oscillatoria tenuis | 4 |
| Pandorina morum | 3 |
| Scenedesmus quadricauda | 4 |
| Stigeoclonium tenue | 3 |
| Synedra ulna | 3 |

Note:

Algal pollution index was developed for use in rating water samples for high or low organic pollution. Increasing number indicates increasing level of organic pollution. The species index is more reliable since it deals with more specific taxonomic units.

| N _o | Species | Group* | No. authors | Total points | No. | Species | Groupa | No. authors | Total points |
|----------------|---|----------------|-------------|--------------|-----|-----------------------------|--------|-------------|--------------|
| - | Euglena viridis | ш | 20 | 93 | 41 | Lepocinclis texta | ш | 12 | 17 |
| 5 | Nitzschia palea | ۵ | 45 | 69 | 42 | Euglena deses | ш | 13 | 17 |
| က | Oscillatoria limosa | 8 | 59 | 42 | 43 | Spondylomorum quarternarium | ш | 13 | 17 |
| 4 | Scenedesmus quadricauda | g | 56 | 41 | 44 | Phormidium uncinatum | В | 15 | 17 |
| သ | Oscillatoria tenuis | 8 | 56 | 40 | 45 | Chlamydomonas reinhardii | ш | 10 | 16 |
| 9 | Stigeoclonium tenue | O | 25 | 34 | 46 | Chlorogonium euchlorum | u. | 10 | 16 |
| 7 | Synedra ulna | ۵ | 25 | 33 | 47 | Euglena polymorpha | ш | 1 | 16 |
| 80 | Ankistrodesmus falcatus | g | 21 | 32 | 48 | Phacus plueronectes | ш | = | 16 |
| თ | Pandorina morum | u. | 23 | 30 | 49 | Navicula viridula | ۵ | 13 | 16 |
| 10 | Oscillatoria chlorina | В | 17 | 59 | 20 | Phormidium autumnale | В | 13 | 16 |
| = | Chlorella vulgaris | g | 19 | 59 | 51 | Oscillatoria lauterbornii | В | 80 | 15 |
| 12 | Arthrospira jenneri | Ф | 15 | 28 | 25 | Anabaena constricta | В | 6 | 15 |
| 13 | Melosira varians | ۵ | 22 | 28 | 23 | Euglena pisciformis | ш | Ε | 15 |
| 4 | Cyclotella meneghiniana | ۵ | 20 | 27 | 24 | Actinastrum hantzschii | Ø | 13 | 15 |
| 15 | Euglena gracilis | ш | 18 | 56 | 22 | Synedra acus | ۵ | 6 | 14 |
| 16 | Nitzschia acicularis | ۵ | 18 | 56 | 26 | Chlorogonium elongatum | ш | 10 | 14 |
| 17 | Navicula crytocephala | ۵ | 19 | 25 | 22 | Synura uvella | ш | 1 | 14 |
| 18 | Oscillatoria princeps | Ф | 16 | 24 | 28 | Cocconeis placentula | ۵ | 12 | 14 |
| 19 | Oscillatoria putrida | œ | 13 | 23 | 29 | Nitzschia sigmoidea | ۵ | 12 | 14 |
| 20 | Gomphonema parvulum | ۵ | 14 | 23 | 90 | Coelastrum microporum | O | 13 | 14 |
| 51 | Hantzschia amphioxys | ۵ | 18 | 23 | 61 | Achnanthales minutissima | ۵ | 10 | 13 |
| 22 | Oscillatoria chalybea | В | 14 | 22 | 62 | Cymatopleura solea | ۵ | 12 | 13 |
| 23 | Stephanodiscus hantzschii | ۵ | 16 | 22 | 63 | Scenedesmus dimorphus | O | 80 | 12 |
| 24 | Euglena oxyuris | ıL | 15 | 21 | 64 | Fragilaria crotonensis | ۵ | 6 | 12 |
| 52 | Closterium acerosum | O | 16 | 21 | 65 | Anacystis cyanea | В | 10 | 12 |
| 56 | Scenedesmus obliquus | o | 16 | 21 | 99 | Navicula cuspidata | ۵ | 10 | 12 |
| 27 | Chlorella pyrenoidosa | O | Ξ | 20 | 49 | Sceneesmus acuminatus | O | 10 | 12 |
| 28 | Cryptomonas erosa | ш | 15 | 20 | 89 | Euglena intermedia | ш | Ε | 12 |
| 59 | Eudorina elegans | ш | 16 | 20 | 69 | Pediastrum duplex | O | 1 | 12 |
| 30 | Euglena acus | ш | 16 | 20 | 20 | Closterium leiblenii | Ó | 80 | = |
| 31 | Surirella ovata | ۵ | 16 | 20 | 7 | Oscillatoria brevis | Ф | 80 | = |
| 35 | Lepocinclis ovum | ш | 4 | 19 | 72 | Trachelomonas volvocina | ш | 80 | = |
| 33 | Oscillatoria formosa | Ф | 4 | 19 | 73 | Dictyosphaerium pulchellum | O | 6 | = |
| 34 | Oscillatoria splendida | Ф | 4 | 19 | 74 | Fragilaria capucina | ٥ | 6 | = |
| 32 | Phacus pyrum | ш | £ | 18 | 22 | Cladophora glomerata | O | 10 | = |
| 36 | Micractinium pusillum | o | 12 | 18 | 92 | Cryptomonas ovata | ш | 10 | = |
| 37 | Agmenellum quadriduplicatum | ш | 13 | 18 | 77 | Gonium pectorale | ш | 10 | = |
| 38 | Melosira granulata | ۵ | 4 | 18 | 78 | Euglena proxima | ш | 7 | 10 |
| 39 | Pediastrum boryanum | O | 15 | 18 | 79 | Pyrobotrys gracilis | ш | 7 | 10 |
| 9 | Diatoma vulgare | ۵ | ٠, | 18 | 8 | Tetraedron muticum | g | 7 | 10 |
| ĈLO " | Groups: B, blue-green; D, diatom; F, flagellate; G, green | igellate; G, j | green. | | | | | | |

for that author.

arranged in order of decreasing to the 80 species having the

determined.

more authors.

to combine the results of A simple procedure was used various workers. A score of I or 2 was given for each alga reported by an author as tolerating high organic enrichment, the larger figure being reserved for the algae that an author emphasised as particularly significant. When an author had published several reports, these were pooled before determining the score for any particular algal By totalling the scores for each species, the ranking of each taxon as emphasized by the 165 authors collectively was The species of algae at the top of the pollutant-tolerant list are total scores. This list is limited highest scores out of more that 700 emphasized by one or

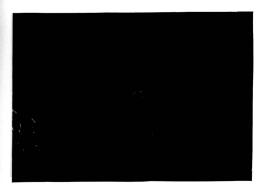


Figure 4. Pollutant tolerant phytoplankton in Tasek Bera : Trachelomonas sp. (0.2μm)

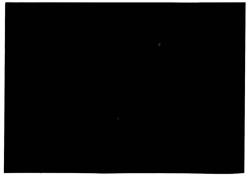


Figure 5. Pollutant tolerant phytoplankton in Tasek Bera : Gomphonema parvulum (1.8µm)



Figure 6. Pollutant tolerant phytoplankton in Tasek Bera : Navicula sp. $(0.8\mu m)$

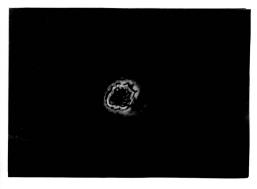


Figure 7. Pollutant tolerant phytoplankton in Tasek Bera : Peridinium sp. (0.5µm)

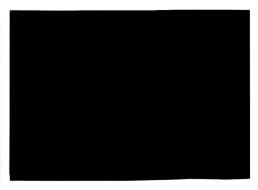


Figure 8. Polutant tolerant phytoplankton species: Euglena acus (2.4µm)

2.5.3 Long term compositional response

Reynolds (1984) suggested that long-term changes in the nutrient supply to lakes represent very large-scale (in terms of decades) shifts in the balance and range of resources to which phytoplankton abundance and quality are known to respond. Such changes occur naturally, at different rates and may be due to a variety of causes. In recent decades, relatively dramatic increases in the amounts of nutrients reaching lakes and reservoirs and subsequent changes in their biology have brought about a shift of focus towards the problems of nutrient enrichment, better known as eutrophication.

Eutrophic waters receive relatively high nutrient loadings and can be distinguished from oligotrophic ones by their larger average standing crops of organisms, including primary producers, as well as other metabolic characteristics.

Anton (1991) noted that freshwater research in temperate regions had identified certain algal assemblages which was found repeatedly in waters of increasing fertility. According to Palmer (1969), Wilhm (1975) and Whitton (1984), these species are known as indicators of productivity and showed good correlation with the amount and type of nutrients present in the water. Some major phytoplankton assemblages related with temperate lakes of increasing fertility are shown in Table 5. Very few studies have been carried out to investigate the distribution of algae in freshwater bodies, species ecological tolerance and to correlate the presence of groups of species with water quality. However, some algal studies had been conducted with relation to water pollution. In their research, Nathan Khan et al. (1986) identified diatom species found to be tolerant, intolerant

Table 5. Characteristics of common major algal associations of the phytoplankton in relation to increasing lake fertility (Wetzel, 1983).

| General Lake | Water Characteristics | Dominant Algae | Other Commonly Occurring Algae |
|--------------|--|--|--|
| Trophy | | | |
| Oligotrophic | Slightly acidic; very low salinity | Desmids Staurodesmus, Staurastrum | Sphaerocystis, Gloecoystis, |
| | | | Rhizosolenia, Tabellaria |
| Oligotrophic | Neutral to slightly alkaline; nutrient-poor lakes | Diatoms, especially Cyclotella and | Some Asterionella spp., some Dinybryon |
| | | Tabellaria | |
| Oligotrophic | Neutral to slightly alkaline; nutrient-poor lakes or | Chrysophycean algae, especially | Other chrysophyceans, e.g. Synura, |
| | more productive lakes at seasons of nutrient | Dinobryon, some Mallomonas | Uroglena; diatom Tabellaria |
| | reduction | | |
| Oligotrophic | Neutral to slightly alkaline; nutrient-poor lakes | Chlorococcal Oocystic or chrysophycean | Oligotrophic diatoms |
| | | Botryoccocus | |

Table 5. Characteristics of common major algal associations of the phytoplankton in relation to increasing lake fertility (Wetzel, 1983) (continued)

| General | Water Characteristics | Dominant Algae | Other Commonly Occurring Algae |
|--------------|--|---|---|
| Lake | | | |
| Trophy | | | |
| Oligotrophic | Oligotrophic Neutral to slightly alkaline; generally nutrient- | Dinoflagellates, especially some Peridinium | Small chrysophytes, cryptophytes and |
| | poor; common in shallow Artic lakes | and Ceratium spp. | diatoms |
| Mesotrophic | Mesotrophic Neutral to slightly alkaline; annual dominants or in | Dinoflagellates, especially Peridinium and | Glenodinium and many other algae |
| Eutrophic | eutrophic lakes at certain seasons | Ceratium spp. | |
| Eutrophic | Usually alkaline lakes with nutrient enrichment | Diatoms much of year, especially Asterionella | Many other algae, especially greens and |
| | | spp., Fragilaria crotonensis, Synedra, | blue-greens during warmer periods of |
| | | Stephanodiscus and Melosira granulata. | year; desmids if dissolved organic matter |
| | | | is fairly high |
| Eutrophic | Usually alkaline; nutrient enriched; common in | Blue-green algae, especially Anacystis, | Other blue-green algae; euglenophytes if |
| | warmer periods of temperate lakes or perennially in Aphanizomenon, Anabaena. | Арћапіготепоп, Апаbаепа. | organically enriched or polluted |
| | enriched tropical lakes | | |
| | | | |

and indifferent to rubber effluent (Table 6). Anton and Wan Othman (1990) identified clean water species of algae, which were replaced by other species particularly tolerant to high NO₃ and silt at downstream stations in a study of rivers at Cameron Highlands to investigate the effect of agricultural practices on water quality (Table 7). Batrachospermum, Oedogonium, Compsopogon, Zygnema and Scytonema were dominant in clean freshwater streams and rivers of Pulau Tioman and the Ulu Endau area (Ratnasabapathy, 1977; Phang and Leong, 1987). Anton (1981) reported that water quality assessment of the headwaters of the Langat River, Selangor, using river periphyton showed a decrease in algal species in the downstream stations that was due to heavy siltation, rather than chemical pollutants.

Gruber (1989) emphasised that apart from field studies, algae have also been used in laboratory bioassays for biomonitoring of water pollution. Only a number of toxicity test had been conducted in Malaysia using algae as indicator organisms. One particular study used two species of *Chlorella*, *C. pyrenoidosa* and *C. vulgaris*, to assess the effect of pollution on Langat River on river organisms (Anton, 1981).

2.6 Effects of human activities and changes of land use on the composition of streams

Moss (1980) reported that changes in land use from mostly forest to mostly agriculture has led to increases in stream concentrations of nutrients. Total phosphorus and soluble orthophosphate increased by about tenfold, total nitrogen and inorganic soluble nitrogen by fivefold that includes nitrate plus ammonium by nearly fourteenfold in the central states of USA. It was observed that disturbance of vegetation and soils by agriculture leads to a rather greater loss of nitrogen than of phosphorus. This could due to the reason that phosphorus is fixed quite strongly by

Table 6. Diatom species tolerant, indifferent and intolerant to rubber effluent (Nather Khan et al., 1986)

Tolerant

Indifferent

Intolerant

| antoici ant | manierent | Tolerant |
|-----------------------|--------------------------|---------------------------|
| Acnanthes minutissima | Coconeis thumensis | Gomphonema parvulum |
| Acnanthes tropica | Eunotia parvulum | Gomphonema subventricosum |
| Cymbella javanica | Gomphonema gracile | Navicula radiosa |
| Cymbella sumatrensis | Navicula cryptocephala | Navicula rhycodephala |
| Cymbella turgida | Navicula hustedtii | Navicula palea |
| Synedra rumpens | Navicula schroteri | Navicula obtusa |
| Suriella tenussima | Navicula feurborni | Melosira italica |
| | Pinnularia microstaurnon | Pinnularia biceps |
| | Suriella linearis | Pinnularia gibba |
| | Suriella angusta | Pinnularia borealis |
| | | |

Table 7. Clean water and polluted water species of diatoms from Sungai Bertam, Cameron Highlands (Anton and Wan Othman, 1990)

Polluted water species

Clean water species

| cican mater species | ronuted water species |
|-----------------------|--------------------------|
| Acnanthes lanceolata | Navicula crptocephala |
| Acnanthes hustedii | Navicula cocconeiformis |
| Acnanthes crenulata | Navicula ryncocephala |
| Acnanthes mutica | Navicula bacillum |
| Chodatella ciliata | Navicula notha |
| Chodatella quadriseta | Navicula variostriata |
| Chamaesiphon sp. | Nitzschia palea |
| | Nitzschia rutiformentis |
| | Suriella ovata |
| | Pinnularia gibba |
| | Eunotia pectinalis |
| | Gomphonema sphaerophorum |
| | Scenedesmus caudriquada |
| | Ankistrodesmus sp. |
| | Coleochaete sp. |
| | |

chemical reactions in soils, but nitrogen compounds are relatively soluble and are easily lost. In addition, Moss (1980) reported that expansion of villages also contributes to increasing amounts of human sewage. Sewage consists of a mixture of wastes from laundry, bathing, cooking and the flushing of faeces and urine in lavatories. Due to the high content of labile organic matter, sewage will cause severe deoxygenation if released directly to streams.

2.6.1 Agricultural drainage and water quality

Dowdell and Webster (1976) noted that the increasing use of nitrogen has led to loss of nitrogen from agricultural soil through denitrification and leaching. Both processes are reported to occur when soil water content is high. In addition, denitrification tends to reduce the nitrate concentration of the drainage water. Owens (1976) pointed out that enrichment of water by plant nutrients is due to an accumulation from many sources within a catchment area. They consist of diffuse and point sources. Diffuse sources include rainfall, run-off and drainage from land and urban areas, droppings from birds and leaf litter. He reported that quantitative estimates for diffuse sources are difficult and so is effective control. Point sources consist of sewage effluents and industrial wastes. However, estimation of the magnitude and control of point sources are easier.

Meyer and Pulliam (1992) stated that although a large variety and quantity of contaminants from anthropogenic point and nonpoint sources are emitted into the environment, the capacity in monitoring most contaminants on a regional basis and assessing their long term impact is limited. Major contaminants include trace metals, pesticides, fertilisers, pathogens and salts. It was noted that nonpoint source of agricultural chemicals and sediments from agroecosystems is a measure of the

efficiency of agroecosystem with regards to resources and inputs. In addition, it also measures the potential for contamination of surrounding areas. Nonpoint sources consist of agricultural chemicals, animal wastes and eroded soils. Since rainfall and other environmental characteristics dominate the timing and magnitude of chemical transport, nonpoint pollution is characterised by highly variable loadings. Chemicals are exported from their site of application to nearby streams and lakes by runoff and subsurface flow, leaching to groundwater and volatilisation. Irrigation practices is reported to enhance leaching of chemicals from soil, including applied chemicals, naturally occurring salts and other trace elements. Besides that, irrigation from contaminated water sources introduce organic chemicals, salts and nitrates to agroecosystems and many of these chemicals are subsequently transported to surface water. One of the main problems with measuring nonpoint source loadings is being able to measure the phenomenon at the time it occurs. For instance, leaching is a highly dynamic process that usually involves transport and transformation of the compound. Moreover, the location of the compound in time or space is dependent on transformation rates and transportation characteristics of the media. Therefore, sampling at any particular point in time and space leads only to an instantaneous measurement that changes very quickly to some other value.

Biggar and Corey (1969) proposed the effects of suspended material on the nutrient status of the water. The impact from raindrops falling tend to break down aggregates of soil particles at exposed soil surfaces. Sheet erosion occurs when runoff waters then pick up the finer particles and carry them downslope. Nitrogen in suspended particles is found mainly in the organic form. Particles that settle out when the water velocity decreases do not have significant contribution to the soluble nitrogen supply. The nitrogen in other organic particles will be converted to soluble

inorganic form by microorganisms in the decomposition process. However, it was noted that fresh organic particles are quite readily decomposed by microorganisms while humified-soil organic matter is quite resistant to decomposition.

Phosphorus are found in suspended particles in both organic and inorganic forms. The organic forms undergo decomposition similar to that of organic nitrogen. However, inorganic phosphorus goes through a more complex system. Biggar and Corey (1969) explained that phosphorus bonded to iron, aluminium, or calcium in the mineral particles tends to equilibrate with the phosphorus in solution. Therefore, particles that come from a surface soil high in phosphorus tend to support a relatively high concentration of phosphorus in solution while particles from subsoil low in phosphorus will support low concentration of phosphorus in solution. In addition, it was mentioned that introduction of subsoil particles into a stream containing a moderate or high concentration of soluble phosphorus would lower the phosphorus concentration since the particles would adsorb phosphorus from the water.

2.6.2 Integrated agricultural practices in palm oil and /or rubber plantations

Felda Agricultural Services Sdn Bhd (FASSB), which parent company is Felda Plantations, facilitated the distribution of fertiliser. Analysis of fertiliser requirements for plantation and research in crop protection is conducted at Tun Razak Plantation Services Centre (Pusat Perkhidmatan Pertanian Tun Razak) in Tekam.

In general, one cycle of fertiliser application at a particular stage or area of the oil palm or rubber plantation is approximately 1.5 months. The frequency of fertiliser application and the respective loadings for several plantations in the catchment area of Tasek Bera are listed in Appendix 19a to 19d. Ninety percent of fertiliser application in the plantation is done using a tractor or spreader while 10% is done manually, usually in sloped areas.

According to Ibrahim (1998), fertiliser is one of the most important input in agricultural activities as it serves to maximise the yield and replenish the soil of its loss of nutrient elements such as nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg). A good fertiliser application programme will enable the nutrients to be fully utilised by the crops. In addition, adequate soil moisture is necessary to facilitate absorption of fertiliser by the root of the plants. Nutrient intake is closely linked to agricultural practices such as weed, pest and disease control. In addition, the type of soil and the soil structure are also factors that influence the efficiency of fertilisers. For instance, Mat Saat et al. (1997) noted that oil palm seedlings planted on shallow laterite soil, sandy soil or soil with poor irrigation often showed symptoms of nitrogen deficiency. Therefore agricultural practice such as proper drainage system in these areas will improve the nutrient intake of N fertilisers by the crops.

Ibrahim (1998) also stated that fertilisers are affected by extremely hot weather where volatilisation leads to loss of nutrients. Apart from that, heavy downpour causes the loss of nutrients through percolation and surface run off. Among the agricultural practices recommended to increase the efficiency of fertilisers include constant clearing of weeds, adherence to fertiliser application schedule and correct dosage of fertiliser. In addition, application of volatile fertilisers should only be done in rainy season with palm fronds that has dropped to be arranged between the stands to maintain soil moisture.

Types of fertiliser used includes NPK Magnesium which is applied only for seedlings, Sulphite ammonia (SA), Muriate of Potash (MOP), Jordan Rock Phosphate (JRP) and Kieserite (KIE).

Ammonium sulphate contains 21% N and 24% sulphur. It is available both in powder form as well as granular form and is commonly applied in areas where sulphur deposition from the atmosphere has reduced and in light land areas. Rock phosphate ore contains about 29% phosphate but is unsuitable to be used in its raw state. Rock phosphate is insoluble and should not be used on soil with a pH of greater than 6.5. The appatite ore should be finely ground if used on acidic soils in order to be effective as a long-term fertiliser. Muriate of Potash typically contains 60% potash. Potash is important in helping plants to grow vegetative matter, reproduce reproductive matter like seeds and also protect itself against drought. Kieserite is the common name for magnesium sulphate. It contains 15% magnesium and 21% sulphur. The magnesium in Kieserite is totally soluble and available at all pH.

Chuah (1996) reported the use of palm oil mill effluent (POME) in FELDA plantations. FELDA palm oil mills are estimated to produce a total of 1.5 thousand tonnes of raw palm oil in the year 2000 and a total of 4.5 thousand tonnes of effluent will be generated as well. The effluent can be used as organic fertiliser and is usually sprayed around tree stands as additional fertiliser. Apart from that, POME serves as a source of water and organic matter. Other benefits include increasing the population and activities of soil microorganism, increasing soil nutrient, encourage root development, improve soil aeration, ion exchange capability, moisture retention in soils and also the soil texture.

Table 8 shows the nutrient composition in 1,000 tonnes of POME and its equivalent ratio to chemical fertilisers. Nutrient intake of oil palm is in the sequence of K>N>Mg>P and this corresponds with the nutrient composition found in POME. Trial application with POME recorded an increase in between 10 to 20% in yield as compared to chemical fertiliser. Rate of POME application is 750 litre / stand / year with 150 litre per cycle. Frequency of application is 5 - 6 cycles a year and is usually between the months of January to August where there is less rainfall. Empty Fruit Branch (EFB) are also reused as compost or replacement for fertiliser as well as soil conditioner for maintaining soil moisture.

There have been no detailed records on the use of pesticides and its frequency of application since the quantity is determined by the severity of pest problems. Liew (1997) stated that the rhinoceros beetle (*Oryctes rhinoceros*) that breeds in rotting standing trunks in replanted areas are a threat to young replants. According to Liau and Ahmad (1991), the adult will appear from its breeding sites and bore holes into the base of the seedlings for food. In serious infestation, the beetle will puncture the seedling up to the shoots and causes the plant to die. However, interviews with Plantation Managers indicated that such problems are insignificant. The common pesticides used in the plantations are Paraquat to control weeds around oil palm seedlings, Sentry for grass-like weeds, Ally for lalang and Butik Super which is a rodenticide.

Table 8. Chemical composition and equivalence to fertilisers in 1,000 tonnes of palm oil mill effluent (POME).

| Nutrient compo | sition(mg/litre) | Equivalence to fertilise | er (ratio) |
|----------------|------------------|--------------------------|------------|
| N | 320 - 3553 | Ammonium sulphate | 5.03 |
| P | 120 - 1180 | Rock phosphate | 1.30 |
| K | 1200 - 2387 | Muriate of Potash | 4.58 |
| Mg | 258 - 2509 | Kieserite | 3.98 |
| | | | |

2.7 Eutrophication

2.7.1 Natural and anthropogenic eutrophication

It has been long assumed that oligotrophic lakes were 'primitive' and the they would naturally develop into eutrophic ones. In fact, Reynolds (1979) explained that lakes do age as catchment-derived silts are in-washed and accumulated as lake sediment. Therefore, even though no change occurs in the amount of nutrient reaching a basin, its effect becomes more pronounced in the diminishing volume of the lake while the reduction in the hypolimnetic volume accentuates the severity of oxygen depletion during the stratified period. This process is known as natural eutrophication.

Vollenweider (1968) and Rohlich (1969) have catalogued many cases during the last four decades where the trophic status of many of the world's lakes has advanced rapidly. The relative enrichment has been a direct consequence of social or cultural advances made by growing human populations. For instance, forest clearance and the implementation of agriculture alter terrestrial nutrient cycles in favour of more labile components, proportionately more of which enter drainage water. In addition, ploughing and the use of modern inorganic fertilisers accentuate the trend. Concentration of human population in large urban settlements, importing nutrients as food but discharging the locally as sewage also contributes to net change in catchment-like equilibria. Apart from that, modern detergents based on polyphosphates are readily hydrolysed to yield biologically-active phosphates (Reynolds, 1984). Such changes inevitably disturb existing individual catchment-lake equilibria and accelerate trophic advance to bring about anthropogenic euthrophication.

Moss (1980) noted that organic matter sedimenting from the increased phytoplankton crops to the hypolimnion increases the rate of hypolimnetic deoxygenation. Lund (1969) noted that destratification of a tropical lake at any time of the year is expected to increase algal production because the nutrients throughout the water body would be available to the algae. In addition, all the algae would receive sufficient light for growth from time to time instead of some of the algae from the epilimnion passing into a hypolimnion, which is partly below the photic zone. Therefore, the productive capacity of the whole water mass could be utilised.

One of the approaches to solve the eutrophication problem is limiting the supplies of nutrients supporting increased productivity. Phosphorus can be most readily controlled because it is readily precipitated, enters the waterways from relatively few sources and has no atmospheric reserves while nitrogen compounds are too soluble, enters the waterways from many diffuse sources and there is a potential supply from the atmosphere through nitrogen fixers (Moss,1980).

However, Lund (1969) argued that situations may exist where increased nutrient inflow will have no significant effect because some other factors may retard the growth of algae. For instance, high turbidity and colour of the water reduce the absorption of radiation to such an extent that photosynthesis is restricted to a shallow depth.

2.7.2 Eutrophication Indices and their relation to other indices of ecosystem change

The criteria of a good euthrophication index, which includes sensitivity, specificity, ubiquity, ease of measurement and interpretation, may be met by several organisms, populations of organisms, or communities. The diversity of the community decreases when nutrients increase while new species invade the lake and may become abundant. Therefore, indicator organisms are useful in characterising eutrophic waters. However, many of the difficulties in using indicator species are caused by lack of specific information about the relations of organisms to the enrichment process. Hooper (1969) suggested four criterias of a useful index. First of all, a good index should distinguish between changes associated with nutrient level and those with other category of environmental change. However, he noted that it will be difficult to find an index that will discriminate between normal changes, like base levelling by run-off, and erosion from the slow changes in nutrient supply associated with changing land use. Nevertheless, he stressed that an index should differentiate between changes in enrichment level and seasonal effects as well as changes associated with short-term climatic changes. Secondly, a good index should have substantial sensitivity to levels of enrichment. The great value of indicator organisms is that the presence or absence of certain species, or the relative abundance of groups of species, in effect, carries out such an integration and relieves the researcher from continuous monitoring of chemical conditions. The third criteria is that a good index should have properties that are widespread geographically and short-lived geologically. For instance, an index of eutrophication should be a biological characteristic that is widespread among aquatic environments yet sensitive to changes in enrichment levels, particularly due to cultural events.

Lastly, a good index should be suitable for long-term surveillance and monitoring. He noted that eutrophication indices are among the most important environmental parameters to be considered. Hooper (1969) reported several eutrophication indices that had been utilised or proposed by researchers. For instance, changes in transparency of the water column are indicative of the abundance of plankton organisms. As such, transparency changes has been used to assess the rate of eutrophication. However, transparency data may be difficult to interpret as they do not discriminate between various types of suspended matter. Other than that, changes in concentration of plant nutrients such as nitrogen and phosphorus and other ions that are indirectly related to eutrophication due to their emergence in domestic drainage have also been used as indices. Nevertheless, it is noted that unless measurements are monitored almost continuously, the sensitivity of direct measurements of nitrogen and phosphorus compounds might be too limited. Yount (1956) and Margalef (1961) reported that increases in nutrient supply may bring about a simultaneous decrease in diversity. Margalef (1961) also stated that species increase in numbers to take full advantage of the increased carrying capacity of the environment. Diversity is decreased since various species have differing capacity to increase in numbers and some multiply more rapidly than others, thus expressing dominance.

Cox (1991) noted that a variety of indices have been devised using diatoms including diversity indices, saprobion, organic pollution, community and river pollution but most tend to be based on a limited number of water quality variables such as dissolved oxygen, biochemical oxygen demand, ammonium, nitrite and phosphate. It is also emphasised that indices can only be as reliable as the ecological data on which they are based.

According to Marvan (1991), methods for biological monitoring of Chechoslovakia rivers are based on "Saprobiensystem" whereby sets of indicator species assigned to different saprobic zones are considered to represent primary biological delimitation for the respective zones. Since the Saprobiensystem is purely empirical, the distribution of indicators in ecological situations corresponding to different zones of saprobity serves as the main source of information to calibrate of revise the lists of indicators. Several scales of saprobity were designed including those by Sladecek (1969) with the aim of providing numerical assessment. The integer values of the scale, also referred to as the PBS-scales, were made equal to ordinal numbers of the saprobic zones arranged according to the increasing pollution. The saprobicity expressed in values of PBS-scales is usually called the saprobic index and symbolised by S. Despite some problematic aspects, this is a widely used quantification of saprobicity. BODs is commonly used as a measure of organic pollution of water and a positive and relatively close correlation between this quantity and \underline{S} has repeatedly been confirmed by different authors based on data from different countries. Different species prefer a particular saprobic zone based on different reasons. For instance, oxygen concentration can play a decisive role for one species but can be less important for another species.

According to Coste et al. (1991), the use of diatoms as indices require perfect taxonomical knowledge of the organisms present within the whole application area, use of standardised sampling procedures, definition of limits of application and reference to natural community growing in similar but unpolluted conditions. Schoeman and Haworth (1986) discussed the pros and cons of using diatom indices. The advantages are that diatoms are cosmopolitan with high diversity, easy to collect and store for reference purposes, good indicators of

environmental changes within both short and long term. However, their identification requires a good taxonomic knowledge and estimate of the live/dead cell ratio remains problematic.

Jorgensen (1992) stated that the application of species composition as ecological indicators has in general been widely accepted in the water quality context. However, it is more time-consuming to determine the species composition compared to physicochemical measurements and the examination of water quality of often limited to the latter. In the saprobic system by Hynes (1960, 1971), a relationship between species composition and chemical water parameters is illustrated in Table 9. Nevertheless, a complete ecological picture is obtained only by assessment of the presence of some key species. Due to the fact that the determination of the saprobic class for a running water system is time-consuming, there had been in many practical cases that physicochemical parameters are solely used for the classification.

2.8 Use of algae for monitoring rivers

2.8.1 Principles and aims of monitoring

According to Whitton (1991), the most important use of biological monitoring is to reflect situations where there is a range of contaminants, whose biological effects may be synergistic or antagonistic, or biological data appear to give conflicting results with those indicated by chemical analysis. This may arise because chemical analysis misses key pollutants or because contamination is intermittent.

Table 9. The saprobic system and physicochemical parameters (Hynes, 1960;1971).

| Physicochemical parameter | Polysaprobic | Alfa-mesosaprobic | Beta-mesosaprobic | Oligosaprobic |
|---|--|-----------------------------------|-------------------|--|
| Dissolved oxygen (percent | 0 - 3 mg/liter | BOD ₅ increasing > 70% | %09< | %06< |
| saturation) | < 50% | BOD ₅ decreasing | | |
| | | Increasing < 30% | | |
| BOD _s (mg/liter) | High | Increasing | \$ | \$ |
| | | \$ | | |
| $\mathrm{NH_4}^*(\mathrm{mg}\ \mathrm{of}\ \mathrm{N}\ \mathrm{per}\ \mathrm{liter})$ | 0.5-2 | 0.3 - 1.2 | < 0.2 | < 0.1 |
| NO ₂ (mg of N per liter) | 0 - 0.2 | 0 - 0.2 | ~ 0.2 | < 0.05 |
| NO ₃ (mg of N per liter) | Very low | 1 - 2 | 2 - 6 | High |
| Turbidity | High | Low | Very low | Very clean |
| | THE RESERVE OF THE PARTY OF THE | | | Andrews of the Control of the Contro |

Round (1991) highlighted a few principles pertaining to the suitability of diatoms for river water monitoring. The most essential requirement is that the group of organisms should be present throughout the length of the river, grow in a specific well-defined habitat easily sampled and present in abundance. In addition, they should be unaffected by life cycle stages that might leave periods of time when the organisms were not present. They should also react to changes in water quality such that species or groups of species can be selected to indicate waters of differing quality. Other than that, the species should be easily identified and quantified without time-consuming labour. However, the only widely used method involves epilithic diatoms. The value of using diatoms is due to the fact that the flora reflects rather precisely the water quality at any one point. Therefore, by monitoring changes in the flora, subtle changes in water conditions will be detected. Since presence/absence can be added to abundance data, it is easier to define communities by the indicator markers. Round (1991) also recommended devising a system based on easily recognised species which can be related to simple water quality zones. The major diatoms which were good indicators of polluted water include Nitzschia palea, Gomphonema parvulum, Navicula goepretiana, Navicula accomoda and Gomphonema pseudoaugur. The polluted sites support large growths of numerous small Nitzschia and Navicula species. However, these are difficult to identify accurately and it is easier to use less common indicators such as Amphora veneta and Navicula goeppertiana.

Cox (1991) indicated that the choice of bioindicator group must satisfy certain criteria. First is that each taxon has precise ecological limits to its range that do not vary unpredictably. In addition, the range can be defined and the taxon can be consistently identified. Ecological ranges for a particular taxa are usually deduced from correlation between occurrence and results of water analyses. In turn, indices have been developed to provide some quantification or objective assessment of the degree of pollution. However, experimental work performed under controlled conditions to determine responses to changes in particular factors, either by itself or in combination, is still lacking. As a result of different species having contrasting ecological preferences, variation occurs in the relative abundance of species within the communities. Therefore, it has been assumed that numerical dominance indicates the existence of conditions favourable to the most abundant taxon.

2.8.2 Methodological aspects and perspectives of bio-monitoring

Whitton et al. (1991) noted that there are a variety of methods for monitoring which do not involve taxonomic identification and those based on measurements of standing crop are the most widely used. In addition, it is easier to sample the plankton to determine cell density, chlorophyll-a or other measures of biomass. In order to detect factors that may be affecting species distribution, comparisons are usually made between the relative abundances and water quality variables. A particular range is cited as favourable to the species when high percentage abundances of a species consistently occurs within a particular range of a physical or chemical factor (Cox, 1991).

Philipose (1960) and Munawar (1970) noted that alkaline waters with high concentration of nitrates, phosphates and oxidisable organic matter supported Volvocales. In his observation, Munawar (1970) stated that a ratio of N:P:K of 2:1:2 was favourable to *Chlorogonium*, *Chlamydomonas* and other Volvocales such as *Pteromonas*, *Eudorina* and *Pandorina*. Munawar (1970) also found that Chlorococcales preferred habitats rich in oxygen and nitrogenous organic matter. Singh (1960), Zafar (1959) and Munawar (1970) stated that Eugleneacea thrive in high concentrations of free carbon dioxide. This is because anaerobic conditions result in release of phosphorus that is favourable to *Euglena*.

Saravanamuthu and Lim (1982) conducted a preliminary limnological survey in a shallow culturally influenced pond in Petaling Jaya, Selangor, Malaysia. The pond is a eutrophic, disused tin-mining pool and is fed by septic tank treated sewage and sullage from surrounding residential areas. Among the biological parameters studied were phytoplankton population, algal indicators, primary production and chlorophyll-a. Dominant phytoplankton identified were Merismopedia, Chlorogonium, Chlamydomonas, Euglena, Cryptomonas and Trachelomonas while less dominant species include Scenedesmus, Chlorophycean sp 1, Chroomonas, Crucigenia, Closterium, Dictyosphaerium, Nitzschia, Oocystis, Phacus, Navicula, Pinnularia and Oscillatoria. The order of dominance of algal classes were reported as Cyanophyta > Chlorophyta > Euglenophyta > Cryptophyta > Bacillariophyta. The relative abundance of the dominant phytoplankton were found to relate to some of the chemical parameters. For instance, low NO3-N and PO4-P levels favour the growth of Merismopedia, Chlorogonium and Chlamydomonas but not Crytophyta, Euglenophyta, Chlorococcales (Dictyosphaerium, Scenedesmus, Crucigenia),

Bacillariophyta and desmids (*Closterium*). However, aerobic conditions are noted to be unfavourable for optimal growth of Cryptophyta and Euglenophyta.

Desmids in Taman Jaya pond (Petaling Jaya, Malaysia) are almost negligible and is likely to be related to the high calcium levels as noted by Pearsall (1932). Another reason is the highly polluted condition of the pond as desmids are usually found in clean water (Lim, 1974). According to Patrick (1948), the poor representation of diatoms is linked to low nitrate levels while Zafar (1964) noted that low phosphate levels is also a likely factor.

Pearsall (1932) and Nygaard (1949) used algal species as indicators to classify the trophic status of pond. In general, it was concluded that the dominance of Cyanophyceae, some Chlorococcales and Euglenaceae indicates eutrophic conditions. On the other hand, dominance of diatoms and desmids is representative of oligotrophic conditions.

According to Friedrich (1991), phytoplankton studies are commonly part of the general monitoring program in large rivers of Germany, such as Rhine, Elbe and Weser by determination and counting of the phytoplankton and by measuring the chlorophyll-a content. The objectives of the monitoring program are to determine the species composition and observe any changes along the river due to different intensity of pollution. In addition, changes in species composition over the years, quantity of the phytoplankton expressed in number of algae of different species and in the quantity of chlorophyll-a are also studied. In fact, the technique of these laboratory tests and the chlorophyll method are standardised.

Schiefele and Schreiner (1991) reported that diatoms were used as indicators for saprobic conditions in saprobic indicator systems by several researchers in monitoring studies on stream water quality despite the role of diatoms as autotrophics.

Nather Khan (1990) conducted the biological assessment of water pollution using diatom community structure and species distribution in the Linggi River Basin, Malaysia, which was polluted by various urban, industrial and agricultural wastes. In his investigation, the mere absence and presence of a species was not used to indicate water quality. Instead, higher constancy values and higher percentage of a species were related to a particular zone of combination. The relative abundance of diatom is estimated using total count data and is expressed as percentage abundance. Constancy is defined as the number of occurrences of a particular species and is expressed as a percentage of the total number of samples examined (Cook and Hirsch, 1958, Broen and Austin, 1973). Nather Khan (1990) reported that a dominant species at any particular station was not necessary present in the rest of the stations. In addition, species commonly associated with polluted waters also occurred in clean waters. Species not recorded at a particular station and generally represented by only a few individuals at other stations are considered rare. Therefore, the assessment of water quality takes into consideration the relative abundance of each species.

According to Nather Khan (1990), the common diatoms found in the Linggi River Basin are classified into clean water species (intolerant species), pollutant tolerant species and facultative species (indifferent species) which are common with significant numbers over a range of both polluted and unpolluted areas. The most common clean water species were Achnanthes minutissima, Achnanthes saxonica and Synedra rumpens. The most tolerant species were Nitzschia palea,

Gomphonema parvulum and Pinnularia braunii. The common facultative species found in the studies were Eunotia vanheurckii and Navicula cryptocephala.

Maznah and Mansor (1999) conducted a study to evaluate the species abundance and diversity of attached diatom community in running waters with different pollution levels in Pinang River (Malaysia). This is followed by testing the reliability of indicator groups against the water quality of the river based on physical and chemical parameters. A marked trend in the abundance of certain group of species was observed. Acnanthes saxonica and Acnanthes minutissima Kütz were abundant in polluted stations, Navicula cryptocephala Kütz and Gomphonema acuminatum Ehr. were common in the moderately polluted stations. In addition, Nitzschia palea (Kütz) W. Sm. and Gomphonema parvulum (Kütz) Grun., which were documented by Department of Environment (1998) as indicators of organic organic pollution were mainly found in severely polluted stations. Lowe (1974) stated that Nitzschia palea is usually found in waters of low quality because they attain dominance due to their tolerance of poor conditions. Kelly et al., (1995) also noted that this species thrive at sites with high level of nutrients and organic pollution. Maznah and Mansor (1999) noted that increased urban and industrial wastes at polluted stations reduced sensitive species and therefore tolerant species dominated in cell count.

Padisak et al. (1991) reported that algological monitoring in Hungary began in the 1960s to 1970s and its technical guidelines were elaboated in 1984. Based on trophic scales such as chlorophyll-a and algal numbers, trophic states are established. Then, a saprobic classification is made based on the list of saprobic indicator species. Chlorophyll-a content was measured and trophic states are estimated according to Felfody (1987). Meanwhile, algal samples were analysed

quantitatively and species composition was compared to the list of saprobic indicator species in Gulyas (1983) while algal density was compared to Felfody's (1987) trophic scales. However, trophic scales that are estimated by both chlorophyll-a and algal numbers are often different. So, a standard method of biomass-estimation by volumes should be introduced.

Statistical tests have been implemented in more recent approaches to detect significant correlations of diatoms distributions in relation to a range of factors. Statistical significance of results requires that distribution of a given parameter is homogeneous so that the probability of species occurrence is equivalent throughout the range. However, conditions are difficult to fulfill. Multivariate and correspondence analyses enable species occurrences to be compared against a wider range of interacting factors but only show where the strongest correlation lie. Jongman et al. (1987) stated that statistical tests may be possible to detect differences and relations between measured variables, yet interpretation of the differences must be made with caution. It is only when the researcher sets up and controls the system under study by experimentation, and influence the procedures to be conducted with treatments can it be concluded that significant differences between response and treatments are a consequence of the treatments. Therefore, statistical classification and multivariate analyses can detect value but require experimentation to test hypotheses and prove causality.

Ecological studies often involves large numbers of highly correlated and interdependent variables which make environmental interpretations very difficult. Moreover, simultaneous changes in variables result in a complex system. In this context, multivariate statistical methods, especially factor analysis, has been very useful in justifying the complexities of ecosystem. In the study of blue-green algae

as indicators of water quality, Fernandez-Pinas et al. (1991) noted that multivariate statistics can summarise the variability of a complex data set and present it in a more interpretable form. The methods involved measurement of principal components of the physicochemical variables using factor analysis and a correlation analysis between the derived factor and abundance of the major groups of blue-green found.

According to Ferreira (1991), algae are used to access the trophic level of the rivers in Portugal and to establish quality classes. Most studies concern free-floating algae and the saprobic index of Pantle and Buck (1955) is the most used. Burton (1986) reported that estimates of the pollution status of freshwater habitats have been made on the taxonomic composition of faunal communities and methods using algae as indicators of changes is the state of river quality have been developed. Burton (1986) also stressed that indices based both on species diversity and on indicator species and communities appeared to be of value in assessing spatial and temporal changes in water quality.

2.8.3 Problems of sampling river algae for monitoring

Friedrich (1991) proposed that the use of algae in river monitoring was hindered by the difficulty of correct determination, the expense of time and manpower. Lack of knowledge of taxonomy by young biologists and insufficient old determination keys are also hindrances to correct identification. University educated staff in routine laboratories of environmental agencies may be reluctant to work at the microscope while technical staff may require special training in order to carry out difficult determinations. Nevertheless, it was stressed that high quality ecology will be quite impossible if taxonomy was to be ignored. This is because the most significant indicators will be found at the species level.

2.9 Management potential of freshwater wetlands

Hughes et al. (1992) noted that in the United States of America, the monitoring to determine if water conditions are improving or degrading requires data collected over long temporal and large geographical scales. In addition, aggregating existing data from many independent monitoring networks has rendered this type of assessment ineffective because of the incomparability of their data over space and time. Most existing monitoring programs have findings that are difficult to extrapolate as it lacks in adequate statistical design. Moreover, assessment of ambient biological conditions of lakes and streams are needed apart from the physical and chemical characteristics. Biological data that are collected in some of the networks are typically filed and unused.

Coste et al. (1991) noted mathematical modelling as a technique used for water quality management whereby a model can theoretically calculate or predict the improvement expected on water quality of the receiving environment, with various policies of management or action.

Philips et al. (1996) stated that top-down process such as fish-zooplanktonphytoplankton interactions is important in the restoration of eutrophic lakes. It was noted that grazing by zooplankton can reduce chlorophyll-a concentrations. Nevertheless, predation by planktivorous fish prevents such populations from developing. In addition, artificial reduction of these fish from the lakes has resulted in an increase in zooplankton grazing and in turn reduced the chlorophyll-a concentration. This has created clear water and allowed the establishment of aquatic vegetation in the lakes. This biomanipulation provides a good tool in the planning of restoration of lakes that are dominated by plankton instead of nutrient removal.