

**STUDIES ON DIVERSITY, PRODUCTIVITY AND NUTRIENT CONTENT  
IN ALGAL COMMUNITIES OF UMIEW RIVER, MEGHALAYA**

**ABSTRACT**

**By  
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**THESIS SUBMITTED  
IN FULFILMENT OF THE REQUIREMENT OF THE DEGREE OF  
DOCTOR OF PHILOSOPHY IN BOTANY**

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## Abstract

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Meghalaya is rich in natural resources with wide variety of flora and fauna. The state is also rich in mineral deposits as well as aquatic resources. Aquatic resources include many rivers, streams, lakes and reservoirs etc. Considerable amount of work is available on the floral and faunal composition of the region but very little is known about its aquatic diversity particularly algae the primary producers of an aquatic system and absolutely no information is available on riverine algal flora. Therefore, there was an urgent need to record the diversity of algae in different water bodies of the region which are facing threat due to various anthropogenic activities. Therefore, the present work was aimed to study the diversity, productivity and nutrient content of algal communities in relation to water quality in Umiew river, an important river of the region supplying water to Greater Shillong.

The study was carried out in Umiew River, in Meghalaya (20.1°-26.5° N, 85.49°-92.52° E) in North-Eastern India. This river is one of the major river in Meghalaya which provide drinking water to Shillong city and its neighbouring areas under the scheme of greater Shillong water supply (GSWS). Four sites along the course of the river were selected for detailed study: site 1 located in Pamлакrai where the river is narrow and shallow and situated at higher altitude (1808 msl). Site 2 located in Nongkrem at an altitude of 1768 msl. The river in this location runs through agricultural catchment area where

during rainy season, lots of agricultural wastes get deposited into the river bed. The river in this area is completely open without any tree canopy and is two to three times wider than in the first site. Site 3 located in Umtyngngar where the water is highly turbid due to deposition of silts and remains of limestone quarrying from upstream of river Umtyngngar. Site 4, located in Mawphlang, the river is obstructed by the construction of concrete dam for the purpose of supplying drinking water to the whole city. This site is completely different from the other three upstream sites. The river is very wide and deep and looks more like a reservoir.

Water quality was assessed at monthly intervals for a period of two years i.e., April 2008 to March 2010 and grouped into different seasons based on the rainfall pattern during the study period i.e., monsoon (late May to August); post-monsoon (September to November); winter (December to February); spring (March to Early May).

Water quality parameters such as temperature, electrical conductivity, turbidity, water current, pH, dissolved oxygen were analyzed in situ using Deluxe Soil and Water analysis Kit (Model-191E). Other parameters such as calcium, magnesium, nitrate, nitrite, phosphate and silica were analyzed in the laboratory by following the standard method prescribed by APHA, (2005). Analysis of physico chemical parameters of water in selected sites showed that the water quality of Umiew River ranged from slightly acidic to mildly alkaline (5.30 to 7.46). An acidic pH was recorded from site 1 and alkaline pH was

recorded from site 3. Water temperature showed seasonal variation where maximum temperature was recorded in spring (24.8°C) and minimum in winter (11.3°C). Water turbidity was maximum in site 3 with a range of 0.09 to 0.33 NTU and in site 1, 2 and 4 it remained almost the same (0.01 to 0.07 NTU) throughout the study period. A significant temporal variation in velocity of current was observed. Velocity of current was high in site 2 and 3 in rainy season with a mean value of 0.51 to 0.53 m/sec and the minimum flow was recorded in site 4 with an average value of 0.01 m/sec. Conductivity ranged from 16 to 126  $\mu\text{S}/\text{cm}$ , dissolved oxygen ranged from 4.07 to 8.64 mg/l, nitrogen ranged from 0.21 to 1.39 mg/l, phosphate varied from 0.13 to 0.52 mg/l and were maximum in site 3. Calcium, ranged from 7.63 to 24.3 mg/l, magnesium ranged from 3.04 to 12.36 mg/l and silica content ranged from (2.74 to 5.79 mg/l) and were maximum in site 3. Detailed analysis of water for different water parameters though varied in between sites and seasons but all put together indicated that the river is oligotrophic with low level of nutrients. Using a hierarchical cluster analysis based on the physico chemical parameters of river water, two main clusters were formed in which site 4 formed a separate cluster which indicated that in site 4, along with change in width and depth in the river water parameters like high pH, low velocity of current separated the site from other three sites.

Planktonic and periphytic algal assemblages collected in two consecutive years were studied and analyzed by following the method prescribed by APHA,

(2005) canonical correspondence analysis (CCA) and hierarchical cluster analysis were employed to relate the diversity and cell abundance of algal assemblages to the water parameters using the statistical software XLSTAT 2009.

Periphytic algae contributed 89-93% of the total algal community and only 7-12 % was contributed by phytoplanktons. Totally, 346 algal species spreading over 8 families were recorded from 4 selected sites in different seasons during the entire study. Out of total taxa 151 species were recorded from Chlorophyceae, 112 species from Bacillariophyceae, 55 species from Cyanophyceae, 20 species from Euglenophyceae, 3 species from Chrysophyceae and 2 species from Xanthophyceae, Dinophyceae and Cryptophyceae respectively. Dinophyceae group was recorded only from site 3 and 4 while Cryptophyceae was recorded from site 1, 2 and 4. Both planktonic and periphytic cell abundance was maximum during spring when water current was minimum in all the sites. Planktonic cell abundance (individuals/l) was more in site 4 with 75 to 1920 individuals/l whereas in other three sites it was almost similar (45 to 635; 120 to 575; 105 to 580 individuals/l in site 1, 2 and 3 respectively). *Cyclotella* sp. a centric diatom and *Scenedesmus obliquus* a green alga were the most dominant planktonic species which contributed more towards the cell abundance in site 4 and 2 respectively. Planktonic species diversity (H') ranged from 0.06-2.3 with a maximum value recorded from site 1 during post monsoon. Periphytic cell abundance was significantly high in site 2 with a

range of  $18.5 \times 10^2$  to  $613.65 \times 10^2$  cells/ml. In site 1, it varied from  $56.12 \times 10^2$  to  $410.95 \times 10^2$  cells/ml. In site 3, it ranged from  $58.3 \times 10^2$  to  $405.6 \times 10^2$  cells/ml whereas in site 4 it ranged from  $40.23 \times 10^2$  to  $460.97 \times 10^2$  cells/ml.

A distinct seasonal variation in periphytic species diversity and richness was obtained in Umiew river in which the maximum value was recorded from site 2 in spring. In site 1, 2, 3 and 4 the species richness was 173, 229, 205 and 154 respectively and diversity index ranged from (1.71 to 2.53), (1.93 to 3.37), (1.88 to 2.55) and (1.39 to 2.46) respectively. No marked temporal and spatial variation in the dominance and evenness indices could be obtained during the study period. Bacillariophyceae was the most dominant group in site 1, 3 and 4 whereas in site 2 it was dominated by Chlorophyceae. Desmid with 71 species was the most dominant group from Chlorophyceae. *Navicula* was the most abundant taxon from Bacillariophyceae with 21 species, *Cosmarium* with 27 species from Chlorophyceae, *Oscillatoria* and *Euglena* with 14 and 9 species from Cyanophyceae and Euglenophyceae respectively. *Woloszynskia* sp. and *Ceracium hirundiniella* was the only representative from Dinophyceae whereas *Dinobryon sertularia*, *Mallomonas* sp. and *Pedinella* sp. represented Chrysophyceae. *Chilomonas paramecium* and *Cryptomonas* sp. were the representatives from Cryptophyceae and *Tribonema* sp. and *Characiopsis* sp. were from Xanthophyceae. Canonical correspondence analysis demonstrated that most of the species are cosmopolitan. Environmental variables like water current, turbidity, pH and depth were the main factors influencing the periphytic

algal growth. *Ankistrodesmus falcatus*, *Spirogyra pratensis*, *Cosmarium constrictum*, *Navicula tripunctata* *N. radiosa*, *Synedra ulna* and *Euglena gracilis* showed preference to nitrogen and dissolved oxygen. *Navicula lanceolata*, *Surirella elegans*, *S. robusta*, *Cymbella cistula*, *C. tumida* and *Gomphonema parvalum* were influenced by high water current, turbidity, silica and calcium. *Oedogonium* sp preferred high current velocity and *Oscillatoria curvicep* showed preference for high pH and phosphate. From the hierarchical cluster analysis, as obtained for water quality analysis, site 4 formed a separate cluster which indicated that it is dissimilar from the other three sites considering algal diversity where planktonic diatom species like *Cyclotella pseudostelligera* Hustedt and *Achnanthes brevipes* Agardh var. *intermedia* (Kutzing) Cleve were recorded in abundance.

Primary productivity of algal community which form the base in the food web for the survival of different heterotrophs mainly fishes was estimated in the river Umiew. Productivity was estimated as concentration of chlorophyll *a* content per unit volume for phytoplanktonic algae and chlorophyll *a* content per unit area for periphytic algae by Spectrophotometric method specified by Strickland and Parsons, (1972). Nutrient content in algal biomass was estimated after tri-acid digestion of the sample in the ratio of 9:1:1. Total nitrogen was estimated by Kjehdahl digestion method. Total carbon was estimated by using Liqui TOC II Elementer. Phosphorus was estimated by stannous chloride colorimetric method. Calcium and magnesium was estimated by atomic

absorption spectrophotometric method (AAS) and sodium and potassium by flame photometer spectroscopy. Relationships between chlorophyll *a* content with different important nutrients in periphytic algal biomass were examined by linear regression analysis. For the determination of elemental nutrients from the sediments, a method prescribed by Round, (1957) was followed. Algal assay procedure-bottle test was followed to determine nutrient limitation of river water as described by US-EPA, 1971 (US Environmental Protection Agency). *Scenedesmus obliquus* isolated from the river was cultured in modified CHU 10 media (Bold & Wayne, 1978) and used as the test material. Student t-test was employed to detect the significant differences ( $p < 0.05$ ) in the algal biomass production in different treated and untreated samples.

Productivity in both phytoplanktonic and periphytic algal assemblages were at its peak in spring and minimum in monsoon to post monsoon season. Productivity of phytoplankton was maximum in site 4 with a range of 0.05 to 0.36 mg/l whereas in the other three sites (site 1, 2 and 3) it was relatively low owing to fast flowing water and ranged from 0.01 to 0.08 mg/l. No significant variation was observed among the sites. Significant seasonal variation in productivity in periphytic algae was observed among the sites. Highest productivity was recorded in site 2 (1.2 to 5.9 mg/cm<sup>2</sup>) followed by that in site 3 (0.73 to 5.21 mg/cm<sup>2</sup>) and minimum was from site 4 (0.16 to 0.82 mg/cm<sup>2</sup>). In site 1 it ranged from 0.64 to 3.65 mg/cm<sup>2</sup>. During dry period (winter and spring), it was observed that the river bed was covered with a turf of filamentous

green algae particularly *Spirogyra* sp. in site 2 and *Oedogonium* sp. in site 3. Significant positive correlation between productivity in dry seasons and velocity of current and negative correlation between productivity in wet season and velocity of current ( $r^2 = 0.14$  to  $0.49$ ;  $p = 0.0001$  to  $0.02$ ) have been established in all the four sites ( $r^2 = 0.01$  to  $0.14$ ;  $p = 0.02$  to  $0.51$ ). A positive correlation was also observed between productivity and total nitrogen and productivity and phosphorus during dry season (S1,  $r^2 = 0.005$  and  $0.004$ ; S2,  $r^2 = 0.07$  and  $0.57$ ; S3,  $r^2 = 0.07$  and  $0.001$  and S4,  $r^2 = 0.05$  and  $0.105$ ) respectively and negative correlation during wet season in all the sites (in S1,  $r^2 = 0.04$  and  $0.01$ ; S2,  $r^2 = 0.03$  and  $0.002$ ; S3,  $r^2 = 0.10$  and  $0.001$ ; S4,  $r^2 = 0.59$  and  $0.0001$ ) respectively.

Different nutrient content in algal biomass was compared to the nutrients present in two media i.e. water and in sediment, nitrogen content was found to be many fold and significantly higher in the algal biomass than the concentration in water and sediment in different sites and in different seasons. Similar trend was observed in case of phosphorus, carbon and sodium concentrations where concentrations of these nutrients were higher in algal biomass. Calcium and magnesium on the other hand were significantly higher in water compared to sediment and algal biomass whereas potassium was significantly higher in sediment than that in water and algal biomass. A strong positive correlation between productivity in periphytic algae (chlorophyll *a* content) and nitrogen, phosphorus and carbon content in the algal biomass could be established. Increase in chlorophyll *a* content in algal biomass was attained as the percentage

of phosphorus ( $r^2 = 0.92$ ,  $p = 0.001$ ), nitrogen ( $r^2 = 0.95$ ,  $p = 0.0001$ ) and carbon ( $r^2 = 0.70$ ,  $p = 0.0001$ ) increased in the periphytic biomass mainly in site 2. In site 3 this strong correlation was observed only between carbon and chlorophyll *a* ( $r^2 = 0.77$ ,  $p = 0.0001$ ), but not with phosphorus ( $r^2 = 0.00005$ ,  $p = 0.98$ ) and nitrogen ( $r^2 = 0.08$ ,  $p = 0.38$ ).

It is established that among the different nutrients, relative availability of nitrogen and phosphorus or co-availability of nitrogen and phosphorus especially their ratio in the water play major role in controlling algal productivity. N: P atomic ratio also known Redfield ratio of Umiew river was found to be low (<16:1) in all the sites which indicated that the river was nitrogen limited. Therefore, to know the effect of different levels of nitrogen and phosphorus nutrients on the algal productivity in the river an experiment was carried out in the laboratory. Culture tubes containing 10 ml of autoclaved river water were supplemented with high phosphorus (0.5 mg/l), and high nitrogen (2.0 mg/l) and also with low P (0.05 mg/l) and low N (0.1 mg/l) and in combination of nitrogen and phosphorus in low N+P (0.1 mg/l +0.05 mg/l) and high doses N+P (2.0 mg/l +0.5 mg/l).  $\text{KNO}_3$  (potassium nitrate) and  $\text{Na}_2\text{HPO}_4$  (Disodium hydrogen phosphate) were used as a source of nitrogen and phosphorus respectively. Addition of nitrogen into the test water raised the chlorophyll *a* content of the test alga significantly specially at high nitrogen level i.e. 2 mg/l in most of the treatments. Addition of phosphorus also increased the chlorophyll *a* content in both low and high doses but the increase was not

significant. Combination of high concentration of nitrogen and phosphorus added into the test alga yielded much higher productivity, 2-3 folds higher than those given singly. The manifold increase in productivity with addition of phosphorus along with nitrogen thus indicated that though phosphorus was not detected as a limiting nutrient according to Redfield ratio but the level phosphorus in the river was low for algal growth.

In the present study it was found that velocity of current played one of the most important role in controlling the diversity and productivity of algal assemblages in Umiew River. To study the role of velocity of current on algal colonization and growth, artificial substrata (ceramic tiles) were placed in different micro habitats of the river like pool formed within the river (with no flow current), different riffle zones (high flow, moderate flow and low flow). The artificial tiles were incubated for 5 weeks. From this experiment, it was found that variation in water current was highly significant among the entire flow zones ( $p < 0.0000006$ ). 13 species were encountered only from the pool, 20 species were found only in low flow and *Pinnularia braunii* was found only in high flow zone. *Synedra acus*, *Synura* sp. and *Pithophora* sp. were present only in moderate flow. Species diversity, richness, cell abundance and productivity were significantly high in low flow and minimum in high flow. Diatoms were the most dominant group in the entire riffle zone, whereas in pool, *Spirogyra varians*, *Euglena mutabilis* and *Scenedesmus obliquus* were the most common and dominant species which contributed maximally to the total cell abundance.

This experiment thus confirmed that low flow in a lotic system supported diverse algal assemblage.

It can be concluded from the present study that though the river water varied in different physiochemical parameters at different sites, the overall water quality was oligotrophic with low nutrient levels favoring the growth of algae, the primary producers of the river. Algal assemblages in river Umiew has been found to be diverse. Recording of 346 algal species from the river representing different groups indicated the richness of riverine algal flora of the region. The presence of 71 species of desmids in the river and occurrence of chrysophytes like *Dinobryon* sp. and *Mallomonas* sp. indicated the nutrient poor condition and confirmed the oligotrophic nature of the river water. Maximum numbers of algal species were recorded in the area of the river where it runs through agricultural land and receive agricultural runoff during monsoon. This observation clearly indicated that deposition of agricultural waste into the nutrient poor river did not affect the algal assemblages adversely but it enhanced the growth of algae by increasing species richness, diversity and productivity. Dominance of Chlorophyceae and Bacillariophyceae members, their even distribution further confirmed the unpolluted nature of the river. Calcium level in the river in Umtyngngar was comparatively higher than other sites which could be due to deposition of remains of lime quarrying. Presence of calciphilic species like *Ceracium hirundinella* and *Woloszynskia* sp., belonging to Dinophyceae and diatoms like *Cymbella tumida*, *C. cistula* and *Achnanthes brevipes* also indicated

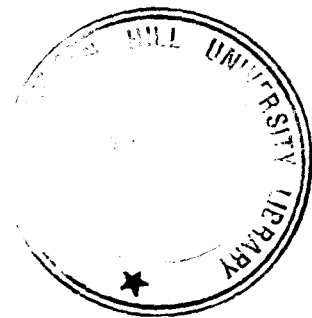
the higher level of calcium in site 3, but in general highly turbid water in site 3 adversely affected the algal assemblages. Thus the present study clearly indicated that shifting of remains of lime quarrying as sand and silts from the catchment area to the river mainly obstructed the flow of water and light penetration in dry seasons which in turn adversely affected the structure and function of algal communities.

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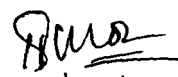
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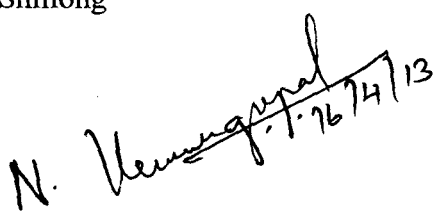
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**DECLARATION**

I, Hygina Siangbood, hereby, declare that the thesis entitled '**Studies on diversity, productivity and nutrient content in algal communities of Umiew river, Meghalaya**' is a record of original and independent research work carried out by me in the Department of Botany, North-Eastern Hill University, Shillong, under the supervision of Dr. Papiya Ramanujam. The work is original and no part of the thesis has been submitted for any other degree or diploma of any University.

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Index name	
AgNO <sub>3</sub>	Silver nitrate
ANOVA	Analysis of variance
C	Carbon
EC	Electrical conductivity
Ca	Calcium
CaCl <sub>2</sub> .2H <sub>2</sub> O	Calcium chloride di-hydrate
CCA	Canonical correspondence analysis
Cl	Chloride
DIN	Dissolved inorganic nutrient
DO	Dissolved oxygen
EDTA	Ethylenediaminetetra acetic acid
H <sub>2</sub> O <sub>2</sub>	Hydrogen peroxide
H <sub>2</sub> SO <sub>4</sub>	Sulfuric acid
HCl	Hydrochloric acid
K	Potassium
K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	Potassium dichromate
K <sub>2</sub> HPO <sub>4</sub>	Potassium bi-phosphate
KI	Potassium iodide
KNO <sub>3</sub>	Potassium nitrate
Mg	Magnesium
MgSO <sub>4</sub> .7H <sub>2</sub> O	Magnesium sulphate hexa-hydrate

N	Nitrogen
Na	Sodium
Na <sub>2</sub> EDTA	Disodium Ethylenediaminetetra acetic acid
Na <sub>2</sub> HPO <sub>4</sub>	Disodium hydrogen phosphate
Na <sub>2</sub> SO <sub>3</sub>	Sodium sulphite
NaHCO <sub>3</sub>	Sodium bi-carbonate
NaNO <sub>3</sub>	Sodium nitrate
NaOH	Sodium Hydroxide
NaSiO <sub>2</sub> .9H <sub>2</sub> O	Sodium metasilicate
NO <sub>2</sub>	Nitrite
NO <sub>3</sub>	Nitrate
P	Phosphorus
PO <sub>4</sub>	Phosphate
SiO <sub>2</sub>	Silicate
SnCl <sub>2</sub>	Stannous chloride
SRP	Soluble reactive phosphorus
TC	Total carbon
TN	Total nitrogen
WC	Water current

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# CHAPTER 1

## GENERAL INTRODUCTION

---

Flowing water contain a small fraction of the stored water in the biosphere yet they are of great importance to our physical, chemical and biological world. Rivers and streams play a critical role in the continuous water cycle and in the fluctuation of minerals and nutrients from elevated to lower land and eventually to the sea. River ecosystems are prime examples of lotic ecosystems. Water flow is the key factor in lotic systems influencing their ecology. The strength of water flow can alter between systems and also within a system. Flowing water can alter the shape of the stream or river bed through erosion and deposition, creating a variety of habitats, including riffles and pools. Other factors like light, temperature, water chemistry, substrates and biota also play a crucial role in describing lotic ecosystem. Algae, consisting of phytoplankton and periphyton, are the most significant source of primary production in most streams and rivers. Phytoplanktons float freely in the water column and thus are unable to maintain populations in fast flowing streams. They can, however, develop sizable populations in slow moving rivers and backwaters. Periphytons are typically filamentous and tufted algae that can attach themselves to any substrates or objects to avoid being washed away by the velocity of current. In places where flow rates are negligible or absent, periphyton may form a gelatinous, unanchored floating mat.

Algal communities show seasonality as they respond to the changing environment. Seasonal changes in algal communities usually depend on seasonal variations of ambient physical factors and nutrient concentrations (Pilkaitite & Razinkovas, 2007). The occurrence of algae in any aquatic ecosystem cannot be considered alone but in relation to the prevailing environmental conditions particularly the physico-chemical factors of the medium in which they grow (Ezra & Nwankwo, 2001; Buzzi, 2002; Celekli *et al.*, 2007; Davies *et al.*, 2009; Ramanujam & Siangbood, 2009). Modifications in physical and chemical parameters in fresh water systems bring serious threat to the ecosystems (Dallas & Day, 2004; Palmer *et al.*, 2004, 2005). For example, fluctuations and changes in pH, temperature, conductivity and nutrient quality in different aquatic system has led to the change in diversity, abundance and succession of different algal communities (Barinova *et al.*, 2004; Zaloscar *et al.*, 2007). Several changes in the dynamics and species diversity of algal communities in freshwater ecosystems are greatly influenced by the alteration or change in physico-chemical and biological properties of water (Reynolds, 1984; Harris, 1986; Sommer, 1989; Postel, 2000; Daniels *et al.*, 2002).

Periphytic and planktonic algal assemblages besides their significance as the primary producers in food webs are also used as an important tool to assess the water quality in streams and rivers worldwide (Kitner & Poulickova, 2003; Rey *et al.*, 2003; Rusanov *et al.*, 2012). The attached nature of periphytons and benthic algae made them particularly more useful in streams and rivers where it serve as a reliable index of water

quality at a given sampling point (Collin & Weber, 1979). The extensive studies on aquatic organisms particularly the algal group serves as a useful mean to detect the anthropogenic impact in those systems in different time scale and also provides a precise fact on the health of an ecosystem (Ector & Rimet, 2005). The occurrence of various forms of algae in the system indicates the level of pollutions (Hassan *et al.*, 2010). Many benthic algae, specially the diatomaceous (diatoms) form has drawn the attention of many algologists to use this particular group which constitute the larger part of the benthos (often 90% to 95%) as a tool for water quality monitoring programme (Acs, *et al.*, 2004).

Among the various physico-chemical factors that affect the algal assemblages in lotic system, water current and nutrient concentrations are the major ones. The velocity of current not only affects the distribution but also induce heterogeneity into benthic algal communities within a habitat (Stevenson *et al.*, 1996). Water current, increase drag on cells and affect immigration and export rates (McIntire, 1966; Peterson & Stevenson, 1989) as well as stimulates algal metabolism by increasing nutrient availability of cells and reducing the laminar sub layer (Whitford, 1960). These stimulatory effects of water current on algal metabolism enhance luxuriant growth of filamentous green algae possibly in the riffle zones of streams (Zimmermann, 1961). The velocity of current can have both positive and negative effects on the biomass and composition of stream algal communities (McIntire, 1966; Reisen & Spencer, 1970; Stevenson 1984; Lamb & Lowe, 1987; Horner *et al.*, 1990; Poff *et al.*, 1990; Uehlinger, 1991;

Stevenson, 1996). Increase in the velocity of current can positively influence biomass production by increasing nutrient availability through reduced thickness of the laminar boundary layer. However, increased velocity negatively impacts the biomass by increasing shear stress on algae. In a nutrient enriched stream, decrease in water velocity showed little impact on nutrient supply but helped to increase biomass by significantly reducing shear stresses (Hayward, 2003).

Algae possess chlorophyll, the green pigment essential for photosynthesis, and often contain additional pigments that mask the green colour like fucoxanthin and phycoerythrin (Wetzel 1983, Horn & Goldman, 1994). They are the major primary producers in the food chain of streams and rivers and are also the main source of food and energy for all the heterotrophic groups. Chlorophyll *a* is a photosynthetic pigment that serves as a measurable parameter for algal production. Quantitative biomass estimate can be made taking into account that an average 1.5% of algal organic matter is chlorophyll *a*. Qualitative assessment of water quality can be based on chlorophyll *a* concentrations (Wever *et al.*, 2008). Light is the most limiting factor for algal growth, followed by nitrogen and phosphorus. Algal productivity is often correlated to levels of nitrogen and phosphorus but other nutrients are also required including carbon, silica, and other micronutrients. Biomass is usually measured by the amount of chlorophyll *a* in the water column or as mass per area for attached species. Periphyton assemblages generally are the most dominant primary producer in stream ecosystems (Vannote *et al.*, 1980), and thus constitute the primary link

between dissolved nutrients and higher trophic levels (Minshall *et al.*, 1985; Mulholland *et al.*, 2000; Finlay, 2001). Exploitation of nutrients by periphytons can influence longitudinal variations in both the form (dissolved, particulate, organic and inorganic) and concentrations of nutrients available to downstream communities (Newbold *et al.*, 1982; Minshall *et al.*, 1985). Periphyton biomass has been correlated with stream nutrient concentrations (Dodds *et al.*, 2002). The quantitative analysis of photosynthetic pigments is of ecological significance to assess taxonomic compositions in natural algal assemblages (Suzuki *et al.*, 1993) and productivity. In any aquatic ecosystem, productivity by periphyton is a useful tool in determining stream water quality because of their rapid response to environmental changes (Hecky & Fee, 1981; Lowe & Laliberte, 1996).

Availability of nutrients can affect many limnological aspects. Lack of nutrients often limits algal production in streams (Allan, 1995). In many cases, the nutrients available in the ambient water especially nitrogen (N) and phosphorus (P) was not sufficient for the growth of algae especially in flowing environment and hence became a limiting factor. Among the elements required for algal growth, there are some that can become limiting. Globally, nitrogen and phosphorus have been marked as the two major elements that immediately limit production of algae in aquatic ecosystem and are known to be frequently in short supply relative to cellular growth requirements (Dodds *et al.*, 2002). Several reports are available where nitrate and phosphorus were added experimentally in stream systems to determine which nutrient limited the algal growth of that system (Bothwell, 1985; Pan

& Lowe, 1994; Wellnitz *et al.*, 1996; Dodds *et al.*, 1997; Kutka & Richards, 1997; Winter & Duthie, 2000; Mosisch *et al.*, 2001).

Agriculture in a particular catchment area is considered as one of the most serious threat to the streams within that area. Although eutrophic impacts due to addition of excess nutrients in the form of fertilizers are thought to be greater in the tropics than at higher latitudes (Downing *et al.*, 1999), studies on the effect of agricultural residue on tropical and subtropical streams are still very scarce. Dissolved inorganic nutrients are sequestered by periphytic and benthic algae. The structure of benthic and periphytic algal communities and their function in terms of biomass and nutrients sequestered is considered as an important measure to determine the status of an aquatic system (Stevenson *et al.*, 1996). Artificial eutrophication, i.e., an exaggerated nutrient enrichment process (mainly nitrogen and phosphorus) occurring in the water column, as a result of excessive nutrient loading, mainly from agriculture (i.e., rural runoff), urban areas (i.e., urban runoff, effluents from waste water treatment plants) and industry is one of the most serious global problems of the lotic systems (Wetzel, 1983; Raike *et al.*, 2003; Wood *et al.*, 2005; Petzoldt & Uhlmann, 2006; Schindler *et al.*, 2006). In some cases, high concentrations of nutrients in rivers may cause algal biomass growth and as a consequence, some deleterious effects may happen, like increase in ionic concentrations, increase in water electric conductivity which in turn may decrease water column transparency and create threats to endangered aquatic species and (Smith, 2003; Calijuri *et al.*, 2006; Calijuri *et al.*, 2008).

The state of Meghalaya is very rich in mineral as well as aquatic resources which include rivers, streams, ponds, reservoirs, etc. The total riverine length in Meghalaya is 556 kms, which constitute only about 0.3% of the total riverine length in India. Most of the rivers are perennial but the main source of water is the monsoon rain. Khasi hills has a large number of rivers and streams that drain the undulating downstream area, serving as important sources of water for domestic use and irrigation, and supporting a rich array of floral and faunal diversity. Unfortunately, rampant domestic and urban discharge, agricultural waste and mining effluents have adversely affected the quality of water of most water bodies. Various anthropogenic activities are the main sources of water pollution which has serious implications on aquatic life. Meghalaya is one of the mega biodiversity hot spot with rich aquatic flora and fauna. But very little is known about its aquatic biodiversity. Absolutely no information is available on riverine algal flora. Therefore, there is an urgent need to record the diversity of algae in different water bodies of the region which are facing threat due to various anthropogenic activities.

The main aim of the present work is to study the diversity, productivity and nutrient content of algal communities in relation to anthropogenic activities like deposition of agricultural run-off and lime quarrying in Umiew river, one of the major river in Meghalaya which provide drinking water to Shillong city and its neighboring areas under the scheme of greater Shillong water supply. The river is also used for cleaning and irrigation purposes.

## CHAPTER 2

### REVIEW OF LITERATURE

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Algal composition, their diversity and seasonality in both lotic and lentic aquatic ecosystem had been extensively studied all over the world (Pfister, 1993; Biggs, 1995; Leukart, 1995; Gonulol & Obali, 1998; Sherwood & Sheath, 1999; Sherwood *et al.*, 2000, Tas *et al.*, 2002; Soylu & Gonulol, 2003; Hassan *et al.*, 2010; Tian *et al.*, 2012) and related the growth and development of algal communities to different abiotic factors such as the type of water bodies (lake, stream or river, light availability (water turbidity and clarity), types and depth of substrate, velocity of current, pH, alkalinity, hardness of water and the amount of nutrients, mainly phosphorus, nitrogen and carbon (Mc Intire, 1966; Moore, 1976; Goldman, 1979; Bothwell, 1985; Hill & Knight, 1988; Lohman *et al.*, 1992; Pan & Lowe, 1994; Dodds *et al.*, 1997; Winter & Duthie 2000; Mosisch *et al.*, 2001; Stelzer & Lamberti, 2001; Notestein *et al.*, 2003; Roberts *et al.*, 2004). Phytoplankton abundance and species richness was negatively correlated to high turbidity and current velocity. Hynes, (1970); Crayton and Summerfield, (1979), Keithan and Lowe, (1985) reported that the change in water current changed the algal composition and abundance of algal communities in streams. In the hilly streams, water temperature, flow of water and substrate composition was considered as the major factors controlling the algal communities (Wetzel, 1983; Sharma *et al.*, 2007). In addition, light, temperature and invertebrate grazing have been shown to possess potential effects in controlling

periphytic populations (Whitton, 1975; Biggs, 1996). Among the different factors, the amount of light reaching the surface of substrate played a significant role on the growth of algae (Stahl *et al.*, 1994; Dodds *et al.*, 1999; Glud *et al.*, 1999; Guasch *et al.*, 2003). A distinct seasonal pattern in the algal composition in streams and rivers and an increase in algal species diversity and richness with increase in temperature up to 25-30°C has been demonstrated in many studies. Squires *et al.*, (1979) and Wilde and Tilly, (1981) reported a variations in periphyton diversity with seasonal changes mainly due to change in temperature. Patrick, (1971) examined changes in species composition on introduced glass slides in different seasons and reported that a small rise in temperature increased diatoms diversity in winter when ambient temperature was near the lower tolerance range for diatoms. When temperature was artificially raised at the upper end of the tolerance range (during summer), diversity of diatoms decreased as cyanobacterial species dominated.

The abundance, diversity and succession of different communities of algae in different rivers and its relation to water chemistry, mainly the fluctuations and changes in pH, temperature, conductivity and nutrients quality were reported by many workers (Reynolds, 1984; Sheath & Burkholder, 1985; Biggs & Close, 1989; Biggs & Gerbeaux, 1993; Mosisch & Bunn, 1997; Barinova *et al.*, 2004; Atici & Caliskan, 2007; Zaloscar *et al.*, 2007; Zabbay *et al.*, 2008; Yang *et al.*, 2009). A seasonal change in species composition was studied by Ismail, (2008) in Himreen Reservoir in Iraq. In Minichinda stream of Nigeria, Ezra and Nawankwo, (2001), Davies *et al.*,

(2009) also reported the seasonal variations in abundance and distribution of planktonic algae. Kobbia *et al.*, (1991) investigated the effect of agricultural run-off on algal diversity and succession in river Nile, and concluded that members of Bacillariophyceae and Cyanophyceae were the dominant groups in nutrient rich water.

Hamed, (2008) reported that diatoms were the most diverse group followed by cyanobacteria in different water bodies of Egypt including river Nile. Similar findings were also reported by Hassan *et al.*, (2010) in Euphrates river where Bacillariophyceae was the most dominant group. Recently, diatom diversity in rivers gained considerable attention in different parts of the globe (Rott, 1991; Round, 1991; Whitton *et al.*, 1991; Coste *et al.*, 1991; Whitton & Kelly, 1995; Rosen, 1995; Lim *et al.*, 2001; Stevenson & Smol, 2003; Ector *et al.*, 2004; Wang *et al.*, 2005; Chessman *et al.*, 2007; Taylor *et al.*, 2007; Porter *et al.*, 2008; Solak *et al.*, 2012). A detailed work on diatom diversity in water systems in Northern and Northeast regions of Thailand was carried out by many workers and many novel diatom members were identified and recorded (Peerapornpisal *et al.*, 2000; Pekthong & Peerapornpisal, 2001; Yana & Peerapornpisal, 2009; Leelahakriengkrai *et al.*, 2009; Suphan & Peerapornpisal, 2010; Leelahakriengkrai & Peerapornpisal, 2010; 2011).

Diversity of desmids as indicator of water quality has been studied since long (Coesel, 1983; Gerrath, 1993; Ngearnpat & Peerapornpisal, 2007). Neostupa *et al.*, (2009) studied desmids diversity in Central European peat lands. Extensive work on desmids diversity collected from various types of

wetlands was studied by Stastny, (2010) in Czech Republic. Distribution of desmids and other green coccoid algae was reported by Coesel and Krienitz, (2007). Fresh water filamentous green algae which belong to chlorophyceae member were studied extensively in Pakistan by Leghari, (2001); Asghar *et al.*, (2010).

Dissolved nutrients like nitrogen, phosphorus, calcium, sulfur, silicon, presence of metals and trace metals, salinity, oxygen and carbon dioxide were other factors that influenced the growth of algae (McCormick & Cairns, 1994; Herbst & Blinn, 1998; Tang *et al.*, 2003; Boivin *et al.*, 2006; Segal *et al.*, 2006; Shun *et al.*, 2009).

Based on the occurrence and diversity pattern, algae have been used as an indicator species in aquatic environment (Stevenson, 1984; Jena *et al.*, 2005). Due to rapid response to a wide range of pollutants and also because of their differential nutritional needs and their position at the base of aquatic food webs, algal indicators provided relatively unique information concerning ecosystem condition as compared to commonly used animal indicators (Palmer, 1969; Round, 1991; McCormick & Cairns, 1994; Pan *et al.*, 1996; Stevenson *et al.*, 2003; Potapova & Charles, 2007). Use of algae in assessing water quality began in the mid 1970's and since then different algal communities have been used worldwide as a valuable tool in monitoring water quality. (Schubert, 1984; Venkateswaralu & Reddy, 1985; Whitton *et al.*, 1991; Acs *et al.*, 2004). Recently, diatoms have been used as an indicator species for monitoring water quality (Palmer, 1969; Round, 1991; Agatz *et al.*, 1999; Belegatis & Economou-Amilli, 2000; Caput & Plenkovi-Moraj,

2000; Potapova & Charles, 2007; Ponander *et al.*, 2007). Besides diatoms, other periphytons mostly some green algae were well recognized in the temperate countries as indicator species (Chessman *et al.*, 1999; Potapova and Charles, 2002). Comparatively work in the tropical and sub-tropical countries using diatom or other periphytons as indicator of environmental changes were less (Lobo *et al.*, 1996; Juttner *et al.*, 2003).

Palmer, (1969) made the first major attempt to identify and prepared a list of genera and species of algae tolerant to organic pollution. Patrick, (1965) and Jafari and Gunale, (2005) reported that *Oscillatoria*, *Euglena*, *Chlorella* and *Ankistrodesmus* were typical inhabitants of polluted waters and highly pollution tolerant genera and, therefore, reliable indicators of eutrophication. The pollution tolerance of *Stigeoclonium tenue*, *Schizomeris leibleinii*, *Cladophora glomerata*, *Spirogyra*, *Ulothrix* were documented by Mclean, (1974); Gunale and Balakrishnan (1981). Euglenophytes, another algal group played an important role in determining water pollution and cleaning waste water (Soylu & Gonulol, 2003). It has been reported that their growth and distribution depended on the carrying capacity of the environment and on the nutrient concentrations, both intracellular and extracellular (Ezra & Nawankwo, 2001; Davies *et al.*, 2009). In tropical regions, mainly in India, such studies has been reported by Venkateswarulu, (1981); Kannan and Krishnamurthy, (1985); Mohanty, (1985); Khan, (1991); Munn *et al.*, (2002); Juttner *et al.*, (2003); Rajakumari and Ritakumari, (2004); Narkhede and Raghothaman, (2007).

Algae, the predominant organisms in water bodies contribute mainly to primary production of an aquatic ecosystem. Productivity in any aquatic system is governed by diversity and abundance of different algal communities which in turn is controlled by nutrients, light and flow regimes (Lohman *et al.*, 1992; Biggs, 2000; Dodds *et al.*, 2002). Dodds *et al.*, (2002) established a positive relation between production and nutrients availability where light was not a limiting factor. Light limitation was considered to be the controlling factor for primary productivity (Lehman, 2007). Toet *et al.*, (2003) reported that light availability in the water column, higher availability of nutrients and less exposure to water current were the main factors that regulated the periphytons biomass. Ariyedej *et al.*, (2008) reported that nitrogen, alkalinity and turbidity were the main factors that affected the variation of phytoplankton biomass as chlorophyll *a* in Banglang reservoir. Seasonal changes in periphyton production and nutrient content were controlled by physical, chemical and biological factors, mainly light (Sand-Jensen *et al.*, 1988, 1989; Hansson, 1992), temperature (Davison, 1991), nutrients (Hansson, 1992), grazing (Cattaneo, 1983; Muller, 1994), current velocity (Biggs and Close, 1989; Sand-Jensen *et al.*, 1989). Great seasonal biomass variability in tropical shallow reservoirs (Moschini *et al.*, 2000; Fermino, 2006) and a great increase in periphytic biomass in dry period were reported (Moschini *et al.*, 2000; Vercellino & Bicudo, 2006; Borduqui *et al.*, 2008).

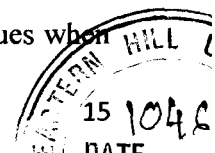
Agriculture, in particular, in the catchment area has been considered as the most-serious threat to the streams within the area (Squires & Saoud,

1986; Johnson *et al.*, 1997; Wilby *et al.*, 1998). A positive relationship between stream nutrient concentrations and the area under agriculture was reported by Leland and Porter, (2000); Rhodes *et al.*, (2001); Kuo and Chiu, (2004); Inwood *et al.*, (2005). Nutrient loading from agricultural land was 10-20 times higher than the load from forested land (Rekolainen, 1989; Pekarova and Pekar, 1996). Agricultural runoff could lead to higher nutrient concentrations in nearby streams (Chetelat *et al.*, 1999; Pan *et al.*, 1999; Dodds *et al.*, 2002). Increased amount of nutrients (phosphorus, nitrogen, potassium), entering a stream from agricultural runoff increased the growth of algae and other organisms (Jones and Knowlton, 1993; Daniel *et al.*, 1994). Yu and Lin, (2009) reported that algal productivity in the subtropical mountain streams of Wuling area in Taiwan varied significantly with the extent of agriculture in the catchment. Algal biomass was correlated directly with dissolved phosphorus and inversely with depth (Allyson *et al.*, 2005) and was also positively correlated with the urban activities (Lilian *et al.*, 2006). Mosisch *et al.*, (2001) reported that nitrogen alone stimulated periphytic algal production in subtropical streams with sufficient light. Direct relationship between chlorophyll *a* and the variations in phytoplankton biomass and productivity were reported by Danielkutty and Sobha, (2006) in two freshwater rocky pools of Kollam District of Kerala.

Ferragut *et al.*, (2010) reported that the periphyton biomass and nutrient content was controlled primarily by the seasonal scale. In Brazilian lentic ecosystems, phosphorus was reported to be the most limited nutrient for algal growth (Huszar's *et al.*, 2005). Studies on the increase in primary

productivity and algal biomass accumulation due to elevated nutrient concentrations in naturally flowing water systems have been carried out by many workers (Hill & Knight, 1988; Hill *et al.*, 1992; Dodds *et al.*, 1997; Biggs, 2000; Tank and Dodd, 2003). Increased biomass of periphytic algae due to addition of phosphorus in phosphorus deficient streams was reported by Peterson *et al.*, (1983); Perrin *et al.*, (1987); Bothwell (1989). Addition of nitrogen and phosphorus in combination doubled the growth of periphytons and tremendously increased the chlorophyll *a* production in flowing river (Stanley *et al.*, 1990; Burton *et al.*, 1991; Lohman *et al.*, 1992; Perrin & Richardson, 1997). Relative growth rate of periphytic algae was directly related to soluble reactive phosphorus in artificial stream (Bothwell, 1985). According to Carey *et al.*, (2007), periphyton chlorophyll *a* production in periphytic algae did not increase well only with nutrients enhancement but increased with modification of physical factor like light intensity. Lewis and Mccutchan, (2010) reported that the nutrient response of periphyton biomass was suppressed by other controlling factors at low nutrient concentration in streams and rivers of the Colorado Mountains. Ghosh and Gaur, (1990) reported that phosphorus deficiency limited the algal productivity in the streams of Shillong.

In the lotic systems, current velocity was one of the significant physical factors affecting distribution and inducing heterogeneity to the algal communities within a habitat (Stevenson *et al.*, 1996). Wendker, (1992) studied the influence of current velocity on diatoms of small soft water streams and showed that there were slight increase in diversity values when



current velocity increased. Soininen, (2004) reported that in a clear river, diversity of diatom communities at the highest velocity level was low while in turbid river, it was more similar, at all velocities. Todd and Poff, (2006) reported that chlorophyll *a* and AFDM (ash free dry mass) were best predicted by interactions between current velocity, grazing duration and regrowth time. Poff *et al.*, (1990) reported that current velocity and flow pattern directly influenced the algal assemblages and composition in streams. Ghosh and Gaur, (1991, 1998) reported that in an unshaded stream, the periphytic biomass and algal colonization were negatively correlated to flow rate. The periphytic algal species of riffles and pool were markedly different from each other in diversity, cell counts and species composition. Lamb and Lowe, (1987) reported that at different current velocities, there was a similarity in the diatom composition in Maumee river in Ohio but the cell densities in the slow current were three times more in the water system with faster current. Humphrey and Stevenson, (1992) reported that rise in water current stimulated algal growth in nutrient-rich water but inhibited algal growth in nutrient-poor streams. An increased species richness and chlorophyll content in algae was reported in upper Colorado river when algal grazers were removed (Ronald *et al.*, 2003).

Periphytic algae absorbed and sequestered inorganic nutrients (Tushman & Stevenson, 1991; Mulholland, 1992) and thereby helped in purifying stream water. Algae require carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, magnesium, iron, potassium, various other cations, and a number of trace elements to carry out the metabolic processes necessary for

their growth. Compared with higher plants, most algae contained high concentrations of essential nutrients and low concentrations of structural compounds and phenols that resisted and inhibited digestion respectively (Hill *et al.*, 2011). Macroalgae are known to possess good biosorptive properties and has been used in waste water management (Davis *et al.*, 2000). Rosell and Srivastava, (1985) reported that the total nitrogen, potassium and phosphorus content in *Macrocystis integrefolia* and *Nereocystis leutkeana* were high during fall-winter and low during spring summer. Micro and macro element of some fresh water algae collected from Hanna and Urak valley of Quetta was studied by Mudassir and Mansoor, (1999). Singh and Gupta, (2011) reported that the nutrient content of the same species of Lemanea fresh water filamentous red algae collected from different rivers in Manipur differed in different sites. The sequestration of metals by filamentous algae has been studied in both field and laboratory (Lawrence *et al.*, 1998; McHardy and George, 1990; Whitton *et al.*, 1989). Rai *et al.*, (1981); Stevens *et al.*, (2001); Das and Ramanujam, (2011) reported that the metal contents sequestered by *Klebsormidium* species was more in the algal biomass than in the ambient water. Mulbry and Wilkie, (2001) reported that the benthic freshwater algae growing on dairy manures contained approximately 1.5–2% phosphorus and 5–7% nitrogen. Stelzer and Lamberti, (2001) studied the effect of N: P ratio and total nutrient concentration in periphyton community structure, biomass and chemical composition in stream, and reported that nitrogen and phosphorus percentage

in periphyton increased with the increase in those two nutrients in stream water.

Substantial contributions have been made on diversity of algae from Indian sub continent by many algologists of the country. Most of the studies concentrated on the phytoplanktons of lakes, pond and large rivers. Anand, (1998); Tejaswini and Vijaya, (2004); Vishnoi and Srivastava, (2004); Misra *et al.*, 2005; Jena *et al.*, 2006; Kumar, (2006); Sridhar *et al.*, (2006); Tiwari and Chauhan, (2006); Muthukumar *et al.*, (2007); Senthilkumar and Sivakumar, (2008); Kumar and Chaudhary, (2009); Makandar and Bhatnagar, (2010). In several river systems, the studies on algal communities have been reported by Sheeba and Ramanujan, (2005) on Ithikkara river in Kerala. Another study was reported by Nivedita and Hema, (2010) in Kosi river in Almora District, Baba *et al.*, (2011) on the periphytic algal community of Himalayan river Sindh, Selvin-Sameul *et al.*, (2012) in Tamraparani river in Tamil Nadu. Some other studies included algal diversity in Panzara river, Maharashtra (More & Nandan 2000), phytoplankton diversity in the hilly streams of Garhwal Himalaya (Sharma *et al.*, 2007), algal biodiversity and succession in Periyar river at Aluva, Kerala (Zacharias & Joy, 2007). An extensive study on the chlorococcales from Eastern and North-Eastern states of India has been carried out by Jena and Adhikary, (2007).

Among all the groups, blue green algae attained maximum attention by algologists all over the world including India due to its high practical importance and therefore most of the available works on algal communities

were centered on this group. Presence of high number of blue green algae characterizes eutrophic water bodies with high nutrient inputs (Sankaran, 2006; Gomathi *et al.*, 2011; Khare & Patil, 2011). Comparatively very less work has been carried out on desmids which were predominant in oligotrophic water (Vidyavati, 2007). A Few studies on this group were reported by Suxena and Venkateswaralu, (1968); Jena *et al.*, (2006); Panikkar *et al.*, (2012).

Literature on Indian diatoms are scanty. Major works on this group were contributed by Gandhi, (1998) and Desikachary, (1987, 1988). Juttner *et al.*, (2003) recorded the diversity and richness of diatoms from the streams of Eastern Himalaya. Jena *et al.*, (2006) recorded from Orissa and North East regions. From Tapti river, it was reported by Kavitha and Balasingh, (2007).

In North East India, reports on algal diversity are still meager. The literature available from this region included algal diversity in a few lakes and ponds. Besides, it included algae from rice fields of Tripura. Sharma, (2004), on the phytoplankton communities of a floodplain lake of Brahmaputra river basin in Upper Assam, Kumar and Rai, (2005), on Cyanophycean and Chlorophycean flora of Sikkim Himalayas, Saha *et al.*, (2007), on cyanobacterial species from freshwater streams of Kakoijana reserve forest, Assam; Das *et al.*, (2010), on algal taxa from different water bodies of Tripura, Sharma, (2009), on the composition, abundance and ecology of phytoplankton communities of Loktak Lake, Manipur and Yasmin *et al.*, (2011) from North East India lying in south of Eastern Himalaya are the other contributors.

Meghalaya is rich in aquatic resources but literature regarding the algal diversity is scanty. The literature available from the state are that of Biswas (1934); Alfred (1975); Ghosh, (1991); Rout, (1991); Sharma and Lyngdoh, (2003); Jena *et al.*, (2006) and Khumanthem *et al.*, (2007). Most recent works on this context were that of Ramanujam and Siangbood, (2009); Das *et al.*, (2009); Das and Ramanujam, (2010); Das and Ramanujam, (2011); Siangbood and Ramanujam (2011) and Ramanujam *et al.*, (2012).

## CHAPTER 3

### STUDY SITES

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The study was conducted in river Umiew located in Meghalaya state (20.1°-26.5° N, 85.49°-92.52° E) of North-Eastern India (fig. 3.1). Umiew river is basically the second order south-flowing major river in Meghalaya. The river is mostly used for drinking, washing and irrigation purposes. The river originates in Shillong peak in the East Khasi Hills at an altitude of 1912 msl and flows south of Shillong Peak over a total stretch of 400 km and finally enters Bangladesh. Umiew river is of vital importance to the state of Meghalaya particularly East Khasi Hills District as it provides water for consumption to greater Shillong and its neighbouring areas. The state experiences a typical humid subtropical climate. Annual rainfall in the region is high. The rainy season usually starts in mid May and continues till September. October and November are the transition months between rainy and winter seasons. The period between December and February is winter and is characterized by cold and dry weather. From March, it starts to get warmer and continues till mid May. The average annual rainfall recorded from 2008-2010 during the study period varied from 0 mm to 452.3 mm. January and February are total dry without any rainfall; and July (2009) was the wettest month with 452.3 mm rainfall. The total annual rainfall received during the study period was 2439.9 mm for the first year (April, 2008 to

March, 2009) and 1885.4 mm for the second year (April, 2009 to March, 2010) (fig. 3.1).

Four sites along the course of the river were selected for detailed study (fig. 3.2). These four sites differ in geomorphological characteristics (Table 3.1). The river is dominated by sequences of long boulders or cobble riffles interspersed with shorter runs and pools. At all the sites, the river bed consisted of silt to fine sand, granite and quartzite rocks ranging in diameter from a few centimeters to a few meters.

**Site-1.** The location of this site is known as Pamlakrai (S-1). Here the river flows through two hillocks on either side. The river in this site is narrow and shallow. The depth and width of the river at this site is only a few centimeters to a few meters respectively. The river passes through a shaded area. The river bed is clearly visible where light can penetrate even to the bottom sediments (fig. 3.3A).

**Site-2.** This site is located downstream (5 kms) of Pamlakrai. This location is known as Nongkrem (S-2). The river in this location runs through agricultural catchment area where during rainy season, abundant agricultural wastes are deposited into the river bed. The river passes through open area throughout since no trees were found growing along the river course except some small shrubs and herbs. River in this site is 5-7 m wide and 0.2- 0.4 m deep. Water is highly transparent due to low depth (fig. 3.3B).

**Site-3.** As the water flows further downstream (8 kms), it reaches a location known as Umtyngngar (S-3). Here the river joins with another river (river Umtyngngar) whereby the width of the river increases. It becomes 16-18 m



**Figure 3.3: View of River Umiew in Pamlakrai (A) and Nongkrem (B)**

wide and 0.4- 0.6 m deep. The water here is highly turbid and the river bed is slushy due to deposition of silts and remains of limestone quarrying carried over by river Umtyngngar from upstream. As the river Umtyngngar converges with river Umiew, the color of the river water changes to milky green (fig. 3.4A).

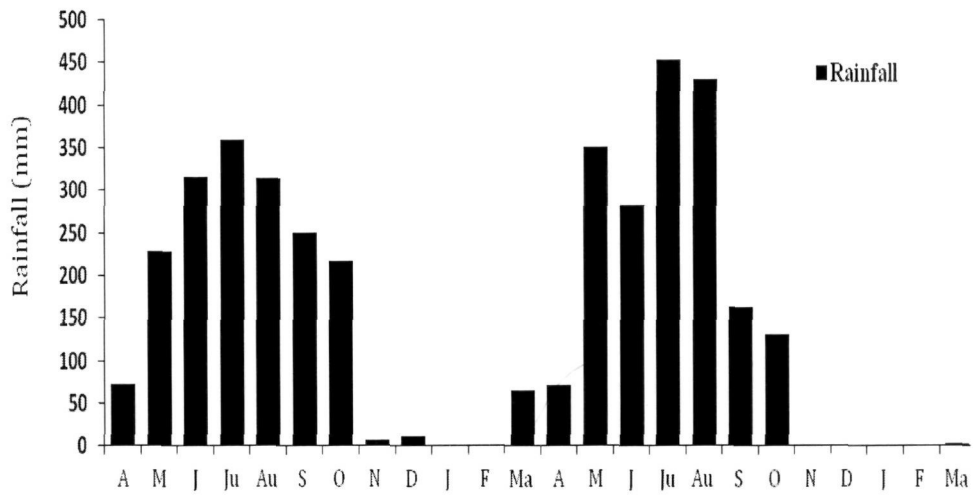
**Site-4.** This site is located in Mawphlang, 13 kms downstream of Umtyngngar. In this location, a concrete dam has been constructed for the purpose of supplying drinking water to the whole Shillong city under the Greater Shillong Water Supply Scheme (fig. 3.4B). Therefore, this particular site is completely different from the other three sites. Here, the free flowing river is suddenly obstructed, making the river very wide (60-70 m) and deep (0.4-100 m). Samples from this site were collected from the river bank only where the water level was low.

**Table 3.1. Physiography of the study sites.**

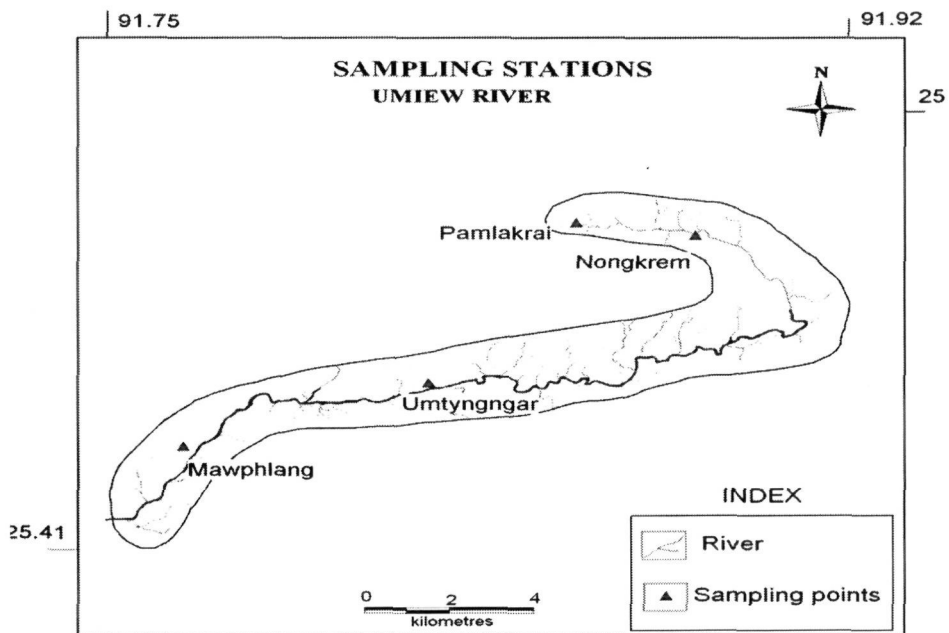
Sites	Pamlakrai (S-1)	Nongkrem (S-2)	Umtyngngar (S-3)	Mawphlang (S-4)
Coordinates	25°31'45.6"N	25°30'34.3"N	25°27'58.0"N	25°26'45.0"N
	91°52'30.44" E	91°53'10.1" E	91°49'34.53" E	91°45'57.4" E
Elevation (m)	1808	1768	1673	1584
Depth range (m)	0.12-0.18	0.23-0.35	0.42-0.58	0.46-100
Width (m)	1.2-2.5	5.3-7.3	16.23-18.48	60-70
Colour	Clear	Clear	Turbid	Clear



**Figure 3.4: View of River Umiew in Umtyngngar (A) and Mawphlang (B).**



**Figure 3.1: Rainfall pattern (mm) during the study periods (from April 2008-March 2010).**



**Figure 3.2: Map showing the locations of the study sites in Umiew river.**

## CHAPTER 4

### ASSESSMENT OF PHYSICO-CHEMICAL CHARACTERISTICS OF UMIEW RIVER

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#### 4.1. INTRODUCTION

Water resource is one of the major components of environmental resources threatened by overexploitation and pollution due to human activity. Physico-chemical parameters of any aquatic environment immensely influence the distribution, richness and biological productivity (Imevbore, 1970; Courtney & Clement, 1998; Unanam & Akpan, 2006). Knowledge of physico-chemical parameters provide information on the productivity of water resources and present better understanding of the survivability of the biotic organisms (Adebisi, 1981; Boyd & Lichtkopeller, 1985; Ayodele & Ajani, 1999; Offem & Ikpi, 2011). Any alteration in physico-chemistry of water contributes to several systematic changes in fresh water ecosystems (Postel, 2000; Daniels *et al.*, 2002). The dynamics and species diversity of algal communities, the primary producers of any aquatic system, are greatly influenced by the physico-chemical and other biological factors of water (Reynolds, 1984; Harris, 1986; Sommer, 1989). Changes in physical and chemical parameters in fresh water systems bring serious threat to ecosystems (Dallas & Day, 2004; Palmer *et al.*, 2004, 2005).

Anthropogenic activities are very common within and along the river systems in tropical countries (Mathooko, 2001). Such activities showed serious impact in deteriorating water quality (Mokaya, 2000). Unplanned urbanization, deposition of domestic and industrial effluents, increased nutrients due to reckless use of pesticides and fertilizers and silt load from the catchment, increased fine sediment concentrations in the rivers. In addition, accidental spillages through mining and quarrying were the other main causes for water quality deterioration (Drew, 1999; Rashid & Romshoo, 2012). Assessment of water quality in relation to its biotic components is very crucial for formulating water monitoring programme.

Meghalaya harbors a number of streams and rivers which serve the purpose of drinking water and irrigation. Umiew river is one of the main rivers in the state supplying water to greater Shillong. Due to deposition of agricultural run-off, remains of lime quarrying from the catchment areas, the river has undergone changes in its physical and chemical characteristics. The present work was undertaken to understand the extent of change in the physico chemical characteristics of the river water.

## **4.2. MATERIALS AND METHODS**

### **4.2.1. Water Sampling and Analysis**

Sampling of water from four selected sites of the river Umiew was carried out in the first week of every month from April 2008 to March 2010. Surface water samples (5 replicates) were collected in 1 litre polyethylene bottles and brought to the laboratory for analysis. In situ data measurement for temperature, pH, dissolved oxygen (DO), conductivity and turbidity were recorded using deluxe soil and water analysis kit (Model-191E). Parameters like calcium (Ca), magnesium (Mg) and chloride (Cl) were analyzed immediately after bringing the water sample to the laboratory. For estimation of nitrate (NO<sub>3</sub>), nitrite (NO<sub>2</sub>), phosphate (PO<sub>4</sub>) and silicate (SiO<sub>2</sub>), the water samples were stored in ice. Collection of water samples and their analysis were carried out following standard methods (APHA, 2005). The methods followed are summarized below.

**Depth and width (meter):** Depth and width of the river were measured with the help of a meter tape and a scale.

**Water Current (m/sec):** The velocity of current of the river was measured by using a float, a stop clock and a measuring tape. A float was released from a fixed point and allowed to float along with the water current for 30 seconds. The distance covered within 30 seconds from the fixed point was measured using a

measuring tape. The velocity of current of river water was calculated by using the equation given below.

$$\text{Water current (m/sec)} = \frac{T}{D} \text{ where,}$$

T = Time and D = Distance covered

**Calcium (mg/l):** Calcium was estimated by titrating against 0.01N standard EDTA with murexide as indicator. In this method, 1 ml of NaOH was added to 50 ml water sample to raise the pH to 12 and a pinch of murexide indicator was added. The solution turned to pinkish colour and when titrated with 0.01N EDTA, changed to purple. The amount of calcium present in water sample was calculated by using the following formula.

$$\text{Calcium (mg/l)} = \frac{T \times 400.5 \times 1.05}{V}$$

Where, T = Volume of titrant (ml)  
V = Volume of sample (ml)

**Magnesium (mg/l):** Magnesium was determined by calculating the difference between the total hardness and the calcium hardness of the sample.

$$\text{Magnesium (mg/l)} = \text{Total hardness (mg/l)} - \text{calcium (mg/l)}$$

**Chloride (mg/l):** Chloride in water was estimated by the argentometric method. In this method, 10 ml of the sample was taken and 5-6 drops of potassium

chromate indicator was added. The solution turned yellow and when titrated with 0.0141N AgNO<sub>3</sub> solution, the yellow coloured solution appeared brick red at the end point.

$$\text{Chloride (mg/l)} = \frac{V \times N \times 35.5 \times 1000}{S}$$

Where, N = Normality of AgNO<sub>3</sub>  
V = Volume of titrant (ml)  
S = Volume of sample (ml)

Nitrate (mg/l): Nitrate estimation was done using the phenol disulphonic acid (PDA) method. 50 ml water sample was evaporated to dryness in a 200 ml conical flask over a hot water bath. 2ml of phenoldisulphonic acid was added to the residue. After 10 minutes the solution was diluted to 50 ml by adding distilled water. Nitrate reacted with 1, 2, 4 phenoldisulphonic acid, which formed an alkali salt and imparted yellow colour. The solution was kept for 5 minutes for the colour to develop and optical density was recorded at 410 nm. The concentration of nitrate was obtained directly from the standard curve prepared from standard potassium nitrate in a series of 0 to 2 mg/l.

Nitrite (mg/l): Nitrite in water was estimated by sulphanilamide method. In this method, 1ml of sulphanilamide solution was added to water sample. After 3 minutes, 1ml of N-(1-naphthyl) ethylenediamine dihydrochloride (NED-dihydrochloride) were added to it. The final volume was adjusted to 50 ml by adding distilled water and allowed to stand for a few minutes. Nitrite ion (NO<sub>2</sub><sup>-</sup>)

reacted with sulphanilamide to form a diazonium salt, which combined with NED-dihydrochloride to form a bright coloured pinkish red azo-dye which was measured spectrophotometrically at 543 nm. The concentration of nitrite in samples was obtained directly from the calibration curve.

Phosphate (mg/l): Phosphate was estimated by stannous chloride colorimetric method. 25 ml of filtered sample and cleared solution was taken in a test tube. 1 ml ammonium molybdate and 1 ml SnCl<sub>2</sub> were added to it. The test tubes were kept at room temperature for 10 minutes for blue colour to develop. Phosphate reacted with molybdate to form phosphomolybdic acids, which on reacting with SnCl<sub>2</sub> produced a blue coloured solution. The coloured solution was compared with reagent blank at 680 nm. The concentration of PO<sub>4</sub> (mg/l) was obtained from standard phosphate graph in a series of 0 to 1 mg/l.

$$\text{Calculation: Phosphate (mg/l)} = \frac{\text{mg of phosphate from curve} \times 1000}{\text{mL sample}}$$

Silicate (mg/l): Silica estimation was carried out by molybdosilicate method. In this method, 5 ml each of 0.25N HCl, 5% ammonium molybdate and Na<sub>2</sub>EDTA respectively were added to 10 ml water sample. After 5 minutes, 10 ml of Na<sub>2</sub>SO<sub>3</sub> was also added to the previous solution and was allowed to stand for 30 minutes to develop blue colour. The intensity of the blue colour solution was recorded spectrophotometrically at 700 nm and the concentration of silica in

water was determined from the standard curve prepared from sodium silicate solution in a series of 0 to 50 mg/l.

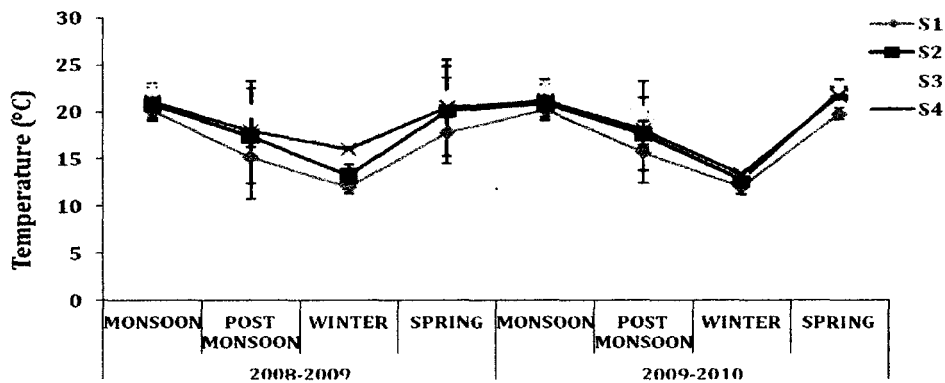
$$\text{Calculation: SiO}_2 \text{ (mg/l)} = \frac{\text{mg of SiO}_2 \text{ from curve} \times 1000}{\text{mL of Sample}}$$

#### **4.2.2. Data Analysis**

One-way analysis of variance (ANOVA) was applied to determine whether the variations in different water parameters in between sites and seasons were significant or not. Complete linkage hierarchical cluster analysis was also performed based on the physico chemical parameters to relate the similarity between sampling sites. All these analyses were performed by using software XLSTAT version 2009.

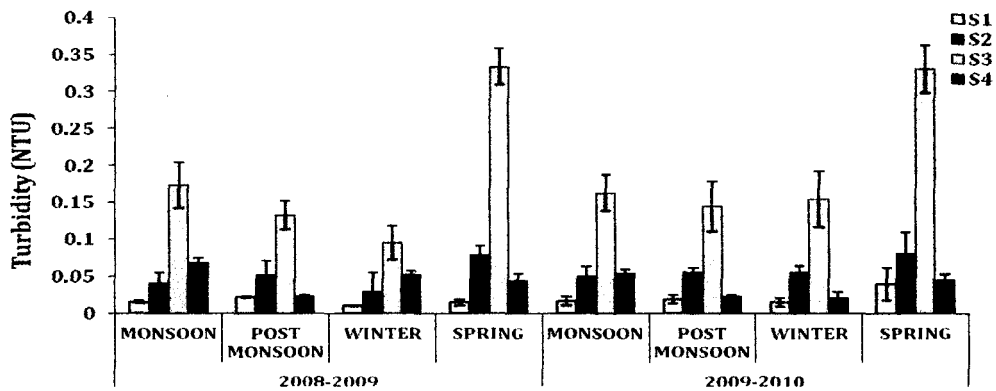
### **4.3. RESULTS**

**Water temperature:** The mean surface water temperature ranged between 11.3°C in winter and 24.8°C in spring and fluctuated spatially (fig. 4.1). The pattern of fluctuation in water temperature was similar in all the sites, decreasing marginally in the winter months and reaching its maximum value in spring. However, no significant variations were observed among the sampling sites although seasonal variations could be obtained (Table 4.2).



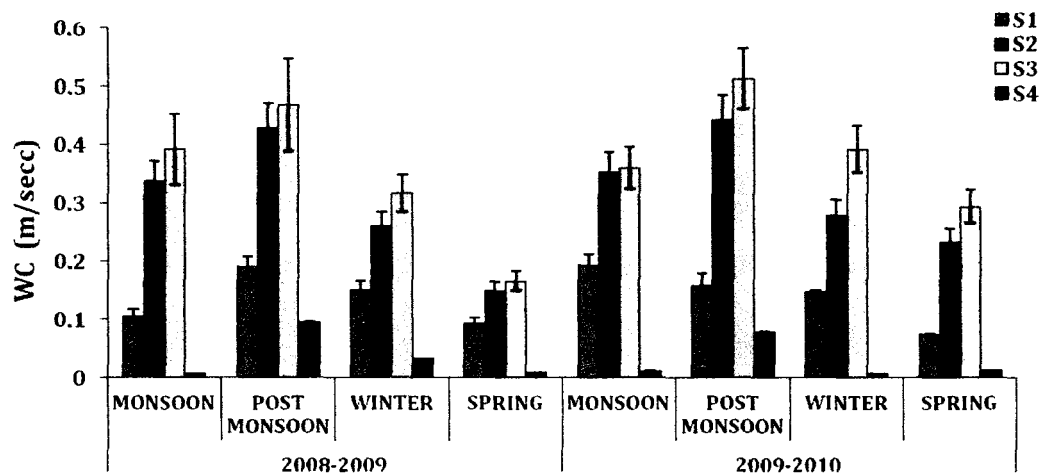
**Figure 4.1: Seasonal variations in water temperature (°C) in four sites in Umiew river. Error bars represent standard deviation.**

Turbidity: Turbidity value was maximum in site 3 during spring season when water current was very low, with a range of 0.09 to 0.33 NTU (fig. 4.2). In sites 1, 2 and 4 turbidity value remained almost the same (0.01 NTU to 0.07 NTU) throughout the year. Significant variations were observed among the sites (Table 4.2).



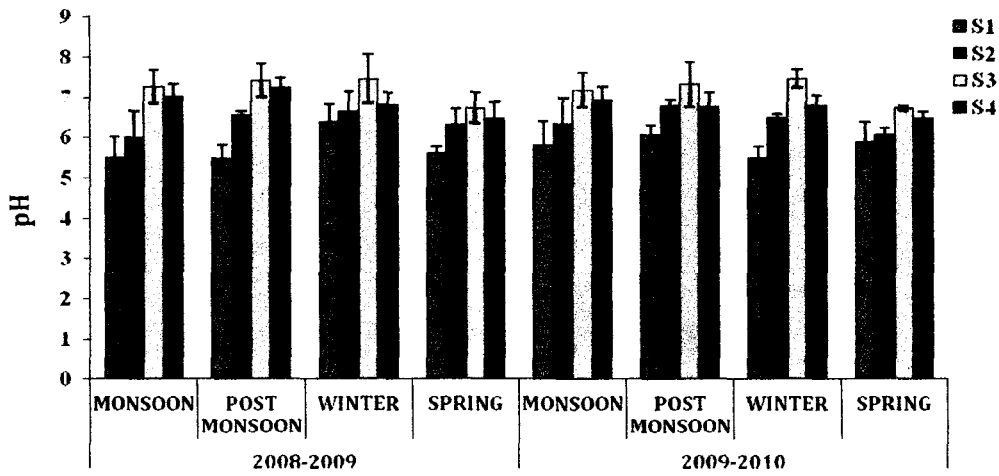
**Figure 4.2: Seasonal variations in turbidity (NTU) in four sites in Umiew river. Error bars represent standard deviation.**

Water current: The mean flow rate in the river was maximum during rainy season in all sites and was minimum in spring. Maximum velocity of current was recorded in site 3 with a mean value of 0.53 m/sec followed by site 2 (0.51 m/sec) while minimum flow was recorded from site 4 (0.01 m/sec) where the velocity of current was negligible (fig. 4.3). Significant variations in WC were observed in between sites but not in between seasons (Table 4.2).



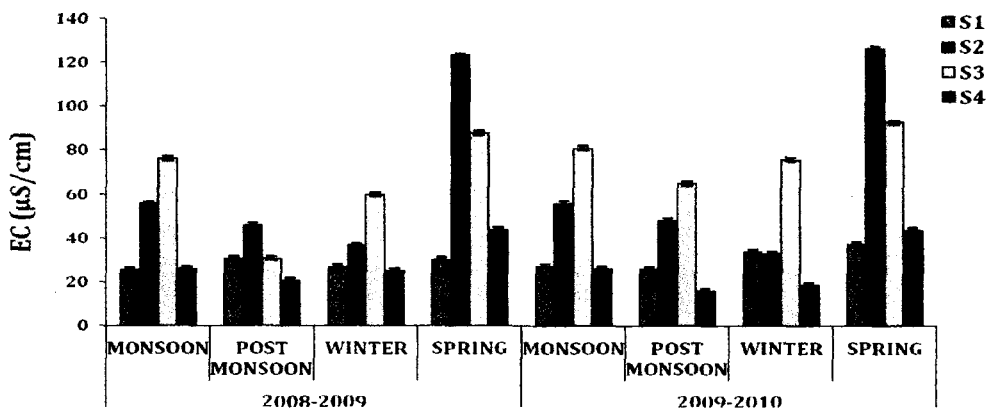
**Figure 4.3: Seasonal variations in water current (m/sec) in four sites in Umiew river. Error bars represent standard deviation.**

pH: The pH value ranged from acidic to alkaline with a range of 5.30 to 7.46 (fig. 4.4). Mild acidic pH was recorded from site 1 and slightly alkaline pH was recorded from site 3. Alkaline pH was observed in site 3 in all the seasons. No significant seasonal variations in pH could be observed but significant variations could be recorded in between sites (Table 4.2).



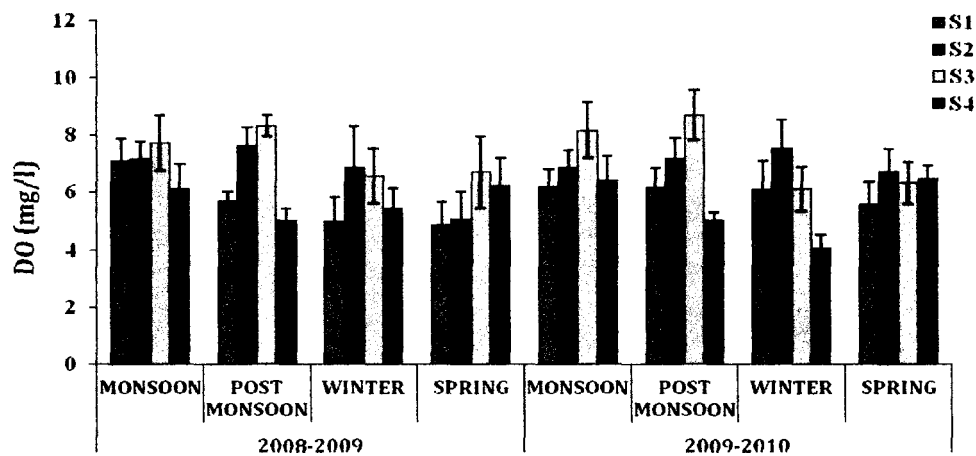
**Figure 4.4: Seasonal variations in water pH in four sites in Umiew river. Error bars represent standard deviation.**

Electrical conductivity: Electrical conductivity was maximum in site 2 during spring with a mean value of 126  $\mu\text{S}/\text{cm}$ . It was minimum in site 4 during winter with a mean value of 16  $\mu\text{S}/\text{cm}$  (fig. 4.5). No significant temporal and spatial variation in EC was observed during the study period (Table 4.2).



**Figure 4.5: Seasonal variations in electric conductivity ( $\mu\text{S}/\text{cm}$ ) in four sites in Umiew river. Error bars represent standard deviation.**

Dissolved oxygen: Dissolved oxygen content ranged from 4.07 to 8.64 mg/l. Dissolved oxygen concentrations generally increased with rain. Maximum dissolved oxygen value was recorded from site 3 during post monsoon season and minimum during winter in site 4 (fig. 4.6). No temporal and spatial significant variation in dissolved oxygen was observed (Table 4.2).

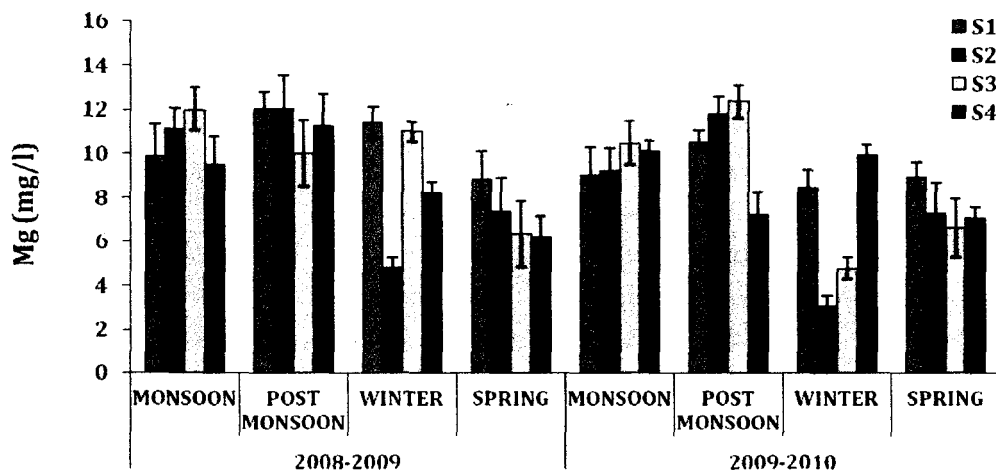


**Figure 4.6: Seasonal variations in dissolved oxygen (mg/l) content in four sites in Umiew river. Error bars represent standard deviation.**

Calcium and Magnesium: Calcium and magnesium were common constituents of natural water and important contributor to the hardness of water. Calcium content ranged from 7.63 to 24.37 mg/l. Calcium was relatively higher in site 3 in all the seasons and varied significantly from all other sites. Magnesium content ranged from 3.04 to 12.36 mg/l (fig. 4.7 and 4.8) and significant temporal changes in between sites could be observed (Table 4.2).

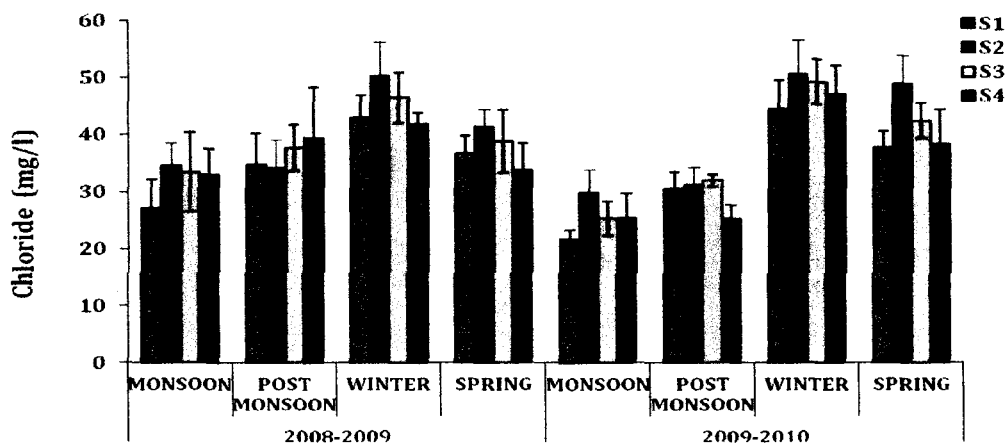


**Figure 4.7: Seasonal variations in calcium (mg/l) content in four sites in Umiew river. Error bars represent standard deviation.**



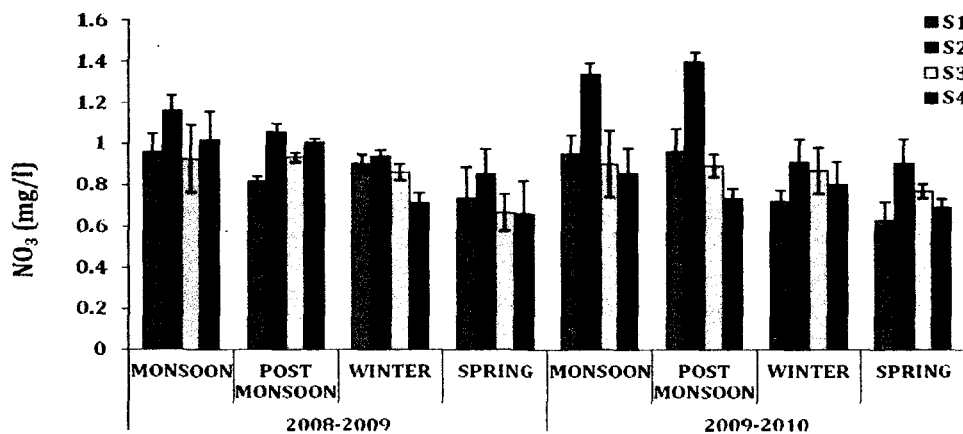
**Figure 4.8: Seasonal variations in magnesium (mg/l) content in four sites in Umiew river. Error bars represent standard deviation.**

Chloride: Chloride content in Umiew river ranged from 21.56 to 50.59 mg/l. Maximum value was recorded from site 2 during winter season and minimum in site 1 during monsoon (fig.4.9). However, distribution of chloride varied significantly among different seasons (Table 4.2).



**Figure 4.9: Seasonal variations in Chloride (mg/l) content in four sites in Umiew river. Error bars represent standard deviation.**

Nitrate and Nitrite: Nitrate and nitrite content were higher in site 2 where maximum value (1.39 and 0.21 mg/l respectively) was recorded during high rainfall season and minimum in site 1 and 4 during spring seasons (fig. 4.10 and 4.11). Significant seasonal variations were observed during the study period (Table 4.2).



**Figure 4.10: Seasonal variations in nitrate (mg/l) content in four sites in Umiew river. Error bars represent standard deviation.**

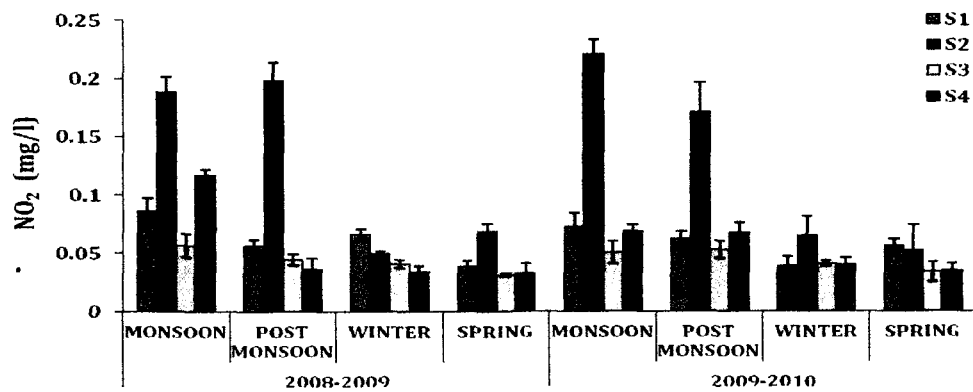


Figure 4.11: Seasonal variations in nitrite (mg/l) content in four sites in Umiew river. Error bars represent standard deviation.

Phosphate: Phosphate varied from 0.13 to 0.52 mg/l. Maximum value was recorded from site 3 and site 4 during high rainfall season whereas minimum value was recorded from site 1 during winter season (fig. 4.12). Seasonal variations observed were only found to be significant during the study period (Table 4.2).

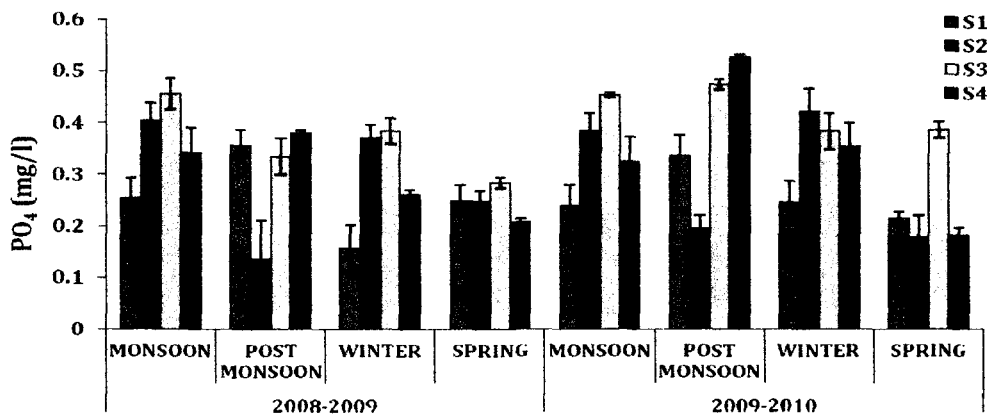
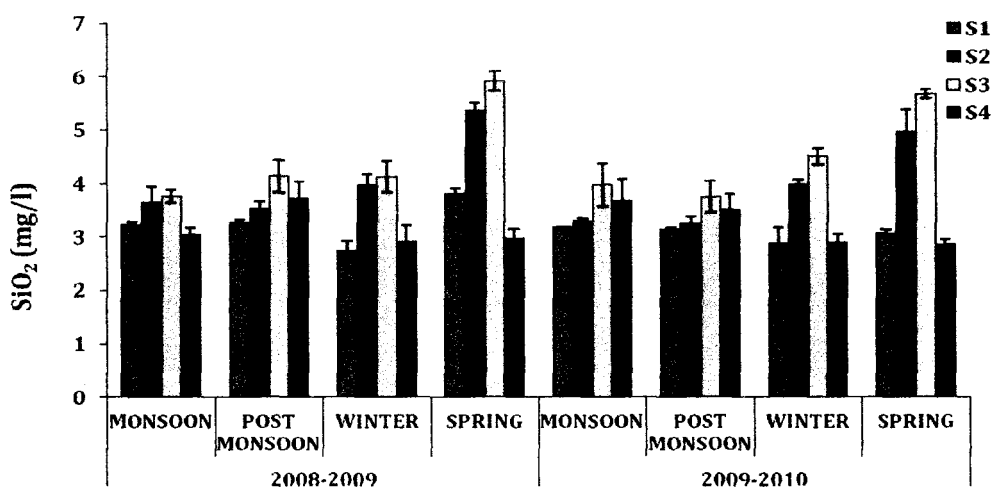


Figure 4.12: Seasonal variations in phosphate (mg/l) content in four sites in Umiew river. Error bars represent standard deviation.

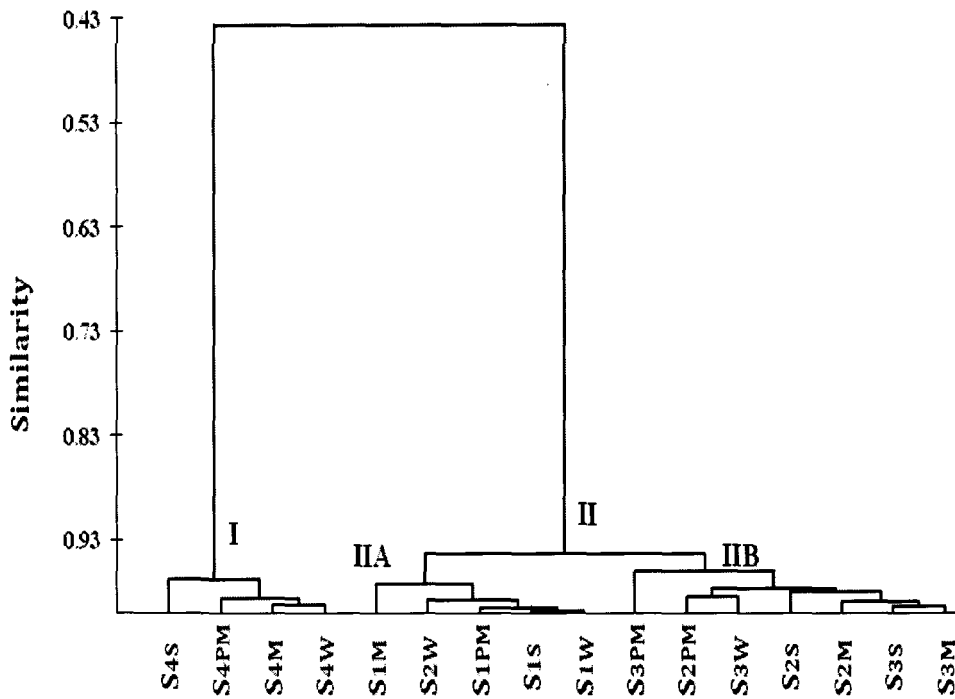
Silicate: Silica content varied significantly among the sampling sites and seasons. It ranged from 2.74 to 5.79 mg/l (fig. 4.13). Maximum content was recorded from site 3 during a period of low flow in spring season and minimum value was recorded from site 1 in winter (Table 4.2).



**Figure 4.13: Seasonal variations in silicate (mg/l) content in four sites in Umiew river. Error bars represent standard deviation.**

The cluster dendrogram based on physico-chemical characteristics of river water in different sites revealed the formation of two main clusters, cluster I and II (fig. 4.14). Cluster I formed a separate cluster of site 4. Cluster II were further subdivided into two sub clusters IIA and IIB respectively. Sub cluster IIA on the dendrogram combined five samples (all the four samples collected from all the season from site 1 and one from site 2 collected during winter). Sub cluster IIB combined seven samples (all the four samples collected from all the

season from site 3 and three samples from site 2 collected during spring, monsoon and post monsoon respectively).



**Figure 4.14: Cluster dendrogram showing similarities between sampling sites based on physico-chemical characteristics of river water in different seasons. S= spring; M= monsoon; PM= post-monsoon; W= winter; S1, S2, S3, S4 indicates sampling sites.**

**Table 4.1: Physico chemical parameters in river Umiew in four different sites with average ranged value.**

Parameters	Study Sites			
	Site 1	Site 2	Site 3	Site 4
Temperature (°C)	11.9 – 20.66	12.81-21.93	14.03 -21.61	13.35 -21.61
Turbidity (NTU)	0.01 – 0.04	0.03 – 0.08	0.09 – 0.33	0.02 – 0.07
WC (m/sec)	0.07 – 0.19	0.15 – 0.44	0.17 – 0.51	0.001 – 0.09
pH	5.47 – 6.39	6.02 – 6.8	6.72 – 7.46	6.47 – 7.24
EC (µS/cm)	25.5 -37.33	33.0 -126.66	31.0 -93.0	16.0 – 44.0
DO (mg/l)	4.87 – 7.09	5.06 -7.6	6.1 – 8.67	4.07 – 6.41
Ca (mg/l)	7.67 – 12.32	12. 7 – 19.6	15.4 – 24.47	8.5 – 16.59
Mg (mg/l)	8.44 – 12.05	4.81 -11.81	4.77 – 12.36	6.18 -11.22
Cl (mg/l)	21.56 -44.44	29.84 -50.59	25.26 -49.17	25.17 -47.04
NO <sub>3</sub> (mg/l)	0.63 -0.96	0.85 -1.39	0.66 -0.93	0.66 -1.01
NO <sub>2</sub> (mg/l)	0.03 -0.2	0.04 -0.42	0.03 -0.25	0.025 -0.205
PO <sub>4</sub> (mg/l)	0.15 -0.35	0.13 -0.42	0.28 -0.47	0.18 -0.52
SiO <sub>2</sub> (mg/l)	2.74 – 3.8	3.25 -5.35	3.75 -5.90	2.85 -3.73

**Table 4.2: One-way ANOVA of physico-chemical parameters to assess the variations in between sites and seasons in two consecutive years.**

	First year				Second year			
	Sites		Seasons		Sites		Seasons	
	F-Value	p-Value	F-Value	p-Value	F-Value	p-Value	F-Value	p-Value
Temperature	1.00	0.42	13.09*	0.0004	0.25	0.85	20.2*	0.0000
pH	14.25*	0.001	0.76	0.546	9.092*	0.005	0.85	0.5022
EC	3.02	0.07	1.74	0.21	2.69	0.11	1.28	0.32
WC	4.96*	0.03	0.892	0.485	22.97*	0.0003	0.2295	0.873
Turbidity	4.14*	0.047	0.064	0.60	8.25*	0.0078	0.473	0.70
DO	0.87	0.49	2.31	0.15	0.42	0.74	2.98	0.096
Ca	18.94*	0.0005	0.22	0.87	9.49*	0.005	0.38	0.77
Mg	0.34	0.79	8.21*	0.007	0.55	0.65	6.47*	0.015
Cl	0.34	0.79	8.13*	0.008	0.32	0.8	26.58*	0.0001
NO <sub>2</sub>	0.78	0.53	6.44*	0.015	3.04	0.09	0.79	0.53
NO <sub>3</sub>	1.8	0.224	2.18	0.16	0.52	0.679	5.34*	0.025
PO <sub>4</sub>	0.54	0.66	27.71*	0.0001	0.15	0.92	25.69*	0.0002
SiO <sub>2</sub>	3.40	0.05	1.61	0.23	4.07	0.04	0.59	0.627

\* indicates significant different at  $p < 0.05$

### 3.4. DISCUSSION

The variations observed in physical and chemical parameters of water collected from different points of river Umiew clearly indicated that anthropogenic activities like deposition of agricultural waste and deposition of remains of lime quarrying has resulted in a change in water quality of the river. Veraart *et al.*, (2008) reported that PO<sub>4</sub> and NO<sub>3</sub> concentration in a forested oligotrophic stream was 0.013 to 0.455 mg/l respectively. Water temperature followed a seasonal trend and coincided with the ambient air temperature. Similar seasonal variations had also been reported by Adebowale *et al.*, (2008) in Nigerian water and Yadav and Srivastava, (2011) in river Ganga at Varanasi.

Dissolved oxygen content which played a vital role in supporting aquatic life and was vulnerable to slight environmental changes has been considered as an important limnological parameter indicating level of water quality and organic pollution in the water body (Wetzel & Likens, 2006). Fakayode, (2005) used dissolved oxygen as a parameter in defining water quality and to evaluate the degree of freshness of a river. In the present study, significantly high water current during monsoon and post monsoon seasons due to heavy rainfall enhanced the dissolved oxygen in the river. The presence of huge rocks in site 3 enhanced turbulency of flowing water and promoted gaseous interchange between the atmosphere and water resulted in increased dissolved oxygen levels. Comparatively higher dissolved oxygen during rainy season was in agreement with the findings of Deekae *et al.*, (2010). Elevated dissolved

oxygen concentration in flowing water as compared to stagnant water was also observed by Gandaseca *et al.*, (2011).

In the present case, the turbidity value in general was low and found to be less than 0.33 NTU. Turbidity value in site 3 only was found to be significantly high especially in spring when the water level was low. This high level of turbidity was caused by suspended matters such as clay, silt owing to surface-runoff and quarrying of sand and lime from upstream of the river. Maximum turbidity in spring could be due to low water flow. Rosli *et al.*, (2010) reported that turbidity value of water below 25 NTU was acceptable for domestic use.

High electrical conductivity in site 2 could be attributed to high ion concentrations due to low vegetation cover and addition of agricultural surface run off to river water during heavy rain. The mild acidic nature of river water in site 2 (5.67 to 6.80) could be due to addition of soil Agro-chemicals by farmers, such as fertilizers and pesticides, which got released to ground and surface and thus lowered the pH of the water. Slightly alkaline pH in site 3 and 4 were probably due to lime quarrying upstream of Umtyngngar and addition of remains of quarrying might have raised the pH of the river water from acidic to alkaline at which points. Rymbai *et al.*, (2012) reported a considerably high electrical conductivity and low pH (acidic) due to agricultural land-use systems in Umbanium micro watershed. Addition of runoff from neighbouring agricultural land could be attributed as the possible explanation for the increased

electrical conductivity in site 2 of the river where micronutrients leached from the neighbouring agricultural soil and reached the river with rain water.

Calcium and magnesium are the most abundant cations found in surface water determining the total hardness of water. A relatively high value of calcium and magnesium in site 3 signified the presence of dolomite limestone rocks upstream of the river which was eroded and deposited downstream (Gupta, 2010). Limestone is composed of calcium carbonate ( $\text{CaCO}_3$ ), and over a period of time calcium carbonate got dissolved in water as  $\text{Ca}^{2+}$  and  $\text{CO}_3^{2-}$  ions (Baird & Cann, 2005). In the present study, this process of breaking down of calcium carbonate might have enhanced the concentration of calcium in the river water in site 3. Though calcium values were relatively high in Umiew river compared to other rivers in the state like Umkhras river in Shillong (Murugan, 2008) and Um-Myntdu of Jaintia Hills (Lyngdoh & Kayang, 2012), however, higher value has also been recorded in some Nigerian river water (Ogbeibu & Edutie, 2002; Ebadin, 2006). Both calcium and magnesium values were found to be minimum during winter and spring and maximum during rainy season which was contradictory to the findings reported by Saha *et al.*, (2000) in Narayani river in Nepal and Singh *et al.*, (2009) in Iril river of Manipur.

High concentration of chloride of water was considered as an indicator of pollution in Mattupalayam Taluk in Tamil Nadu (Venkatasubramani & Meenambal, 2007). Chloride content in river Umiew was found to be low and within the permissible limit for drinking water. However, among the 4 sites,

chloride concentration was high in site 2 during winter compared to other sites. Higher concentration of chloride could be due to addition of runoff from surrounding agricultural fields and discharge of domestic sewage. Khan *et al.*, (1978) and Mahananda *et al.*, (2010) reported increased chloride level in surface and ground water in Chartal pond in Bargarh District of Orissa. Other sources of chloride could be the extensive use of organic manures like cowdung for farming. In the present study, the level of chloride recorded from river Umiew was similar to the findings of Tiwari *et al.*, (2004) in Shahpura Lake, but was lower than the level reported by Murugan, (2008) from Umkhras river in Shillong.

In the present study, higher level of phosphate, nitrate and nitrite during rainy seasons in site 2 could be related to various anthropogenic activities like farming and addition of sewage from neighbouring areas and extensive use of fertilizers and pesticides in the agriculture and horticulture lands. Similar results were reported by Chapman and Krammer, (1991) in a tropical dry forest stream in Santa Rosa National Park, Costa Rica and Akin-Oriola, (2003) in Ogunpa and Ona river in Nigeria. This finding could be further confirmed by the presence of comparatively low level of nitrogen and phosphorus concentration in river Umiew in dry season due to little or no addition of runoff into the river from the neighbouring areas, because of low or no precipitation. Higher nitrogen level in rainy season in site 2 could also be related to high water flow in rainy season. Nutrients entered the water body in the form of agricultural runoff and

significantly increased nitrogen concentrations in water. Similar findings were also reported by Turner and Rabelais, (1991); Carpenter *et al.*, (1998); Donner *et al.*, (2002); Royer *et al.*, (2004) and Kumar *et al.*, (2012). Davies *et al.*, (2008) reported that Nigerian surface water rarely contained as much as 5 mg/l of nitrate. However, in areas where inorganic fertilizers were used, nitrate in water could go up to 1000 mg/l. Nitrogen content in river Umiew has been found to be still within the permissible limit (10 mg/l as per WHO 2006). Veraart *et al.*, (2008) reported that phosphate and nitrate concentration in a forested oligotrophic stream was 0.013 to 0.455 mg/l respectively.

Phosphorus in natural surface water mostly ranged between 0.005 and 0.020 mg/l (Chapman & Kimstach, 1992). The phosphorus level in Umiew river was high in all the sites with maximum value in site 3 and 4 during rainy seasons. This condition was probably due to the use of phosphate fertilizers for agriculture (Singh *et al.*, 2010), resuspension from sediments (internal loading) and weathering of phosphorus bearing rocks and decomposition of organic matter which are the natural sources of phosphorus.

Silica has been reported as an important nutrient for the growth of algae mainly diatoms (Reynolds, 1984). Silica in natural water is primarily derived from the weathering of silicates and aluminosilicates in the bedrock and soils of an area (Berner & Berner, 1996; Drever, 1997). In our study, silica content ranged from 2.74 to 5.79 mg/l. Neil *et al.*, (2005) reported that silica content in United Kingdom surface water ranged from 0.7 to 7.6 mg/l. The source of silica

in the present case might be due to weathering of silica-rich rocks in the river bottom. Maximum silica content was recorded during spring season. Similar finding was also reported by Wright, (1982) in West African rivers and in forested stream of Shillong (Rout & Gaur, 1994).

The multivariate classification of the sampling sites based on the physico-chemical properties of the river water showed that sites 1, 2 and 3 were similar in their water qualities and thus have been grouped together (cluster II). It also clearly demonstrated that the site 4 (Mawphlang reservoir) was different from the other three sampling sites and formed a separate cluster (cluster I). The analysis of Umiew river water for different parameters clearly indicated that the river is oligotrophic with low level of nutrients and the nutrient level are within the acceptable limits for drinking purposes.

## **CHAPTER 5**

### **SEASONAL VARIATIONS IN ALGAL ASSEMBLAGES IN UMIEW RIVER**

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#### **5.1 INTRODUCTION**

Lotic ecosystems present a unique pattern of distribution of diverse biological communities represented by different taxonomic groups and in different regions (Allan & Flecker, 2003; Tundisi & Tundisi, 2008). In any aquatic environment, algae consisting mainly of phytoplankton and periphyton form the most significant source of primary production. Phytoplanktons float freely in the water column and thus are unable to maintain populations in fast flowing systems. They however, develop sizable populations in slow moving rivers and backwater. Periphytons are typically filamentous and tufted algae that could attach themselves to any substrate or object to avoid being washed away by fast current. In places where flow rates are negligible or absent, periphytons mostly form a gelatinous, unanchored floating mat (Stevenson *et al.*, 1996).

Algal communities in streams and rivers show seasonality as they respond to the changes in environment. Seasonal changes in algal communities usually depend on seasonal variations of ambient environmental factors (physical and nutrient concentration) prevailing in that area (Buzzi, 2002; Celekli & Kulkoyluoglu, 2007; Pilkaitite & Razinkovas, 2007). Generally, the

occurrence of algae in any aquatic ecosystem is not considered alone but in relation to the prevailing environmental conditions particularly the physico-chemical factors of the medium in which they grow (Ezra & Nawankwo, 2001; Davies *et al.*, 2009; Ramanujam & Siangbood, 2009). It is well documented that changes in pH, temperature, conductivity and nutrient concentrations in different aquatic systems led to the changes in diversity, abundance and succession of different algal communities (Barinova *et al.*, 2004; Zaloscar *et al.*, 2007).

Diversity and abundance of algal assemblages has since long been considered as indicator of water quality as they are known to reflect the ecological changes in the environment. The attached nature of periphytons and benthic algae made them particularly more useful in streams and rivers where it served as a reliable index for water quality measurement at a given sampling point (Colling & Weber, 1979). The presence of different algal groups in various aquatic systems indicated some level of pollution (Brook, 1965; Palmer, 1969, 80; Lobo *et al.*, 1996; Rott *et al.*, 1998; Sonneman *et al.*, 2001; Walsh *et al.*, 2001; Newall & Walsh, 2005; Hassan *et al.*, 2010). Thus the study of algal groups serves as useful means to detect the anthropogenic impact in any aquatic system at different time scale. In addition, it also provides a precise idea about the health of the ecosystem (Ector & Rimet, 2005). Recently, diatoms which form a large part of the benthic community (often 90%-95%) have drawn the attention of many algologists as a tool for water quality monitoring programme (Kelly & Whitton, 1995; Acs *et al.*, 2004; Potapova *et al.*, 2005). Such studies

have also drawn the attention of many Indian workers (Juttner *et al.*, 1996; Juttner *et al.*, 2003; Kumar *et al.*, 2008).

Information regarding the algal potential in Meghalaya is scattered and meager (Ramanujam & Siangbood, 2009) and most of the work is confined to only a few lentic water bodies. The present study thus is aimed to record the seasonal variations in diversity of algal communities in relation to its water quality in a lotic system i.e. in the river Umiew.

## **5.2. MATERIALS AND METHODS**

### **5.2.1. Sampling and analysis of water**

Water sampling and analysis was carried out following: APHA, (2005); and detailed methodology is mentioned in the previous chapter.

### **5.2.2. Sampling of planktonic algae**

Sampling of planktonic algae was carried out in all the four selected sampling sites. Planktonic algae were collected monthly from April 2008 to March 2010 by following the method given in APHA, (2005). The collected data were grouped into seasonal basis based on rainfall pattern prevailing in the area, i.e., monsoon (late May to August); post-monsoon (September to November); winter (December to February); spring (March to Early May).

### **5.2.2.1 Collection**

The planktonic algae were collected from the surface water by towing a plankton net having mesh size of 45  $\mu\text{m}$ . The collected samples were transferred into a 1 litre sample container which was washed thoroughly with field water.

### **5.2.2.2. Preservation**

Samples that required counting later were preserved immediately at the sampling site by adding Lugol's solution at a ratio of 1:100 (Vollenweider, 1969). This gave the sample a weak tea colour. Lugol's solution was prepared by mixing 20g of potassium iodide (KI) with 200 ml distilled water, followed by dissolving 10 g of pure iodine in the solution. Glacial acetic acid (20g) was added a few days before use (Schwoerbel, 1970). The stock solution was stored in the dark and well-ventilated space (Vollenweider, 1969) in a glass bottle that remained effective for at least a year. The fixed samples were brought to the laboratory and allowed to stand for 24 to 48 hours without disturbance to allow the planktonic algae to settle down.

### **5.2.2.3. Enumeration**

The preserved plankton samples were collected through centrifugation. 1 ml of the concentrated sample was transferred into Sedgwick-rafter counting chamber with the help of a dropper. The counting chamber was covered with a thin cover slip, taken care to avoid trapping of air bubbles inside. The planktons were

allowed to settle down for 15 minutes. Enumeration of the cells was done with the help of a trinocular light microscope (Olympus-BX41) and photographed by using a digital camera directly fitted to the microscope. Counting was carried out in replicates and the final result was expressed as number of cells/ml by following the formula mentioned below.

$$\text{Phytoplankton (Cells/ml)} = \frac{N \times C \times 1000}{L \times D \times W \times S \times V} \quad \text{Where,}$$

N = Number of organisms counted in 1 ml of concentrated sample

C = Total volume of concentrated sample (ml)

L = Length of strip of S-R Cell in which counting has been made (50 mm)

D = Depth of strip in S-R Cell (1mm)

W = Width of strip counted by Whipple grid, mm

S = Number of strips counted

V = Total volume of sample concentrated (ml)

### **5.2.3. Sampling of periphytic algae**

#### **5.2.3.1. Collection and preservation**

Periphytic algae were collected from different substrata like stones, rocks, pebbles, dead leaves and sediments with the help of scalpel and tooth brush. The samples were transferred into a 60ml poly ethylene sample container that had been washed thoroughly with field water. The algal samples were preserved in 4% formaldehyde and brought into the laboratory for qualitative and quantitative analysis.

### **5.2.3.2. Enumeration**

Enumeration was done by Lackey's Drop Method. In this method, 0.1 ml of sample was placed on a glass slide and covered with a piece of cover slip of known area in such a way that no air bubbles formed inside the cover slip. Algal samples were examined in temporary preparations under a trinocular microscope (Olympus-BX41) and photographed with the help of digital camera directly fitted to the microscope. For the enumeration of diatom, an aliquot of algal suspension from each sample was prepared by acid oxidation with concentrated sulfuric acid ( $H_2SO_4$ ), potassium dichromate ( $K_2Cr_2O_7$ ) and hydrogen peroxide ( $H_2O_2$ ) (Barber & Haworth, 1981). Permanent slides were made using Naphrax with refractive index of 1.74. Around 400 diatom valves were examined with a trinocular light microscope, measured and photographed.

### **5.2.3.3. Identification**

Taxonomic identification up to species level wherever possible were carried out with the help of floras and monographs. For non-diatom algae, monograph of Tiffani and Britton, (1952); Prescott, (1982); Desikachary, (1985); John *et al.*, (2002) were followed. For diatoms, monographs of Gandhi, (1998) and Krammer and Lange-Bertalot, (1986-1991) were followed and taxonomy was updated using the online database Algae Base (Guiry & Guiry, 2012) and ADIAC (Automatic Diatom Identification and Classification) Diatom image

database funded by the European Marine Science and Technology (MAST) programme.

#### 5.2.3.4. Data Analysis

**1. Shannon–Weaner diversity index (H')** - It was calculated by the following formula:

$$H' = \sum_{i=1}^s p_i \ln p_i$$

**2. Simpson's dominance index (D)** - It was calculated according to the following formula:

$$D = \sum_{i=1}^s \left( \frac{n_i}{N} \right)^2$$

**3. Pielou's evenness index (J)** – this index was calculated by the following formula:

$$J = \frac{H'}{\ln S}$$

**4. Species richness index (S)** – This was calculated as the total number of species present in a unit area.

Where,

S = total number of species

$p_i$  =  $n_i/N$  proportion of individuals of the total sample belonging to the  $i^{\text{th}}$  species.

$n_i$  = number of individuals belonging to the  $i^{\text{th}}$  species.

N = total number of individuals of all the species.

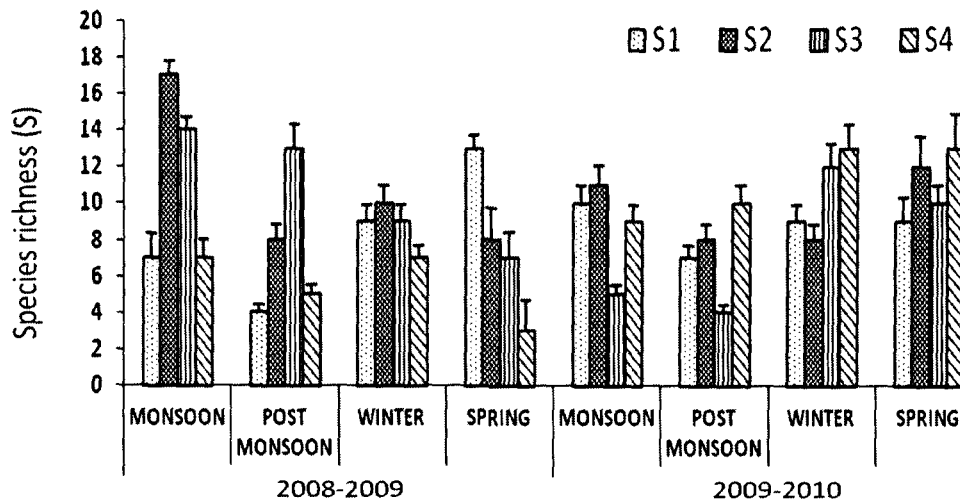
#### **5.2.3.5. Statistical analysis**

One way analysis of variance (ANOVA) was applied to compare the mean value of different attributes like species diversity, cell abundance and species richness of algal assemblages. Canonical correspondence analysis (CCA) a multivariate statistical analysis was employed to investigate how algal species responded to specific environmental variable. The data derived from analysis of algal samples were first screened to remove rare taxa. Species with a relative abundance of one or more than 3% was regarded as a rare taxon and were excluded from further analysis. Both the planktonic and periphytic algal species were considered for the analysis. Prior to the analysis, all environmental variables were log transformed and algal taxa were square root transformed in order to meet the assumptions of homoscedasticity. The statistical mean of each variable was tested with a Monte Carlo permutation test (500 permutations). Only significant variables ( $p < 0.05$ ) were included in the analysis. CCA could reduce the dimensionality of a complex data set and graphically summarized data in low dimensional diagrams. Environmental variables were displayed as arrows with species and sites as points in a CCA diagram. Arrow length represented the strength of the correlation between environmental variable and the ordination axes. Statistical significance was set at  $\alpha = 0.05$ . Complete linkage hierarchical cluster analysis was also performed based on the relative abundance data of algal species to relate the similarity between sampling sites. Software XLSTAT version 2009 was used for the statistical analysis.

### 5.3. RESULTS

#### 5.3.1 Phytoplankton assemblages

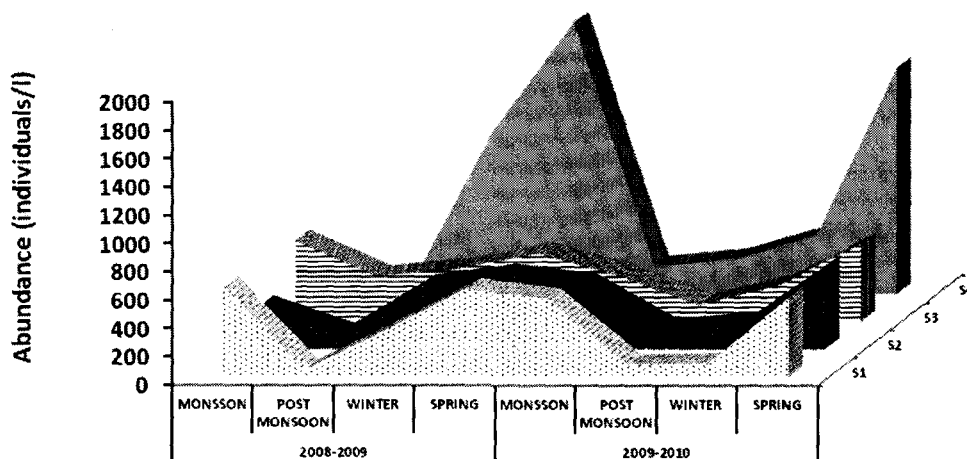
A total of 57 planktonic algal taxa were recorded in different seasons from 4 selected sites in Umiew river during 2 year period of study. Maximum planktonic algae were represented by members of Chlorophyceae with 23 species, followed by Bacillariophyceae with 19 species, Cyanophyceae with 9 species, Euglenophyceae with 5 species and Dinophyceae with 1 species. Species richness was maximum in site 3 with 29 species followed by site 2 (28 species), site 1 (21 species) and site 4 (12 species) respectively.



**Figure 5.1: Seasonal variations in planktonic Species richness (S) in four sites in Umiew river. Error bars represent standard deviation.**

Cell abundance was significantly high in site 4 where the river is more like a reservoir and with low water flow (fig. 5.2). Cell abundance ranged from 45 to

635 individuals/l in site 1, 120 to 575 individuals/l in site 2, 105 to 580 individuals/l in site 3 and 75 to 1920 individuals/l in site 4 respectively. Maximum cell abundance was recorded during spring season in all the sites where water flow was minimum. *Cyclotella pseudostelligera* Hustedt a centric diatom and *Scenedesmus obliquus* (Turpin) Kutzinger, a green alga was the most dominant planktonic species that contributed more towards the cell abundance.



**Figure 5.2: Seasonal variations in cell abundance (individuals/l) of planktonic algal assemblages in four sites in Umiew river.**

Species diversity ranged from 0.37 to 2.3 in site 1, 0.87 to 2.17 in site 2, 1.0 to 2.13 in site 3, 0.06 to 2.1 in site 4 respectively (fig.5.3). Maximum diversity value was recorded during post monsoon season in site 1. As the cell abundance of a few particular species increased, species richness and diversity decreased, thereby attaining its minimum value in site 4.

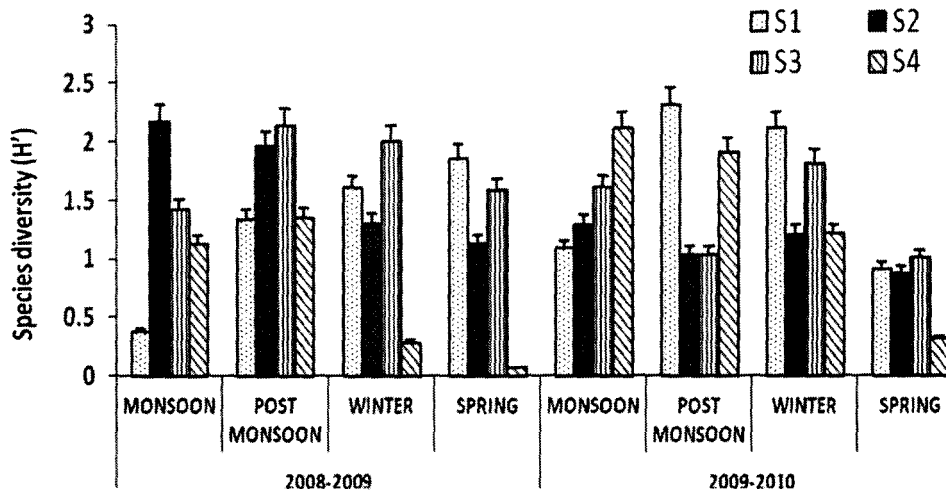


Figure 5.3: Seasonal variations in planktonic Species diversity ( $H'$ ) in four sites in Umiew river. Error bars represent standard deviation.

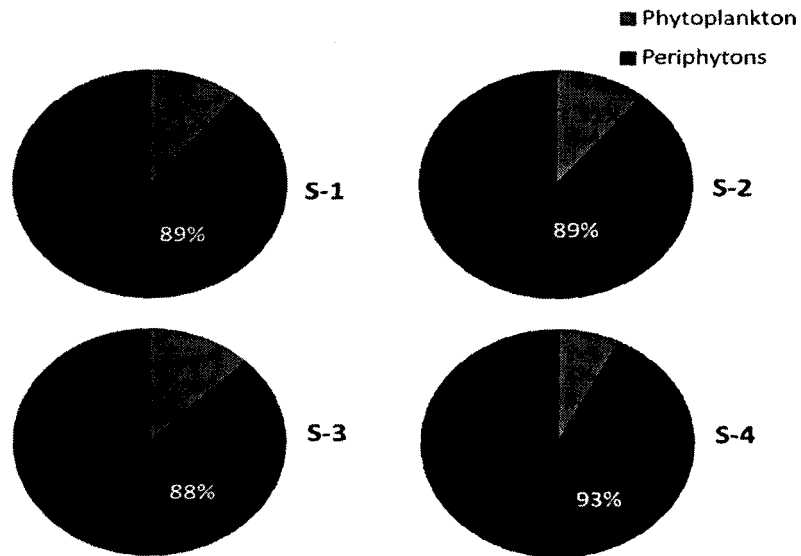


Figure 5.4: Proportion (%) of periphytic and planktonic algal assemblages from four sites in Umiew river.

The periphytons contributed 89% to 93% of the total algal community in river Umiew as compared to that of phytoplanktons which contributed only about 7% to 12 % (fig. 5.4).

### 5.3.2. Periphyton assemblages

A total of 346 algal taxa have been identified from Umiew river spreading over 8 families, out of which 151 species were recorded from Chlorophyceae, 112 species from Bacillariophyceae, 55 species from Cyanophyceae, 20 species from Euglenophyceae, 3 species from Chrysophyceae and 2 species each from Xanthophyceae, Dinophyceae and Cryptophyceae. List of all the algal species recorded are given in Table 5.1.

**Table 5.1: List of Algal species in four sites in Umiew river.**

<b>CHLOROPHYCEAE</b>	<b>S-1</b>	<b>S-2</b>	<b>S-3</b>	<b>S-4</b>
<i>Actinastrum</i> sp. Lagerheim	-	-	-	+
<i>Ankistrodesmus falcatus</i> (Corda) Ralfs	+	+	+	+
<i>Ankistrodesmus spiralis</i> (W.B.Turner) Lemmermann	-	+	+	+
<i>Apiocystis</i> sp. Nageli in Kutzing	-	+	-	-
<i>Asterococcus limneticus</i> G.M.Smith	+	+	+	+
<i>Bulbochaete</i> sp. C.Agardh	-	-	-	+
<i>Chaetophora pisiformis</i> (Roth) Agardh	+	+	+	-
<i>Chlamydomonas globosa</i> J. Snow	+	-	+	-
<i>Chlamydomonas reinhardtii</i> P.A.Dangeard	+	+	-	+
<i>Chlorella</i> sp. Beijerinck	+	+	-	+
<i>Chlorococcum</i> sp. Meneghini	+	+	+	-
<i>Cladophora</i> sp. Kutzing	-	+	-	-
<i>Closterium abruptum</i> West	-	+	+	-
<i>Closterium acerosum</i> (Skrank) Ehrenberg ex Ralfs	-	+	-	-

<i>Closterium attenuatum</i> Ralfs	-	+	-	+
<i>Closterium closterioides</i> var. <i>intermedium</i> (J.Roy et Bisset) Ruzicka	-	+	+	-
<i>Closterium cornu</i> Ehrenberg ex Ralf	+	+	+	-
<i>Closterium diana</i> Ehrenberg ex Ralfs	-	+	-	-
<i>Closterium directum</i> W. Archer	+	-	-	+
<i>Closterium gracile</i> Brebisson ex Ralfs	+	-	-	-
<i>Closterium gracillimum</i> Smith	-	-	+	-
<i>Closterium idiosporum</i> West et G.S West	+	-	-	-
<i>Closterium incurvum</i> Brebisson	-	+	+	-
<i>Closterium intermedium</i> Ralfs	+	-	-	-
<i>Closterium Kuetzingii</i> Brebisson	-	+	-	+
<i>Closterium leibleinii</i> Kutzing ex Ralfs	+	+	-	-
<i>Closterium littorale</i> F.Gay	-	+	+	-
<i>Closterium navicula</i> (Brebisson) Lutkemuller	+	+	-	-
<i>Closterium rostratum</i> G.W.Prescott	+	-	-	-
<i>Closterium sigmoideum</i> Lagerheim & Nordst	+	+	+	+
<i>Closterium striolatum</i> Ehrenberg ex Ralfs	-	-	+	-
<i>Coelastrum cambricum</i> W. Archer	-	+	+	-
<i>Coelastrum microsporum</i> Nageli in A.Braun	+	+	+	-
<i>Coelastrum pseudomicrosporum</i> Korshikov	-	+	+	+
<i>Cosmarium amaenum</i> Brebisson ex Ralfs	-	-	+	-
<i>Cosmarium angulosum</i> Brebisson	-	+	-	-
<i>Cosmarium angulosum</i> var. <i>concinnum</i> (Rabenhorst) West and G.S.West	-	+	-	-
<i>Cosmarium awadhense</i> Prasad et Mehrotra	+	-	-	-
<i>Cosmarium bidentatum</i> W.B. Turner	-	-	-	+
<i>Cosmarium bioculatum</i> Brebisson ex Ralfs	-	+	-	-
<i>Cosmarium circulare</i> Reinsch var. <i>messikimeri</i> Krieger et Gerloff	+	+	+	+
<i>Cosmarium connatum</i> Ralfs	+	-	-	-
<i>Cosmarium cucumis</i> Corda ex Ralfs	-	-	+	-
<i>Cosmarium cucurbita</i> Brebisson	+	+	+	+
<i>Cosmarium decoratum</i> West and G.S.West	+	-	-	-
<i>Cosmarium hammeri</i> Reinsch	-	+	+	-
<i>Cosmarium impressulum</i> Elfving	+	-	+	-
<i>Cosmarium meneghini</i> Brebisson in Ralfs	-	+	-	-
<i>Cosmarium obsolatum</i> (Hantzsch) Reinsch	+	-	-	-

<i>Cosmarium polygonum</i> (Nageli) W.Archer	+	-	-	-
<i>Cosmarium portianum</i> Archer	+	+	-	-
<i>Cosmarium pseudocognatum</i> Nordstedt	-	+	-	-
<i>Cosmarium punctulatum</i> Brebisson	-	-	+	-
<i>Cosmarium quadrum</i> P. Lundell	-	+	-	-
<i>Cosmarium quinarium</i> P.Lundell	-	-	+	-
<i>Cosmarium</i> sp.Corda ex Ralfs	+	-	-	-
<i>Cosmarium speciosum</i> P. Lundell	-	+	+	-
<i>Cosmarium subcirculare</i> Turner	-	-	+	-
<i>Cosmarium subcostatum</i> Nordstedt	+	+	-	+
<i>Cosmarium subcrenatum</i> Hantzsch in Rabenhorst	-	-	+	-
<i>Cosmarium undulatum</i> var. <i>Minutum</i> Corda ex Ralfs	-	+	-	-
<i>Crucigenia rectangularis</i> (Nageli) Komarek	+	-	-	-
<i>Crucigenia tetrapedia</i> (Kirchner) Kuntze	-	-	+	-
<i>Cylindrocystis brebissoni</i> (Meneghinii ex Ralfs) de Bary	+	+	-	+
<i>Cylindrocystis subpyramidota</i> West and G.S.West	+	+	-	-
<i>Desmidium baileyi</i> (Ralfs) Nordstedt	+	+	+	-
<i>Desmodesmus brasiliensis</i> (Bohlin) E.Hegewald	+	-	+	-
<i>Desmodesmus spinosus</i> (Chodat) E.Hegewald	-	+	-	+
<i>Dictyosphaerium</i> sp. Nageli	-	+	+	+
<i>Elakatothrix</i> sp. Wille	+	+	-	-
<i>Euastrum coralloides</i> West & G.S.West	-	+	+	-
<i>Euastrum dubium</i> Nageli	-	+	-	-
<i>Euastrum sinuosum</i> Kutzing	-	+	-	-
<i>Euastrum spinulosum</i> Nordstedt.	-	+	-	-
<i>Golenkinia radiata</i> (Chodat) Wille	+	+	+	+
<i>Gonatozygon kinahanii</i> Archer	-	+	-	+
<i>Haematococcus</i> sp. C. Agardh emend. Flotow	-	+	-	-
<i>Hyalotheca dissiliens</i> Brébisson ex Ralfs	+	+	-	+
<i>Kirchneriella aperta</i> Teiling	+	-	-	+
<i>Kirchneriella lunaris</i> (Kirchner) K.Mobius)	-	+	-	-
<i>Kleborsormidium</i> sp. P.C. Silva, Mattox et W.H.Blackwell	+	+	-	-
<i>Mesotaenium</i> sp. Nageli	-	+	+	-
<i>Microspora irregularis</i> (W. West & G. S. West) Wichmann	-	+	+	+
<i>Microspora tumidula</i> Hazen	+	+	-	+
<i>Microspora willeana</i> Lagerheim	+	-	-	-
<i>Monoraphidium conturtum</i> (Thuret in Brebisson) Komarkova-	-	+	-	-

Legnerova				
<i>Monoraphidium irregulare</i> (G.M.Smith) Komarkova Legnerova	+	+	-	-
<i>Monoraphidium litorale</i> Hindak	-	+	-	-
<i>Monoraphidium tortile</i> (West et G.S.West)	-	+	+	-
<i>Mougeotia</i> sp. C. Agardh	-	+	-	+
<i>Nephrocytium</i> sp. Nageli	+	-	-	-
<i>Netrium digitus</i> (Ehrenberg ex Ralfs) Itzigsohn et Rothe	+	+	+	-
<i>Oedogonium</i> sp.1 Link	+	+	+	+
<i>Oedogonium</i> sp.2 Link	+	+	+	+
<i>Oedogonium undulatum</i> (Brebisson) A.Braun in de Bary	-	+	-	-
<i>Oocystis borgei</i> J.Snow	-	+	-	-
<i>Oocystis gigas</i> Lagerheim	+	+	-	-
<i>Oosystis marssonii</i> Lemmermann	+	-	-	-
<i>Pandorina</i> sp. Bory	-	+	-	-
<i>Pediastrum buryanum</i> var <i>cornutum</i> (Raciborski) Sulek in Fott	-	-	+	-
<i>Pediastrum duplex</i> Meyen	-	+	+	-
<i>Pediastrum duplex</i> var <i>clathratum</i> (A.Braun) Lagerheim	-	-	+	-
<i>Pediastrum duplex</i> var <i>gracillimum</i> West & G.S.West	-	+	+	-
<i>Pediastrum tetras</i> (Ehrenberg) Ralfs	-	-	+	-
<i>Pediastrum tetras</i> var <i>tetraodon</i> Corda	-	-	+	-
<i>Pediastrum tetras</i> var. <i>excisum</i> (Rabenh) Hansgirg	-	-	+	+
<i>Penium cylindrus</i> (Ehrenberg) Brebisson ex Ralfs	-	-	+	-
<i>Penium margaritaceum</i> (Ehrenberg) Brebisson in Ralfs	-	-	+	-
<i>Pleurotenium ehrenbergii</i> (Ralfs) Delponte	-	-	+	-
<i>Pleurotenium trabecula</i> Nageli	-	-	-	+
<i>Radiococcus</i> sp. Schmidle	-	-	+	-
<i>Roya obtusa</i> (Brebisson) West et G.S.West	+	+	+	+
<i>Scenedesmus abundans</i> (Kirchner) Chodat	-	-	+	+
<i>Scenedesmus aculeolatus</i> Reinsch	-	-	-	+
<i>Scenedesmus acuminatus</i> (Lagerheim)	-	+	+	-
<i>Scenedesmus acutiformis</i> Schroder	-	+	-	-
<i>Scenedesmus arcuatus</i> (Lemmermann) Lemmermann	+	-	+	-
<i>Scenedesmus bicaudatus</i> Dedusenko	-	+	-	-
<i>Scenedesmus bijuga</i> (Turpin) Lagerheim	-	+	+	+
<i>Scenedesmus bijugatus</i> var. <i>Alternans f.parvus</i>	-	+	+	-
<i>Scenedesmus brasiliensis</i> Bohlin	-	+	+	-

<i>Scenedesmus caudatus</i> Corda	+	+	-	-
<i>Scenedesmus communis</i> E.H.Hegewald	-	-	-	+
<i>Scenedesmus dimorphus</i> (Turpin) Kutzing	+	+	+	-
<i>Scenedesmus hystrix</i> Lagerheim	+	-	+	+
<i>Scenedesmus longispina</i> R.Chodat	-	+	-	-
<i>Scenedesmus obliquus</i> (Turpin) Kutzing	-	+	-	-
<i>Scenedesmus opoliensis</i> P.G.Richter	-	-	+	-
<i>Scenedesmus perforatus</i> Lemmermann	+	+	-	-
<i>Scenedesmus quadricauda</i> (Turpin) Brébisson	-	+	+	-
<i>Scenedesmus subspicatus</i> Chodat	+	-	-	-
<i>Spirogyra pratensis</i> Transeau	+	+	+	+
<i>Spirogyra</i> sp. Link	-	+	+	-
<i>Spirogyra varians</i> (Hassall) Kutzing	+	+	+	-
<i>Spirotaenia condensata</i> Brébisson	-	-	+	-
<i>Spirotaenia</i> sp. Brébisson ex Ralfs emends. Brook	-	-	+	-
<i>Staurastrum asperum</i> Brébisson ex Ralfs	-	-	+	-
<i>Staurastrum brebissonii</i> Archer	+	-	-	-
<i>Staurastrum chaetoceros</i> (Schroder) G.M.Smith	-	-	+	-
<i>Staurastrum gracile</i> Ralfs ex Ralfs	+	+	-	-
<i>Staurastrum punctulatum</i> Brébisson	+	+	+	-
<i>Staurastrum tetracerum</i> Ralfs ex Ralfs	-	-	+	+
<i>Staurodesmus incus</i> var <i>ralfsii</i> (West) Teiling	+	-	-	-
<i>Staurodesmus triangularis</i> (Lagerheim) Teiling	+	-	+	+
<i>Stigeoclonium glomeratum</i> (Hazen) Collins	+	+	-	+
<i>Tetraedron</i> sp. Kutzing	-	-	+	-
<i>Tetraspora</i> sp. Link	-	+	-	+
<i>Tetrastrum glabrum</i> (Y.V. Roll) Ahlstrom and Tiffany	+	-	-	-
<i>Ulothrix zonata</i> (Weber and Mohr) Kutzing	-	+	+	+
<i>Volvox</i> (Linnaeus) Ehrenberg	+	+	-	+
<i>Westella linearis</i> G.M.Smith	+	+	+	-
<i>Xanthidium cristatum</i> Brébisson in Ralfs	-	+	+	-
<i>Zygnema pectinatum</i> (Vaucher) Agardh	+	-	+	+
TOTAL				151
<b>BACILLARIOPHYCEAE</b>				
<i>Achnanthes brevipes</i> Agardh	-	+	+	+
<i>Achnanthes brevipes</i> Agardh var. <i>intermedia</i> (Kutzing) Cleve	+	+	+	+
<i>Achnanthes inflata</i> Kutzing	-	-	+	+

<i>Achnanthes lanceolata</i> (Brebisson) Grunow in Cleve & Grunow	-	+	+	-
<i>Amphora coffeaformis</i> Agardh	+	-	-	-
<i>Amphora elliptica</i> Kutzing	+	+	-	+
<i>Amphora ovalis</i> Kutzing	+	+	+	+
<i>Aulacoseira</i> sp. Thwaites	-	+	+	+
<i>Bachysira serians</i> (Brebisson ex Kutzing) Round & Mann	-	+	-	-
<i>Bachysira vitrea</i> (Grunow) Ross in Hartley	+	+	-	-
<i>Caloneis bacillum</i> (Grunow) Cleve	-	+	+	+
<i>Ceratoneis arcus</i> Kutzing	-	-	+	+
<i>Cocconeis pediculus</i> Ehrenberg	+	+	+	+
<i>Craticula cuspidata</i> (Kutzing) Mann in Round, Crawford	+	+	+	+
<i>Cyclotella pseudostelligera</i> Hustedt	+	+	+	+
<i>Cymatopleura solea</i> (Brebisson) W. Smith	-	+	+	-
<i>Cymbella affinis</i> Kutzing	-	-	-	+
<i>Cymbella amphicephala</i> Naegeli	-	+	+	+
<i>Cymbella cistula</i> (Ehrenberg) Kirchner	+	+	+	-
<i>Cymbella cuspidata</i> Kutzing	-	-	+	-
<i>Cymbella lanceolatum</i> Ehrenberg	+	+	+	+
<i>Cymbella naviculiformis</i> (Auerswald) Cleve	+	+	+	+
<i>Cymbella proxima</i> Reimer in Patrick & Reimer	+	-	-	-
<i>Cymbella tumida</i> (Brebisson) V.Heurck	+	+	+	+
<i>Cymbella ventricosa</i> Kutzing	-	+	+	+
<i>Diatoma vulgare</i> Bory	+	-	+	-
<i>Diploneis ovalis</i> (Hilse) Cleve	+	+	+	-
<i>Encyonema neogracile</i> Krammer	-	+	+	-
<i>Encyonema silesiacum</i> (Bleisch in Rabenhorst) Mann var. lata Krammer	-	-	-	+
<i>Eunotia bilunaris</i> (Ehrenberg) Mills	+	+	+	+
<i>Eunotia flexuosa</i> (Brebisson) Kutzing	+	+	-	+
<i>Eunotia major</i> (W. Sm.) Hust	+	+	-	-
<i>Eunotia paludosa</i> Grunow	+	-	+	+
<i>Eunotia pectinalis</i> (O.F.Muller) Rabenhorst	-	+	+	-
<i>Fragilaria biceps</i> (Kutzing) Lange-Bertalot	+	+	+	+
<i>Fragillaria capucina</i> Desmazieres	-	-	-	+
<i>Fragillaria crotonensis</i> Kitton	+	+	+	+
<i>Frustulia rhomboides</i> (Ehrenberg) De Toni	-	+	+	-
<i>Gomphonema constrictum</i> Ehrenberg	-	-	+	+

<i>Gomphonema contractum</i> Kutzing	+	+	+	+
<i>Gomphonema gracile</i> Ehrenberg	+	-	+	+
<i>Gomphonema lanceolatum</i> Ehrenberg	+	+	+	+
<i>Gomphonema minutum</i> (Agardh) Agardh	+	-	-	-
<i>Gomphonema montanum</i> Schumann	-	-	+	+
<i>Gomphonema olivaceum</i> (Hornemann) Brebisson	+	+	+	+
<i>Gomphonema parvulum</i> (Kutzing) Kutzing	+	+	+	+
<i>Gomphonema septa</i> Moghadam	+	+	+	-
<i>Gomphonema sphaerophorum</i> Ehrenberg.	+	+	-	+
<i>Gomphonema telographicum</i> Kutzing	+	+	+	+
<i>Gomphonema truncatum</i> Ehrenberg	-	+	+	+
<i>Gomphonema vibrio</i> Ehrenberg	+	+	+	+
<i>Gomphonema viridis</i> Ehrenberg	-	-	-	+
<i>Grammatophora</i> sp. Richard Laws	+	+	+	+
<i>Gyrosigma acuminatum</i> (Kutzing) Rabenhorst	-	+	+	+
<i>Hantzschia amphioxys</i> Ehrenberg	+	+	+	-
<i>Melosira italica</i> Ehrenberg (Kutzing)	-	+	+	-
<i>Melosira</i> sp. C.A.Agardh	-	+	+	-
<i>Navicula capitata</i> Ehrenberg	+	+	-	+
<i>Navicula cryptocephala</i> Kutzing	+	+	+	+
<i>Navicula dicephala</i> (Husted) Hustedt	-	+	-	-
<i>Navicula gracilis</i> Ehrenberg	+	+	+	+
<i>Navicula kariana</i> Kutzing	+	+	+	-
<i>Navicula capitoradiata</i> Germain	+	+	+	-
<i>Navicula lanceolata</i> (Agardh) Ehrenberg	+	+	+	-
<i>Navicula major</i> Kutzing.	+	+	+	+
<i>Navicula microspora</i> Kant and Gupta	+	+	+	+
<i>Navicula oblonga</i> (Kutzing ) Kutzing	-	+	+	+
<i>Navicula minima</i> Grunow in Van Heurck	-	-	-	+
<i>Navicula platystoma</i> Ehrenberg	-	+	+	-
<i>Navicula protracta</i> (Grunow) Cleve	+	+	+	+
<i>Navicula radiosa</i> Kutzing	+	+	+	+
<i>Navicula reinhardtii</i> Grunow in Van Heurck	+	-	-	+
<i>Navicula rhynchocephala</i> Kutzing	-	+	+	+
<i>Navicula sphaerophora</i> Kutzing	+	+	-	+
<i>Navicula tripunctata</i> (O. F. Muller) Bory	+	+	+	+
<i>Navicula viridis</i> Kutzing	+	+	+	+

<i>Navicula viridula</i> (Kutzing) Ehrenberg	-	+	+	+
<i>Neidium ampliatum</i> Ehrenberg Krammer	-	+	-	-
<i>Neidium affine</i> Ehrenberg Krammer	+	-	-	-
<i>Neidium productum</i> (W. Smith) Cleve	+	+	+	-
<i>Nitzschia stagnorum</i> Rabenhorst	+	+	+	+
<i>Nitzschia perminuta</i> (Grunow in Van Heurck) M. Peragallo	-	+	+	+
<i>Nitzschia palea</i> (Kutzing) W. Smith	+	+	+	+
<i>Pinnulacep biceps</i> Gregory	+	+	+	+
<i>Pinnularia braunii</i> (Grunow) Cleve	+	+	+	-
<i>Pinnularia gibba</i> Ehrenberg	+	-	+	-
<i>Pinnularia microstauron</i> (Ehrenberg) Cleve	+	+	+	+
<i>Pinnularia major</i> Kutzing	+	+	+	+
<i>Pinnularia mesolepta</i> (Ehrenberg)W. Smith	-	+	+	+
<i>Pinnularia viridis</i> (Nitzsch) Ehrenberg	+	+	+	+
<i>Placoneis clementis</i> (Grunow) Cox	-	+	-	+
<i>Rhoicosphenia abbreviate</i> (C.Agatdh) Lange-Bertalot	-	+	+	-
<i>Sellaphora pupula</i> (Kutzing) Mereschkowsky	-	+	+	+
<i>Stauroneis anceps</i> Ehrenberg	-	-	+	-
<i>Stauroneis obtusa</i> Lagerst.	+	+	-	+
<i>Stauroneis phoenicenteron</i> (Nitzsch) Ehrenberg	-	+	-	-
<i>Surirella angusta</i> Kutzing	+	+	+	-
<i>Surirella brebissonii</i> Krammer & Lange Bertalot	+	-	-	-
<i>Surirella capronii</i> Brebisson	+	-	+	+
<i>Surirella didyma</i> Kutzing	+	-	-	-
<i>Surirella elegans</i> Ehrenberg	+	+	+	+
<i>Surirella linearis</i> W. Smith	+	-	+	+
<i>Surirella minuta</i> Brebisson	-	-	+	-
<i>Surirella ovata</i> Kutzing	-	-	+	-
<i>Surirella robusta</i> Ehrenberg	+	+	+	+
<i>Synedra capitata</i> Ehrenberg	-	+	+	+
<i>Synedra gracilis</i> Mereschkowsky	-	-	-	+
<i>Synedra ulna</i> (Nitzsch) Ehrenberg	+	+	+	+
<i>Tabellaria fenestrata</i> (Lyngb.) Kutzing	-	-	-	+
<i>Tabellaria flocculosa</i> (Roth) Kutzing	+	-	-	-
<i>Tabellaria quadriseptata</i> Knudson	-	+	-	-
<i>Thalassionema</i> sp. Grunow	+	+	-	-
TOTAL				112

CYANOPHYCEAE				
<i>Anabaena constricta</i> (Szafer) Geitler	+	+	+	-
<i>Aphanothece castagnei</i> (Brebisson) Rabenhorst	+	+	+	-
<i>Aphanothece</i> sp. Nageli	+	-	-	+
<i>Calothrix</i> sp. (C.Agardh) Bornet et Flahault	-	-	-	+
<i>Chroococcus limneticus</i> Lemmermann	+	+	+	+
<i>Chroococcus turgidus</i> (Kutzing) Nageli	-	+	+	-
<i>Coelasphaerium</i> sp. Nageli	-	+	-	-
<i>Dactylococcopsis acicularis</i> Lemmermann	+	-	-	+
<i>Dactylococcopsis raphidioides</i> Vasishta	-	-	-	+
<i>Dimorphococcus</i> sp. A.Braun	+	-	-	-
<i>Gloeocapsa aerogenosa</i> Kutzing	-	+	+	+
<i>Gloeocapsa alpina</i> (Nageli) Brand	-	+	-	+
<i>Goleothece linearis</i> Nageli	+	-	-	-
<i>Hapalosiphon</i> sp. (Nageli) Bornet et Flahault	-	-	-	+
<i>Johannesbaptistia</i> sp. De Toni	-	+	-	-
<i>Leptolyngbya fragilis</i> (Gomont) Anagnostidis et Komarek	-	+	+	+
<i>Leptolyngbya</i> sp. Anagnostidis et komarek	-	-	-	+
<i>Lyngbya aestuarii</i> (Liebmann) Gomont	+	-	+	-
<i>Lyngbya limnetica</i> Lemmermann	-	-	+	+
<i>Lyngbya martensiana</i> (Meneghini) Gomont	-	-	-	+
<i>Lyngbya</i> sp. 1 Agardh	-	-	+	-
<i>Lyngbya</i> sp. 2 Agardh	-	-	-	+
<i>Lyngbya</i> sp. 3 Agardh	-	-	-	+
<i>Merismopedia elegans</i> A.Braun ex Kutzing				
<i>Merismopedia minima</i> Beck	-	+	+	+
<i>Merismopedia glauca</i> (Ehrenberg) Nageli	-	+	-	+
<i>Microcoleus</i> sp. (Desmazieres) Gomont	-	-	-	+
<i>Microcystis aeruginosa</i> (Kutzing) Kutzing	+	+	-	-
<i>Nostoc coruleum</i> (Lyngbye) Bornet et Flahault	-	-	+	-
<i>Nostoc</i> sp. Vaucher	-	+	+	-
<i>Oscillatoria acuminata</i> Gomont	+	-	-	+
<i>Oscillatoria agardhii</i> Gomont	-	+	+	-
<i>Oscillatoria amphibia</i> (C.Agardh) Gomont	+	+	-	+
<i>Oscillatoria chalybea</i> (Mertens in Jurgens) Gomont	-	+	-	-
<i>Oscillatoria curviceps</i> C. Agardh	+	+	+	+
<i>Oscillatoria limnetica</i> Lemmermann	+	+	+	+

<i>Oscillatoria limosa</i> (C.Agardh)Gomont	+	+	+	-
<i>Oscillatoria princeps</i> (Vaucher)Gomont	-	-	+	-
<i>Oscillatoria pseudogerminata</i> G. Schmidle	+	+	+	-
<i>Oscillatoria redekei</i> Van Goor	-	+	-	-
<i>Oscillatoria sancta</i> (Kutzing) Gomont	-	+	+	+
<i>Oscillatoria splendida</i> (Greville) Gomont	-	+	+	+
<i>Oscillatoria subbrevis</i> Schmidle	-	+	-	+
<i>Oscillatoria tenuis</i> (C.Agardh) Gomont	-	-	+	+
<i>Phormidium ambiguum</i> (Kutzing) Gomont	+	+	-	-
<i>Phormidium autumnale</i> (C.Agardh) Gomont	-	-	+	-
<i>Phormidium favosum</i> (Bory) Gomont	-	-	+	-
<i>Phormidium fragile</i> (Meneghini) Gomont	-	+	+	+
<i>Phormidium molle</i> Kutzing	+	+	+	+
<i>Phormidium purpurescens</i> Gardner	+	-	+	+
<i>Phormidium tenue</i> (Meneghini) Gomont	-	-	-	+
<i>Phormidium uncinatum</i> (C.Agardh ex Gomont) Gomont	-	-	+	+
<i>Spirulina major</i> (Kutzing) Gomont	+	+	+	-
<i>Spirulina</i> sp. (Turpin) Gomont	-	-	-	+
<i>Stigonema</i> sp. (C.Agardh) Bornet <i>et</i> Flahault	-	+	-	+
<i>Synechococcus nidulans</i> (Pringsheim) Komarek	-	-	+	-
<i>Synechococcus</i> sp. Nageli	+	+	+	-
TOTAL				55
<b>EUGLENOPHYCEAE</b>				
<i>Euglena acus</i> Ehrenberg	+	+	+	+
<i>Euglena caudata</i> (Ehrenberg) Lemmermann	+	+	-	-
<i>Euglena ehrenbergii</i> Skuja	-	+	-	+
<i>Euglena elastica</i> Prescott	+	+	+	+
<i>Euglena gracilis</i> G.A.Klebs	+	+	+	+
<i>Euglena haematodes</i> (Ehrenberg) Lemmermann				
<i>Euglena mutabilis</i> Schmitz	-	-	+	+
<i>Euglena oxyuris</i> Schmarda	-	+	-	-
<i>Euglena polymorpha</i> P.A. Dangeard	+	+	+	+
<i>Euglena proxima</i> P.A.Dangeard	+	-	-	-
<i>Euglena spirogyra</i> Ehrenberg	+	+	-	-
<i>Lepocinclis ovum</i> Ehrenberg	+	+	-	-
<i>Lepocinclis steinii</i> Lemmermann	+	-	-	-
<i>Phacus brevicaudatus</i> (Klebs) Lemmermann	-	+	-	-

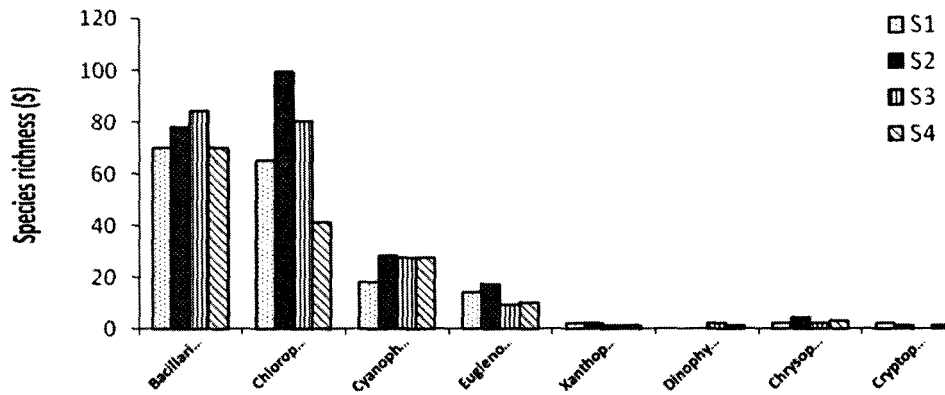
<i>Phacus caudatus</i> Hubner	-	+	+	+
<i>Phacus pleuronectes</i> O. F. Muller	-	+	-	-
<i>Phacus pyrum</i> (Ehrenberg) W.Archer	-	+	-	-
<i>Phacus ranula</i> Pochmann	+	+	+	-
<i>Trachelomonas abrupta</i> var. <i>splendida</i> (Playfair) Deflandre	-	+	-	+
<i>Trachelomonas intermedia</i> P.A.Dangeard	+	+	+	+
<i>Trachelomonas volvocina</i> Ehrenberg	+	+	+	+
TOTAL				20
<b>DINOPHYCEAE</b>				
<i>Ceracium hirundiniella</i> (O. F. Muller) Schrank	-	-	+	-
<i>Woloszynskia</i> sp. R.H.Thompson	-	-	+	+
TOTAL				2
<b>CHRYSOPHYCEAE</b>				
<i>Dinobryon sertularia</i> Ehrenberg	+	+	-	-
<i>Mallomonas</i> sp. Perty	+	+	+	+
<i>Pedinella</i> sp. Vysotskji	-	-	-	+
TOTAL				3
<b>CRYPTOPHYCEAE</b>				
<i>Chilomonas paramecium</i> Ehrenberg	+	+	-	+
<i>Cryptomonas</i> sp. Ehrenberg	+	-	-	-
TOTAL				2
<b>XANTHOPHYCEAE</b>				
<i>Characiopsis</i> sp. Borzi	+	+	-	+
<i>Tribonema</i> sp. Derbes <i>et</i> Solier	+	+	+	+
TOTAL				2

(+) indicate present; (-) indicate absent.

Dinophycean group was recorded only from site 3 and site 4 while Cryptophyceae was recorded from site 1, site 2 and site 4. From Bacillariophyceae, *Navicula* Bory was the most abundant taxon with 21 species. Most of the diatom species were of pinnate type and very less of centric type. From Chlorophyceae desmids were represented by 71 species in which *Cosmarium* Corda ex Ralfs was the most abundant taxon from this group with

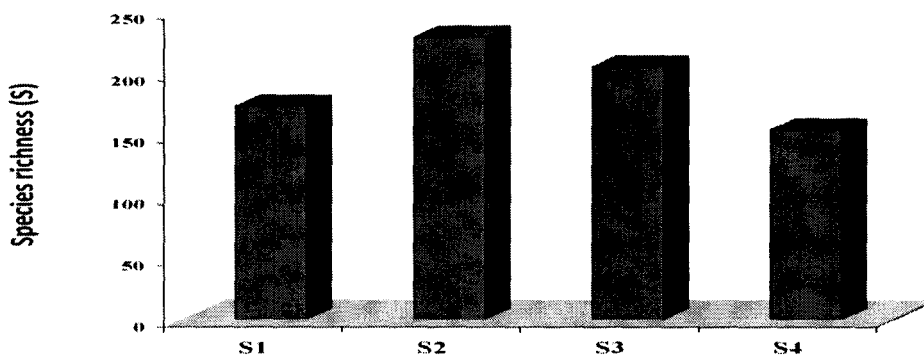
27 species. *Oscillatoria* Vaucher and *Euglena* Ehrenberg were the most abundant taxa from Cyanophyceae and Euglenophyceae with 14 and 9 species respectively. *Woloszynskia* sp. R.H.Thompson and *Ceracium hirundiniella* (O. F. Müller) Schrank was the only representative from Dinophyceae whereas *Dinobryon sertularia* Ehrenberg, *Mallomonas* sp. Perty and *Pedinella* sp.Vysotskji represented Chrysophyceae. From Cryptophyceae, *Chilomonas paramecium* Ehrenber, *Cryptomonas* sp. Ehrenberg was recorded and Xanthophyceae was represented by *Tribonema* sp. Derbes *et* Solier and *Characiopsis* sp. Borzi. 47 species were common in all the study sites. *Ceracium hirundiniella* (O. F. Muller) Schrank was found only in site 3 and *Cryptomonas* sp. Ehrenberg in site 1. *Spirogyra* sp. Link filamentous green algae was found abundantly in site 2 and 3 during spring and occurred mostly as free floating mats. Other than *Spirogyra* sp.Link *Oedogonium* sp. Link was found in abundant in site 3, and was found mainly attached to substrata. 71 species of desmids were recorded from all the sites.

In site 1, site 3 and site 4, Bacillariophyceae showed the maximum number of species whereas Chlorophyceae was maximum in site 2 (fig. 5.5). Distinct seasonal variations could be observed. Maximum numbers of taxa were recorded during spring season in two consecutive years, and the minimum number was recorded during monsoon to post monsoon.

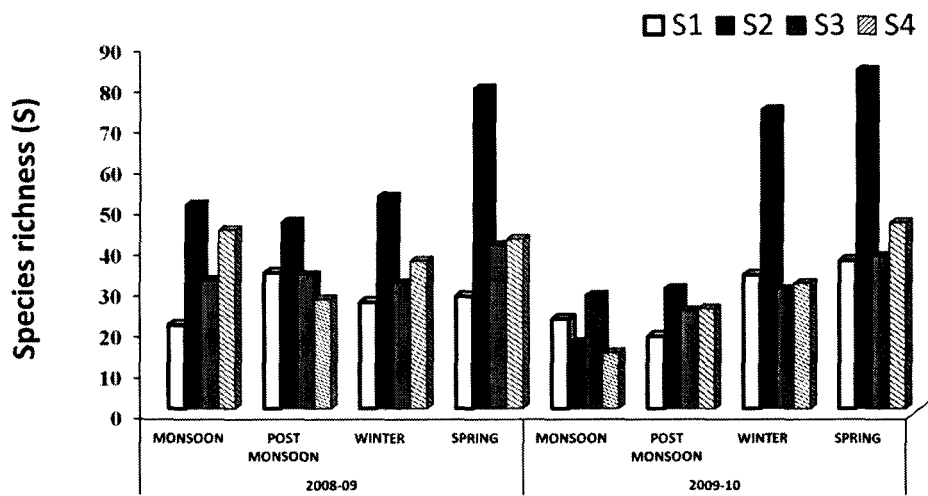


**Figure 5.5: Species richness (S) and distribution of different algal groups in four sites in Umiew river.**

Species richness was minimum in monsoon and increased gradually till it attained its maximum value during spring (figure 5.7). Distinct seasonal difference was observed in site 2. Species richness was maximum in site 2 (229 species) followed by site 3 (205 species), site 1 (173 species) and site 4 (154 species) respectively (fig. 5.6). Total species richness in site 2 was significantly higher than the other three sites (Table 5.2).



**Figure 5.6: Species richness (S) of periphytic algal assemblages in four sites in Umiew river.**



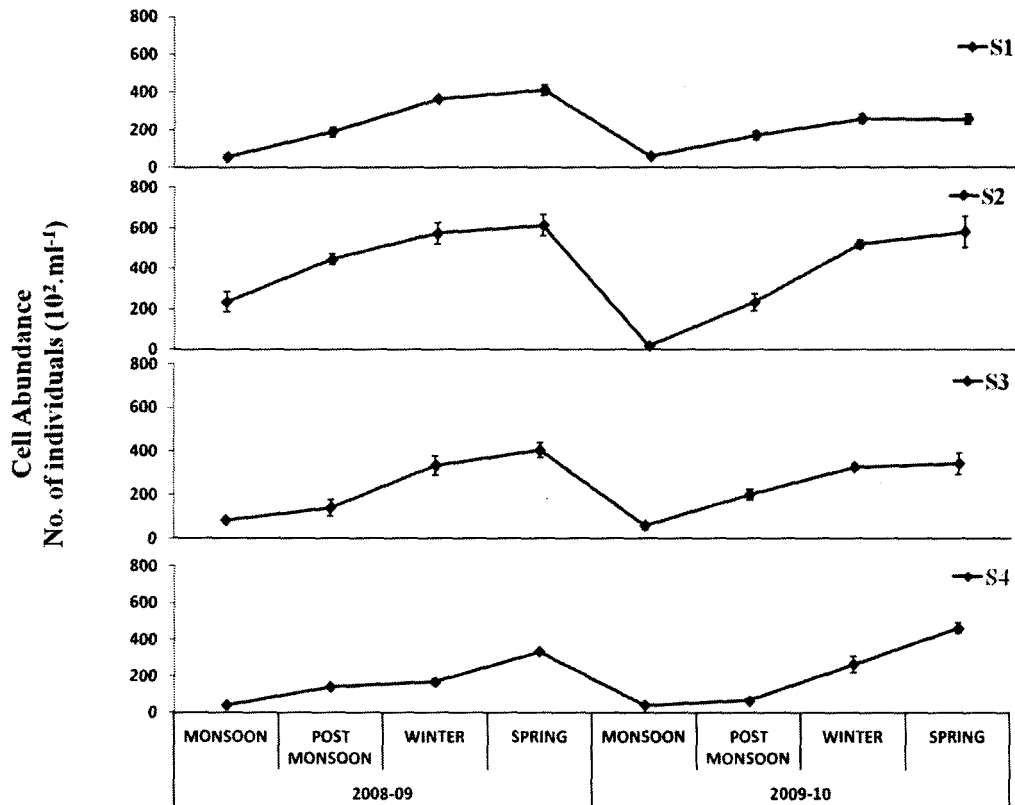
**Figure 5.7: Seasonal variations in species richness (S) in periphytic algae in four sites in Umiew river.**

A significant seasonal variation was recorded in species abundance also i.e., cell number per ml of sample. Gradual increase in cell abundance in all the sites were observed from monsoon (minimum) to spring (maximum) season in two consecutive years. Maximum cell abundance was recorded from site 2 which ranged from  $18.5 \times 10^2$  to  $613.65 \times 10^2$  cells/ml. In site 1, the cell abundance varied from a minimum of  $56.12 \times 10^2$  cells/ml to a maximum of  $410.95 \times 10^2$  cells/ml. In site 3, it ranged from a minimum of  $58.3 \times 10^2$  cells/ml to a maximum of  $405.6 \times 10^2$  cells/ml, whereas in site 4, cell abundance ranged from  $40.23 \times 10^2$  to  $460.97 \times 10^2$  cells/ml (fig. 5.8). Only in site 2 differences in cell abundance was significantly higher from all the other sites (Table 5.2).

**Table.5.2: One-way ANOVA for diversity, richness and abundance to show the variations among sampling sites.**

	Diversity		Richness		Abundance	
	F	p-value	F	p-value	F	p-value
S1;S2	8.9598**	0.0044	17.673**	0.0001	9.564846**	0.003
S1;S3	0.0672	0.7965	2.1753	0.1470	0.729612	0.397
S1;S4	0.1677	0.6840	1.3605	0.2494	0.0000045	0.994
S2;S3	9.3968**	0.0036	12.497**	0.0009	5.80147*	0.020
S2;S4	13.181**	0.0007	10.725**	0.0020	9.607371**	0.003
S3;S4	0.5522	0.4611	0.0001	0.9903	0.742441	0.393

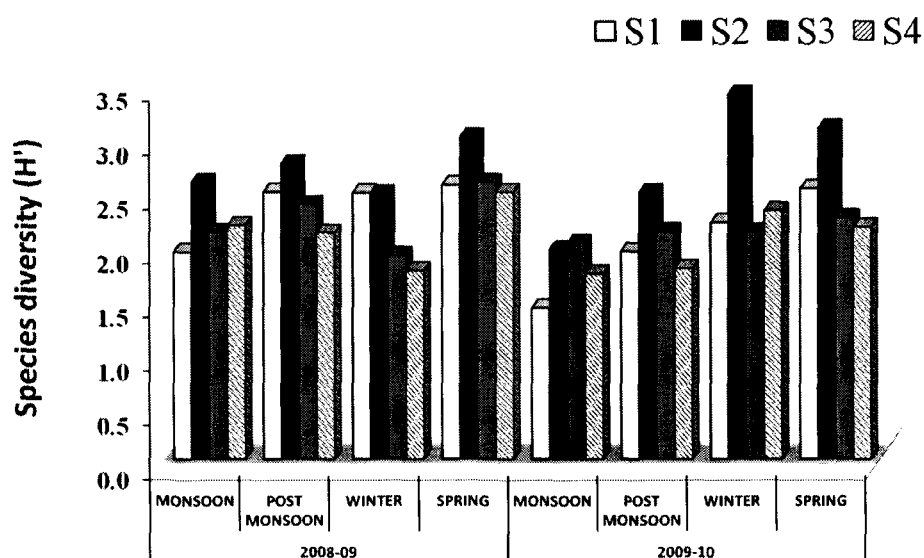
\*significant at  $p < 0.05$ ; \*\* significant at  $p < 0.001$ .



**Figure 5.8: Seasonal variations in cell abundance (No. of individuals  $\times 10^2$   $ml^{-1}$ ) in four sites in Umiew river.**

Bacillariophyceae and Chlorophyceae were the two main algal classes which contributed maximum to the total cell abundance in all the four sites. In site 4 Cyanophyceae also contributed more towards the cells number. Euglenophyceae and Xanthophyceae contributed maximum during winter in site 1 and site 3 respectively. Chrysophyceae was recorded maximum during spring season in site 1. Dinophyceae was recorded only during monsoon in both site 3 and site 4. Cryptophyceae contributed more during winter in site 1.

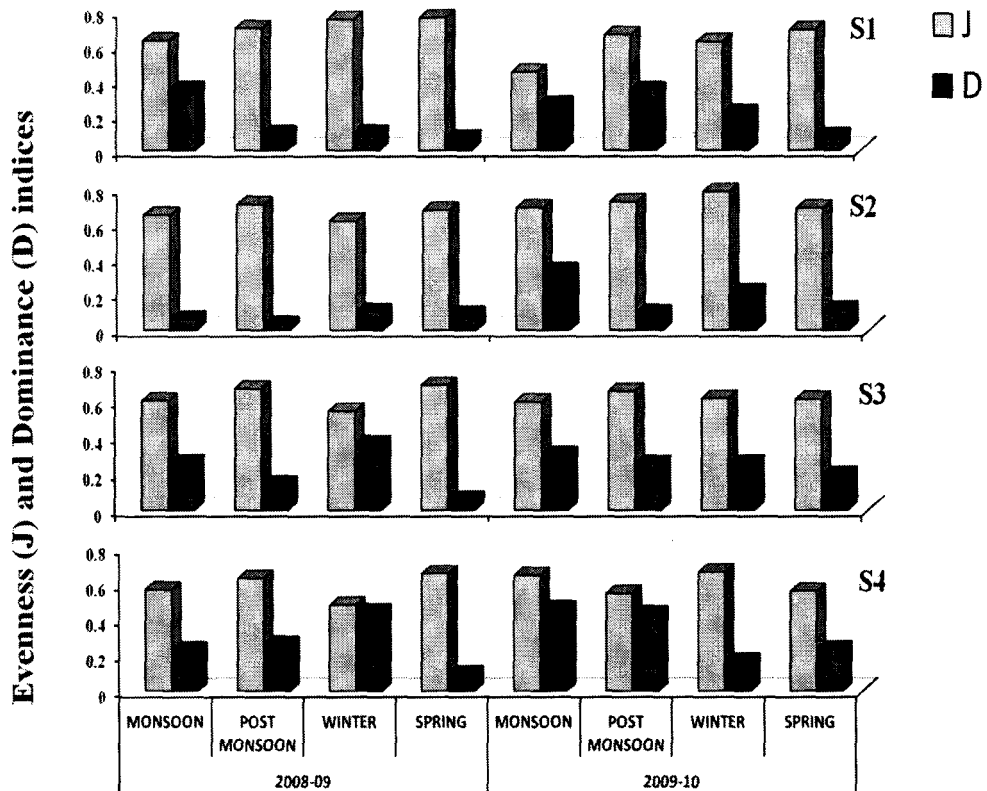
Shannon Species diversity index ( $H'$ ) varied from 1.71 to 2.53 in site 1, 1.93 to 3.37 in site 2, 1.88 to 2.55 in site 3 and 1.39 to 2.46 in site 4 respectively (fig. 5.9).



**Figure 5.9: Seasonal variations in periphytic species diversity ( $H'$ ) in four sites in Umiew river.**

High species diversity could be related to low rainfall (winter and spring) with low and steady water flow. But in some cases like that of site 1 during post monsoon season because of the predominance of certain green algae, mainly the filamentous form, a decline in species diversity was observed during low rainfall period. As expected, species diversity was significantly higher in site 2 in almost the entire period of study, except during winter (first year) and monsoon (second year), a slight increase was observed at site 1 and site 3 respectively. Diversity index in site 4 was always low as compared to other three sites and the species diversity index in site 2 only showed a significant difference from all the sites (Table 5.2). Simpson dominance index varied from a minimum of 0.03 to 0.46. In site 1, the index value ranged from 0.07 (spring) to 0.35 (monsoon). In site 2, it varied from 0.03 (post monsoon) to 0.33 (monsoon). In site 3, it varied from 0.06 (spring) to 0.36 (winter) whereas in site 4, the index value ranged from 0.09 (spring) to 0.46 (monsoon) (fig. 5.10).

No marked temporal and spatial deviation in the dominance index could be obtained during the study period. Nevertheless, the overall value was low and less than 1 in all the four sites. But, on the contrary, evenness index was high in all the four sites and ranged from a minimum of 0.48 to a maximum of 0.76.



**Figure 5.10: Seasonal variations in periphytic Evenness (J) and Dominance (D) indices in four sites.**

In site 1, evenness index ranged from 0.45 (monsoon) to 0.76 (spring). In site 2, it ranged from 0.61 to 0.78 during winter respectively. In site 3, the value ranged from 0.54 (winter) to 0.69 (spring) whereas in site 4 it ranged from 0.48 to 0.66 during winter respectively (fig.5.10). Generally, no significant seasonal variations in the evenness index value could be observed during the study period and moreover, the differences among the study sites were also less.

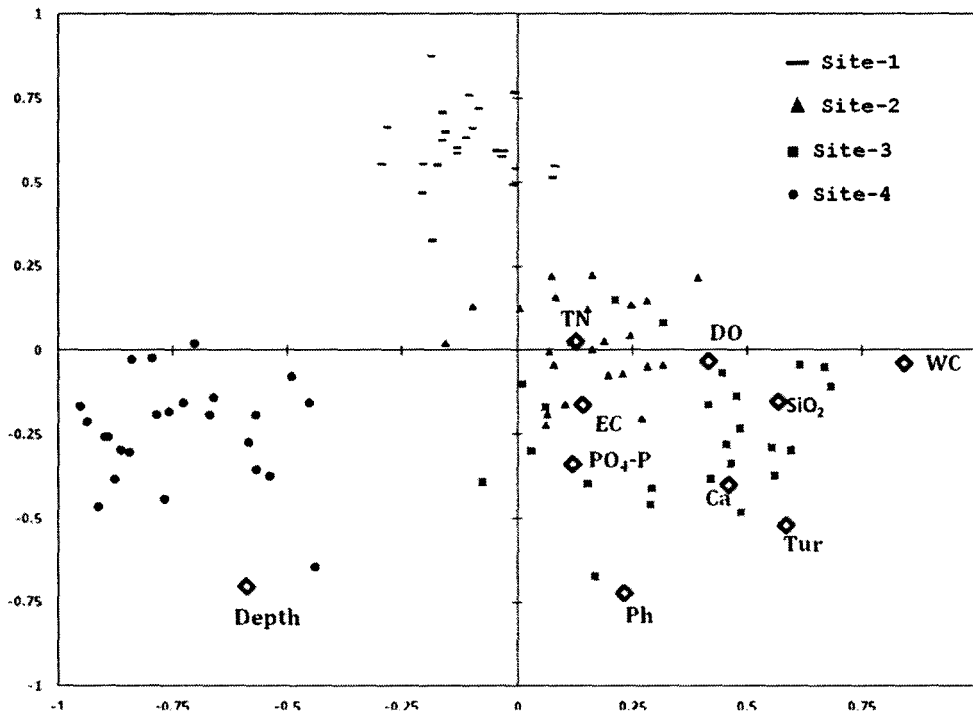
**Table 5.3: List of algal species with their species code indicated in CCA ordination diagram.**

<b>Algal species</b>	<b>Species Code</b>
<i>Achnanthes brevipes</i> var. <i>intermedia</i>	<i>Ach bre</i>
<i>Amphora ovalis</i>	<i>Amp ova</i>
<i>Ankistrodesmus falcatus</i>	<i>Ank fal</i>
<i>Cosmarium cucurbita</i>	<i>Cos cuc</i>
<i>Cosmarium subcrenatum</i>	<i>Cos sub</i>
<i>Cyclostella pseudostelligera</i>	<i>Cyc pse</i>
<i>Cymbella amphicephala</i>	<i>Cym amp</i>
<i>Cymbella cistula</i>	<i>Cym cis</i>
<i>Cymbella naviculiformis</i>	<i>Cym nav</i>
<i>Cymbella tumida</i>	<i>Cym tum</i>
<i>Euglena gracilis</i>	<i>Eug gra</i>
<i>Euglena mutabilis</i>	<i>Eug mut</i>
<i>Golenkinia radiata</i>	<i>Gol rad</i>
<i>Gomphonema olivaceum</i>	<i>Gom oli</i>
<i>Gomphonema parvalum</i>	<i>Gom par</i>
<i>Gomphonema sphaerophorum</i>	<i>Gom sph</i>
<i>Gomphonema vibrio</i>	<i>Gom vib</i>
<i>Grammatophora</i> sp.	<i>Gra sp</i>
<i>Graticula cuspidata</i>	<i>Gra cus</i>
<i>Mallomonas</i> sp.	<i>Mol sp</i>
<i>Navicula cryptocephala</i>	<i>Nav cry</i>
<i>Navicula gracilis</i>	<i>Nav gra</i>
<i>Navicula lanceolata</i>	<i>Nav lan</i>
<i>Navicula radiosa</i>	<i>Nav rad</i>
<i>Navicula sphaerophora</i>	<i>Nav sph</i>
<i>Navicula viridis</i>	<i>Nav vir</i>
<i>Oedogonium</i> sp.	<i>Oed sp</i>
<i>Oscillatoria curvicep</i>	<i>Osc cur</i>
<i>Oscillatoria limnetica</i>	<i>Osc lim</i>
<i>Phormidium molle</i>	<i>Pho mol</i>
<i>Sellaphora pupula</i>	<i>Sel pup</i>
<i>Spirogyra pratensis</i>	<i>Spi pra</i>
<i>Surirella elegans</i>	<i>Sur ele</i>
<i>Surirella robusta</i>	<i>Sur rob</i>
<i>Synedra ulna</i>	<i>Syn uln</i>

Out of 346 species, only 35 species having relative abundance more than 3 percent were obtained from the data set for statistical analysis. The lists of those species with their code are given in Table 5.3. CCA (canonical correspondence analysis) of species abundance data and environmental variables produced an

ordination in which the first two axes were statistically significant ( $p < 0.0001$ ) with Eigen values of 0.176 and 0.102 respectively. Correlation coefficients or intraset coefficients of environmental variables with the first two axes are given in Table 5.4. The cumulative percentage of variance in the species–environment relationship explained by the first two axes was 58.27% where axis 1 accounted for 36.93% and axis 2 accounted for 21.33% of the diversity in algal assemblages. Among 35 taxa used in the CCA analyses, most of them were close to the center of the CCA diagram which indicated that they were cosmopolitan. Environmental variables correlated with the first CCA axis described a gradient from site 2 (fig. 5.11a) with total nitrogen (TN) as the significant variable and site 3 at the positive end with, turbidity, calcium (Ca), electrical conductivity (EC), silica (SiO<sub>2</sub>), dissolved oxygen (DO) and water current (WC) as the important parameters influencing the site. At the negative end, site 4 with higher depth as the influential parameter correlated with the first CCA axis. Several diatoms like *Navicula lanceolata* (Agardh) Ehrenberg, *N. radiosa* Kutzing, *N. viridis* Kutzing, *Surirella elegans* Ehrenberg, *S. robusta* Ehrenberg, *Cymbella cistula* (Ehrenberg) Kirchner, *C. tumida* (Brebisson) V. Heurck, *Gomphonema parvalum* (Kutzing) Kutzing and Chlorophytes like *Ankistrodesmus falcatus* (Corda) Ralfs, *Cosmarium subcrenatum* Hantzsch in Rabenhorst *Oedogonium* sp. and *Spirogyra* sp., Euglenoids like *Euglena gracilis* Klebs showed strong positive correlation with the first CCA axis. Diatoms like *Achnanthes brevipes* Agardh var. *intermedia* (Kutzing) Cleve, *Amphora ovalis*

Kutzing, *Cyclostella pseudostelligera* Hustedt, *Gomphonema olivaceum* (Hornemann) Brebisson, *Navicula cryptocephala* Kutzing, *Graticula cuspidata* Kutzing, euglenoids like *Euglena mutabilis* F.Schmitz, chrysophytes like *Mollamonas* sp. Perty and Cyanophytes like *Oscillatoria limnetica* Lemmermann showed negative correlation with the first CCA axis (fig. 5.11b).



**Figure 5.11a: CCA (Canonical Correspondence Analysis) ordination diagram of selected environmental gradients correlated with different sites in Umiew river change along CCA axes 1 and 2.**

Environmental variables correlated with the second CCA axis described a gradient from site 1 with no significant environmental parameters at the positive end and pH, phosphate (PO<sub>4</sub>) at the negative end (fig. 5.11a). Several

diatom species including *Grammatophora* sp. Richard Laws, *Sellaphora pupula* (Kutzing) Mereschkowsky chlorophytes like *Cosmarium cucurbita* Brebisson, *Golenkinia radiata* Ghodat, and cyanophyte like *Phormidium molle* Gomont, showed strong positive correlation with the second CCA axis (fig. 5.11b).

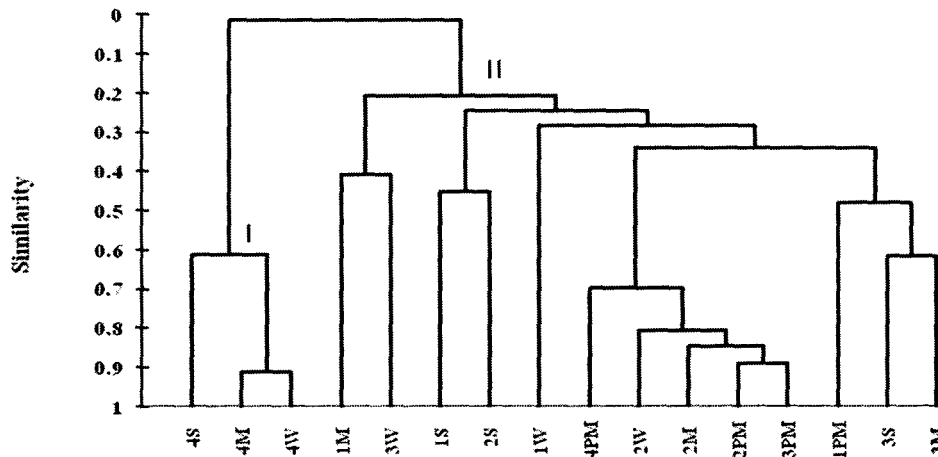
**Table 5.4: Correlation coefficients or intraset coefficients of environmental variables with the first two axes (F1 and F2) of canonical correspondence analysis (CCA).**

Axis Variable	F1-axis	F2-axis
Ph	0.097	-0.236
WC	0.351	-0.015
TUR	0.240	-0.160
DO	0.172	-0.010
Ca	0.191	-0.127
PO <sub>4</sub>	0.057	-0.117
EC	0.172	-0.101
SiO <sub>2</sub>	0.251	-0.054
Depth	-0.250	-0.230
TN	0.050	0.002

Diatom species like *Cymbella amphicephala* Naegeli in Kutzing, *C. naviculiformis* (Auerswald) Cleve, *Navicula gracilis* Ehrenberg, *N. sphaerophora* Kutzing, and Cyanophytes like *Oscillatoria curvicep* C. Agardh ex Gomont, showed strong negative correlation with the second CCA axis. *Synedra ulna* (Nitzsch) Ehrenberg and *N. tripunctata* (O.F. Muller) Bory showed positive correlation while *Gomphonema sphaerophorum* Ehrenberg showed negative correlation with both the CCA axes respectively.



site 2 during spring also showed similarity at 0.43 based on Pearson correlation coefficient on the unweighed pair group average values.



**Figure 5.12: Cluster dendrogram showing similarities among sampling sites based on algal assemblages in different seasons. S= spring; M= monsoon; PM= post-monsoon; W= winter; number along X-axis indicates study sites.**

#### 5.4. DISCUSSION

The algal assemblages of Umiew river were contributed maximum by the periphytons as the phytoplanktons could not maintain populations due to the influential effect of water current. Majority of the algal assemblages and species composition encountered from Umiew river during the present study are cosmopolitan. As expected, the algal assemblages in the river Umiew showed seasonal response. Dominance of green algae and diatoms in terms of species number and cell count observed in the algal community of Umiew river was found to be a common feature in many fresh water lotic systems (Hynes, 1970).

The dominance of Bacillariophyceae and Chlorophyceae was also reported elsewhere by Temel, (2006); Saadet and Sahin, (2009); Spackova *et al.*, (2009); Sahin *et al.*, (2010); Baba *et al.*, (2011) and Hussein and Gharib, (2012). Similar trend was reported in the Ganges and its tributaries (Joshi *et al.*, 1996; Negi *et al.*, 2012). Dominance of Bacillariophyceae was reported in periphytic community by Gurumayum *et al.*, (2000) in river Subansiri in Arunachal Pradesh and Singh and Das, (2009) in a peninsular river. Presence of adequate concentration of silica in water bodies which probably helped in the frustules formation might be attributed to the occurrence of more diatoms in the river (Wetzel & Likens, 2006). According to Lund, (1954), silicate content should be above 0.5 mg/l for rich growth of diatoms. In the present study, silicate values were in the range of 2.74 to 5.79 mg/l, which explained the dominance of diatoms in all the study sites except in site 2. According to Tiseer *et al.*, (2008), the presence of more number of green algae and diatom species in lotic system would indicate relatively clean water body. Rashid and Pandit, (2008) observed that abundance of Chlorophyceae in river Sindh in Kashmir Himalaya indicated oligotrophic nature of water. Abiotic factors (light, water current, temperature) directly influenced the abundance and distribution of algae in lotic systems (Duncan & Blinn, 1989). Essential nutrients, particularly nitrogen and phosphorus were likely to be important determinants of algal abundance (Notestein *et al.*, 2003; Stevenson *et al.*, 2007). The contribution of blue green algae to the algal assemblages in terms of species number and cell counts was

This could be attributed to low pH and nutrient content of river water (Maurice *et al.*, 1987; Shapiro, 1997). Okogwu and Ugwumba, (2009) reported a strong positive correlation between cyanobacteria abundance and pH in river floodplain in Nigeria. The occurrence of low number of Chrysophycean group could be attributed to low pH and low nutrients condition as reported by Nedbalova *et al.*, (2006) in forested lake. Presence of large number of desmids in South of Eastern Himalayas rivers indicated the oligotrophic nature of the river (Yasmin *et al.*, 2011). Kristiansen, (2005) reported that chrysophytes like *Dinobryon* sp. Ehrenberg and *Mallomonas* sp. Perty showed affinity for slightly acidic and nutrient poor medium, and the presence of a few species indicated oligotrophic conditions in the present study. The occurrence of *Ceracium hirundinella* (O.F.Muller) Dujardin in site 3 and *Woloszynskia* sp. R.H.Thompson, both in site 3 and site 4 might be due to its adaptability to hard and turbid water. Bellinger and Sigee, (2010) confirmed that *Ceracium* sp. Schrank and *Woloszynskia* sp. R.H.Thompson occurred particularly in waters that had high calcium-ion concentrations (hard waters) and low level of inorganic nutrients.

Cell abundance in Umiew river showed temporal and spatial variations. High cells abundance was recorded during spring (dry season) in all the sites. This might be attributed to low flow of current. The temporal seasonal trend observed in algal population in the present case was in accordance with the findings of Bishop, (1973) and Dudgeon, (1982, 2000) where prominent seasonal variations prevailed mainly in monsoonal Asia and in many other

tropical countries (Mosisch & Bunn, 1997; Davies, *et al.*, 2008). During monsoon, when the river received maximum rainfall, water current was the main physical factor that influenced the growth and establishment of periphytons in lotic system. In riverine habitats, seasonal variation in flow could be considered as the significant factor. Water flow inhibited the growth of periphytic algae by its shearing effect. There were some reports where a few algal species required an environment with high water current (Blum, 1956; Whitford, 1960; Wetzel, 1979). In case of extensive flood, increased water velocity in the streams negatively influenced the taxonomic richness (Biggs & Smith, 2002) and the periphytic algae on various substrata were stripped away by the streams flow (Yamada & Nakamura, 2002). Heavy spates significantly reduced the abundance of algae and altered the composition of algal assemblages considerably by dislocating more loosely attached species (Acs & Kiss, 1993; Komulaynen, 2004).

In the present study, diversity and cell abundance were found to be significantly high in site 2 with green algae as the dominant group compared to other study sites. This finding could be attributed to low turbidity value or increased light penetration and presence of sufficient amount of nutrients particularly nitrogen. Notestein *et al.*, (2003) found that increased nutrient concentrations rendered increase in periphyton abundance. In the present case, as the river runs through agricultural field in site 2, nitrogen (nitrite + nitrate) content was significantly high (chapter 4), and this might have led to the

content was significantly high (chapter 4), and this might have led to the abundant growth of algae in that site. Similar findings have been reported by Yu and Lin, (2009) in subtropical mountain stream where total cell numbers were significantly higher in stream with larger area of agriculture. Stelzer and Lamberti, (2001) also reported that an increase in nitrogen alone would stimulate periphyton growth, especially when light was not a limiting factor (Lohman *et al.*, 1992; Mosisch *et al.*, 2001). Furthermore, the availability of more surface area and the presence of rocks, boulders, pebbles etc., provided substrata for periphytons attachment. Although turbidity value in site 1 and site 4 was low, due to shading effect formed by the riparian vegetation in site 1 and higher depth in site 4 and low nutrient concentration of the water column, lower cell abundance was obtained. Furthermore CCA (fig.5.11a) also supported the findings where no particular parameters could play any significant effect in site 1 whereas in site 4, depth was a major factor. In site 3, in general, cell abundance was significantly low compared to that of site 2. Low cell abundance in site 3 might be due to highly turbid nature of the water and elevated water current throughout the sampling period. Phosphorus was comparatively high in site 3, but low nitrogen and light intensity resulted in poor growth of periphytic algae. These findings have been illustrated by CCA biplot (fig.5.11a) where DO level, nutrient concentrations like  $PO_4$ ,  $SiO_2$ , Ca and pH level were high in site 3, but high turbidity and fast WC played a dominant role in reducing algal assemblages.

The result obtained from Canonical Correspondence Analysis (CCA) showed that the environmental variables like WC, turbidity, pH and depth were the main factors influencing the periphytic algal growth. Most of the species used in CCA analysis were close to the centroid. This was probably due to the cosmopolitan characteristics of those species with high levels of tolerance to changes in environmental variables. Many green algae like *Ankistrodesmus falcatus* (Corda) Ralfs, *Spirogyra pratensis* Transeau, *Cosmarium subcrenatum* Hantzsch in Rabenhorst and diatoms like *Navicula tripunctata* (O. F. Muller) Bory, *N. radiosa* Kutzing and *Synedra ulna* (Nitzsch) Ehrenberg and also *Euglena gracilis* G.A. Klebs, showed preferences to total nitrogen and dissolved oxygen. The preference of *Euglena gracilis* G.A. Klebs for nitrogen was in agreement to the work of John *et al.*, (2002) who reported that this particular species was common in those systems which have more nitrogenous matter. Rout and Gaur, (1994) showed that most green algae were stimulated by increased phosphorus concentration in stream water of Meghalaya which was contradictory to our findings. However majority of the species did not show any response to variation in DO and TN. For example, although the number of individuals of *Navicula cryptocephala* Kutzing was more in site 2, but still showed negative correlation with TN. The reason might be due to its high abundance during spring (dry months) when TN content in the water was low. Many diatom species like *Navicula lanceolata* (Agardh) Ehrenberg, *Surirella elegans* Ehrenberg, *S. robusta* Ehrenberg, *Cymbella cistula* (Ehrenberg) Kirchner, *C*

*tumida* (Breb.) V. Heurck and *Gomphonema parvalum* (Kutzing) Kutzing were influenced by high WC, turbidity, SiO<sub>2</sub> and Ca. Most of these diatom species like *Gomphonema*, *Cymbella* preferred to grow in high current by forming a gelatinous stalk and get attached to the substratum to avoid from being washed away by the fast current. Similarly, *Oedogonium* sp. Link preferred to grow in high current by attaching to the surface of substratum with the help of specialized cell (hold fast). In the present study, pH and PO<sub>4</sub> showed inhibitory effect and strong affinity to Ca. Celekli and Kulkoyluoglu, (2007) reported that *Cymbella* and *Achnanthes* could tolerate high Ca concentration in water and they were known as calciphiles or Ca loving organisms. The presence of more indicator species like *Cymbella* sp. {*Cymbella cistula* (Ehrenberg) Kirchner, *C. tumida* (Brebisson) van Heurck} in site 3 with high calcium concentration indicated clearly that this site has been affected by lime quarrying to some extent. Cyanobacteria like *Oscillatoria curvicep* C. Agardh showed preference for high pH and PO<sub>4</sub>. This indicated that the species might act as an indicator of alkaline system. Majority of the algal assemblages in Umiew river showed negative correlation with depth except *Cyclostella pseudostelligera* Hustedt which occurred mostly as phytoplankton rather than as periphyton. Similarity among the sampling sites shown by Cluster analysis (based on the algal composition and abundance) revealed that site 4 which is a reservoir formed a separate cluster which is separated from the other three sites due to high

abundance level of *Cyclostella pseudostelligera* Hustedt and *Achnanthes brevipes* Agardth var. *intermedia* (Kutzing).

From the present study, it could be concluded that the algal assemblages of Umiew river is rich in species diversity. Agricultural activities along the catchment increased the nutrient concentrations particularly nitrogen which showed positive effect, that enhanced the diversity and abundance of algae. Thus, it could be said that addition of nutrients to this nutrient poor river water, stimulated growth of algae. Lime quarrying in the upstream of river Umtyngngar (site 3) increased carbonate ions of calcium and magnesium and slightly raised the pH of the water from acidic to alkaline. But though the pH was high, other factors like turbid nature of water in site 3 lowered the diversity of algal assemblages indicating the adverse effect of lime quarrying along the catchment area of the river.

## CHAPTER 6

### PRODUCTIVITY AND NUTRIENT CONTENT IN ALGAL ASSEMBLAGES IN UMIEW RIVER

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#### 6.1. INTRODUCTION

Primary productivity is the main functional characteristic of a community. In the river systems, algae are the primary producers and are vital energy source for secondary consumers, including invertebrates and fishes (Sanderson *et al.*, 2009). In unshaded rivers, limited biomass of primary producers due to low rates of primary production affected the higher trophic levels in aquatic food webs (Peterson *et al.*, 1993). Factors influencing rates of primary production by phytoplanktons, periphytons and macrophytes in lotic systems include nutrient content, light availability, temperature, disturbance, and grazers (Findlay *et al.*, 1993; Rosemond *et al.*, 1993; Biggs, 1996, 2000; Hill, 1996). Chlorophyll *a* content in algal biomass has long been used as a measure for primary production (Steinman & Lamberti, 1996).

Streams and rivers are open ecosystems that receive large inputs from their catchments (Mulholland, 1996). Cycling of nutrients through different biotic groups played a major role in maintaining nutrient level in those systems. Nutrient uptakes by algal biomass in flowing water sometime result in depletion of nutrient concentration and increase nutrient limitation of benthic algae (Mulholland, 1996). A number of studies are available where nutrient limitation

due to accumulation of nutrients in algal biomass have been demonstrated in different lotic systems suggesting the importance of nutrient cycling (Peterson *et al.*, 1983; Grimm & Fisher, 1986; Perrin *et al.*, 1987; Hill & Knight, 1988; Bothwell, 1989; Hill *et al.*, 1992; Rosemond *et al.*, 1993; Flecker *et al.*, 2002; Capps *et al.*, 2011). Dissolved nutrient ratios in the water column are often used to predict which nutrient specifically limits algal production (Edwards *et al.*, 2000; Vieux & Moreda, 2003). Redfield, (1958) demonstrated that ratio of atomic N: P for balanced algal growth should be 16: 1. For ambient nutrient ratios, nitrogen becomes potentially limiting when the ratio of dissolved inorganic nitrogen (DIN) to SRP (soluble reactive phosphorus) is much less than 16 and phosphorus become potentially limiting when the ratio is much greater than 16 (Qian, 2000). It is well known from existing literature that the addition of phosphorus whether solely or concurrently with nitrogen, increases periphyton abundance (Bothwell, 1985; Pan & Lowe, 1994; Dodds *et al.*, 1997; Winter & Duthie, 2000). There are several reports where different doses of nitrogen and phosphorus has been applied experimentally in the stream systems to determine which nutrient limit the algal growth and has been found that it varied in different systems (Stockner & Shortreed, 1978; Gregory, 1980; Fairchild & Lowe, 1984; Lowe *et al.*, 1986; Kutka & Richards, 1997; Mosisch *et al.*, 2001). Nitrogen limitation may be more common in tropical systems than in temperate systems (Talling & Lemoalle, 1998; Lewis, 2000). The question of nutrient limitation and the relationship between nutrient concentrations and

chlorophyll content is increasingly gaining importance because increased human activity is resulting in accumulation of nutrients giving rise to the problems associated with eutrophication and rapid deterioration of water quality (Meybeck *et al.*, 1988; Downing *et al.*, 1999). Literature on the productivity and nutrient content of algal assemblages in lotic system in India is still lacking and reports on only a few lakes are available (Khan & Zutshi, 1980; Zutshi & Wanganeo, 1984; Sarwar & Zutshi, 1989). In Meghalaya, in particular, reports on algal productivity and its role in nutrient cycling in different water bodies is scarce. Hence, the present study was aimed to determine the algal productivity in Umiew river, nutrient content in periphytic algal biomass, role of nutrients, mainly nitrogen and phosphorus ratio on algal productivity and nutrient sequestration by periphytic algae from the river water.

## **6.2. MATERIALS AND METHODS**

### **6.2.1. Estimation of chlorophyll *a* from phytoplankton biomass.**

For the estimation of chlorophyll *a* from phytoplanktons, the initial volume of water sample was recorded and the phytoplankton cells were separated by filtration. The filter papers were placed in a tissue-grinder and 2-3 ml of 90% acetone was added and ground until the filter fibers were separated. The acetone along with ground filters were transferred into a centrifuge tube, the tube was rinsed with another 2 ml of 90% acetone and added to centrifuge tube. The total volume was made to 10 ml with 90% acetone. The samples were stored in

darkness at 4°C for 10-12 hours. The absorbance of supernatant was measured at 664nm, 647nm and 630nm. Chlorophyll *a* was calculated by following the method given by Strickland and Parsons, (1972).

$$\text{Chlorophyll } a \text{ (mg/l)} = 11.85 (\text{OD}_{664}) - 1.54 (\text{OD}_{647}) - 0.08 (\text{OD}_{630}).$$

The chlorophyll concentrations in given water sample was calculated by the following formula.

$$\text{Chlorophyll } a \text{ (mg/l)} = \frac{\text{Chlorophyll } a \left(\frac{\text{mg}}{\text{L}}\right) \times \text{extract (L)}}{\text{Volume of sample (L)}}$$

#### **6.2.2. Estimation of periphytic chlorophyll *a*.**

Periphytic algae were collected from a known area (1cm<sup>2</sup>) of natural substrate for estimation of algal productivity. Samples were transferred to centrifuge tube and kept in ice box under complete darkness, transported to laboratory and stored till chlorophyll *a* estimation was carried out. Algal samples were washed several times with distilled water by centrifugation each time. Chlorophyll *a* was extracted in 90% acetone and kept overnight at 4°C to allow complete extraction of the pigments. The absorbance of supernatant was measured at different wavelengths using Parkin Elmer Spectrophotometer. The amount of chlorophyll *a* was calculated following the above equation. This equation gave chlorophyll *a* concentration in extract on a volume basis. Hence, the data were converted on area basis, i.e., mg/cm<sup>2</sup> of substrate.

Correlation between chlorophyll *a* content in periphytic algal biomass with different important water parameters were examined by linear regression

analysis using XLSTAT 2009. Chlorophyll *a* (mg/cm<sup>2</sup>) was regressed against total nitrogen (TN), phosphorus (P) and water current (WC).

### **6.2.3. Determination of elemental nutrients from periphytic algae and sediments.**

Algal biomass was mainly collected from periphytic algae. Biomass from site 1 and site 4 was too less for analyzing the nutrient content. Therefore, biomass was collected from site 2 and 3 during two dry seasons (winter and spring), i.e., from December to May where adequate amount of biomass could be obtained. During these two seasons, a conspicuous green algal mat dominated by *Spirogyra* sp. was observed in site 2 and *Oedogonium* sp. in site 3. The algal biomass was washed repeatedly with distilled water. The washing technique removed most of the unicellular algae but the filamentous algae remained. The algal samples were dehydrated in hot air oven at 100°C. The dried sample was made into fine powder and used for analysis of different macro and micro nutrients. Five replicates were taken for each nutrient analysis. 1 g of algal powder was digested in tri acid mixture containing nitric acid, sulfuric acid and perchloric acid in the ratio of 9:1:1. Digested samples were used for the analysis of different nutrients. Total nitrogen (TN) was estimated by Kjeldahl digestion method. In this method, 1 mg dried powdered alga was taken in a digestion flask. To this was added, 1g catalyst mixture and 5 ml concentrated H<sub>2</sub>SO<sub>4</sub>. Solution was digested at about 150°C till the solution turned light green to

colorless. The sample was cooled. The digest was transferred into 100 ml volumetric flask and the final volume was brought to 100 ml with distilled water. 25 ml of this digested sample was taken into another Kjeldahl's flask. The pH was adjusted to 9 and 1 ml of 10N NaOH was added.

Total carbon (TC) was estimated by using Liqui TOC II Elementer. Phosphorus was estimated by stannous chloride colorimetric method as mentioned for water analysis, calcium and magnesium by atomic absorption spectrophotometric (AAS) method whereas sodium and potassium by flame photometer spectroscopy. Relationships between periphyton chlorophyll *a* with percentage of nitrogen, phosphorus and carbon content of the algal biomass were examined by linear regression analysis.

For the determination of elemental nutrients from the sediments, a method prescribed by Round, (1957) was adopted. In this method, the sediment was air dried and powdered. 5 g powdered sediment was shaken with 200 ml of 0.5N acetic acid extractant for 6 hrs on a shaker at a constant speed. The solution was filtered and the resultant clear solution was analyzed for different nutrients following the methods as carried out for water samples. Differences in nutrient content (water, algae and sediment) were tested in between water and algae, water and sediment and algae and sediment by student t-test at  $p < 0.05$ .

#### 6.2.4. Nutrient limitation experiment

Water samples were collected from all the four sites during July, October and February representing monsoon, post monsoon and winter season respectively. At the same time, phosphate, total nitrogen (TN) were estimated. Algal assay procedure-bottle test was followed to determine the nutrient limiting condition as described by US-EPA, 1971 (US Environmental Protection Agency). *Scenedesmus obliquus* (Turpin) Kutzing isolated from the river was cultured in CHU media and was used as the test material. CHU media composition {modification of Chu No.10 (Bold & Wayne, 1978)} is mentioned below:

CaCl <sub>2</sub> .2H <sub>2</sub> O	36.7 mg/l
MgSO <sub>4</sub> .7H <sub>2</sub> O	36.9 mg/l
NaHCO <sub>3</sub>	12.6 mg/l
K <sub>2</sub> HPO <sub>4</sub>	8.70 mg/l
NaNO <sub>3</sub>	85.0 mg/l
NaSiO <sub>2</sub> .9H <sub>2</sub> O	28.4 mg/l
Ferric citrate solution	1ml
Micronutrients	1ml
pH	6.8

Field water was filtered, sterilized by autoclaving for 25 minutes. Experiment was carried out in culture tubes containing 10 ml of autoclaved river water, supplemented with nitrogen and phosphorus in different proportions. Tubes containing only test water were kept as control. KNO<sub>3</sub> (potassium nitrate) and Na<sub>2</sub>HPO<sub>4</sub> (disodium hydrogen phosphate) were used as a source of nitrogen and phosphorus respectively. Experiment for algal bioassay was designed as follows:

Sl.No	Treatment	
1	river water (Control)	C
2	river water +2 mg/l of N	HN
3	river water +0.5 mg/l of P	HP
4	river water +0.1 mg/l of N	LN
5	river water +0.05 mg/l of P	LP
6	river water + 2 mg/l of N + 0.5mg/l of P	H(N+P)
7	river water + 0.1mg/l of N +0.05 mg/l of P	L(N+P)

HN=high nitrogen; HP=high phosphorus; LN=low nitrogen; LP=low phosphorus; H(N+P)=high nitrogen and phosphorus; L(N+P)=low nitrogen and phosphorus.

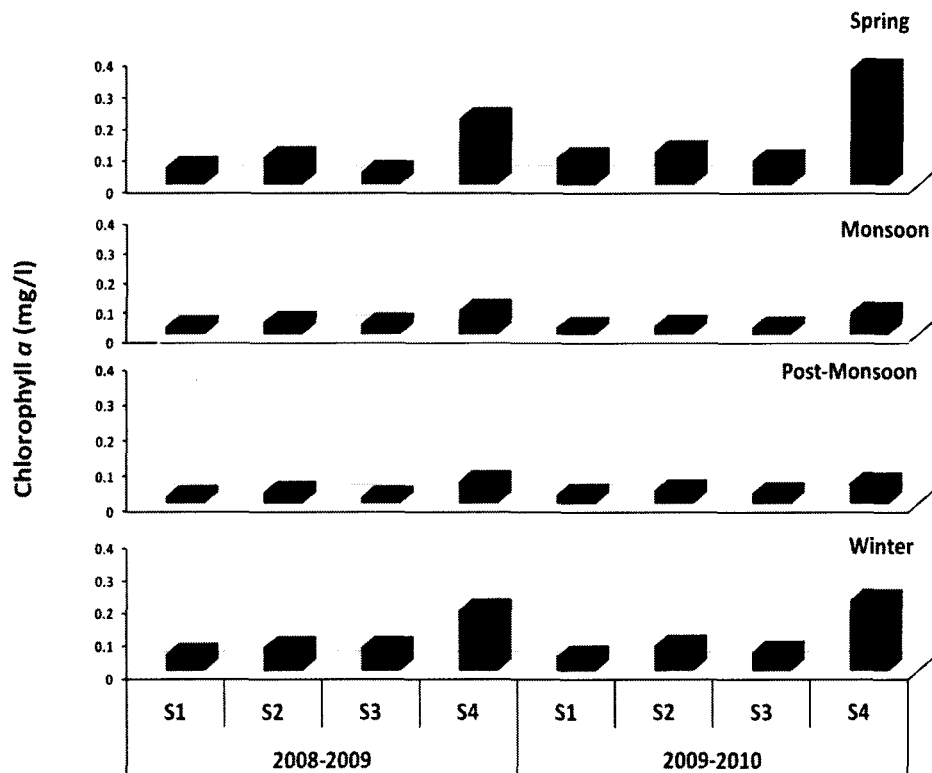
1 ml of *Scenedesmus obliquus* (Turpin) Kutzinger cells suspension having cell density of 1000 cells/ml was inoculated in each culture tube. The tubes were incubated in culture racks at a temperature of  $24 \pm 1^\circ\text{C}$  at  $45 \text{ m.mol m}^{-2}\text{S}^{-1}$  photon flux intensity, 16h/8h light and dark cycle. The tubes were hand shaken twice daily to resuspend the cells. Chlorophyll *a* was measured spectrophotometrically after 15 days by extracting the pigment in 90% acetone. Student *t-test* was employed to detect the significant differences ( $p < 0.05$ ) in the algal biomass production in different treated and untreated samples.

### 6.3. RESULTS.

#### 6.3.1. Planktonic productivity.

Planktonic chlorophyll *a* content was at its peak during spring and minimum during monsoon to post monsoon season. Productivity of phytoplanktons (chlorophyll *a*) was maximum in site 4 with a range of 0.05 to 0.36 mg/l. In other three sites (S1, S2 and S3), the productivity (chlorophyll *a* content) was

very low and ranged from 0.01 to 0.08 mg/l (fig. 6.1). No significant variation was observed among the sites (Table 6.1).



**Figure 6.1: Seasonal variations in planktonic algal productivity (chlorophyll *a* mg/l) in four study sites.**

### 6.3.2. Periphytic productivity.

Periphytic algal productivity (chlorophyll *a*) also showed variation among sites and seasons (fig. 6.2). Significant seasonal variations were observed among the sites (Table 6.1). Maximum production was recorded from site 2 with a range of

1.2 to 5.9 mg/cm<sup>2</sup> and minimum from site 4 with a range of 0.16 to 0.82 mg/cm<sup>2</sup>. In site 1, chlorophyll *a* production ranged from 0.64 to 3.65 mg/cm<sup>2</sup> and in site 3, it ranged from 0.73 to 5.21 mg/cm<sup>2</sup>.

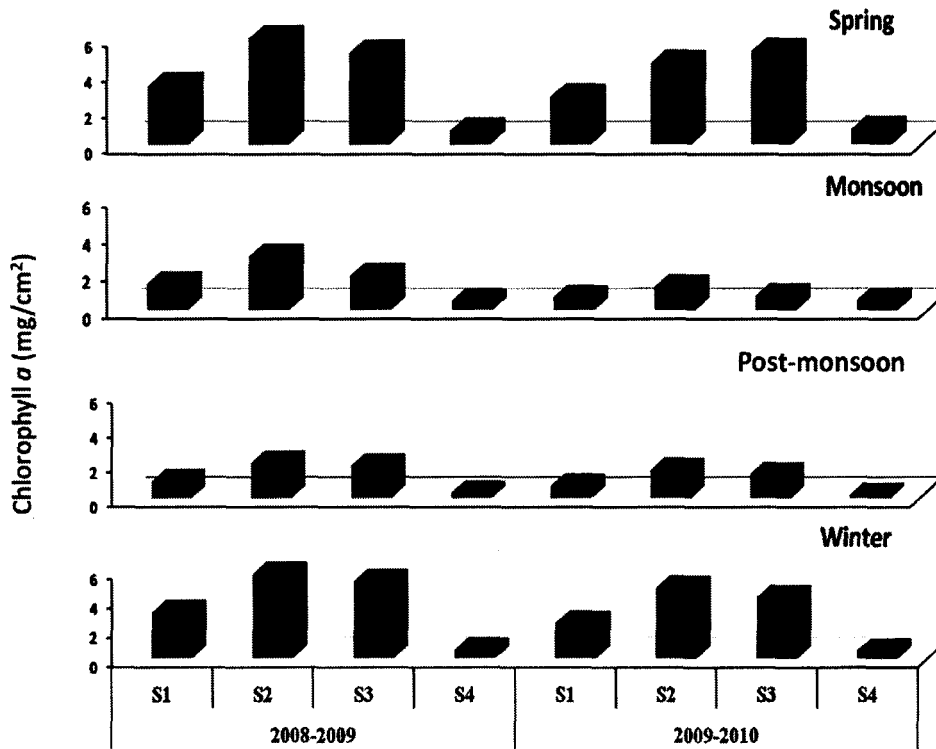


Figure 6.2: Seasonal variations in periphytic algal productivity (chlorophyll *a* mg/cm<sup>2</sup>) in four study sites.

Generally, the chlorophyll *a* content attained its peak during winter and spring season in all the study sites, when the rainfall was insignificant. Heavy rainfall during monsoon to post monsoon season increased the water current and reduced the algal productivity significantly. It was observed that during dry period (winter and spring), the river bed in site 2 was covered by a thin to a thick

turf of filamentous green algae particularly *Spirogyra* sp. and similarly by *Oedogonium* sp. in site 3 which contributed to higher productivity.

**Table.6.1: One-way ANOVA for algal productivity (periphyton and phytoplankton) analyzed in between sites in season at  $p < 0.05$ .**

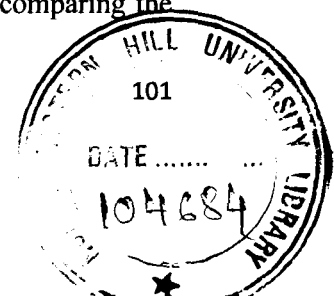
	Periphytons		Phytoplanktons	
	<i>F</i>	<i>p</i> -value	<i>F</i>	<i>p</i> -value
MONSOON	4.242	0.029	0.284	0.834
POST MONSOON	8.414	0.007	4.140	0.101
WINTER	19.99	0.0004	0.302	0.822
SPRING	4.171	0.0471	0.003	0.999

A correlation was established when a linear regression analysis was done between primary productivity (chlorophyll *a*) of periphytic algal biomass and nutrient concentrations such as total nitrogen (TN), phosphorus and also with water current which were found to be the main influential physical factors controlling productivity in two different and distinct seasons, i.e., dry season (winter and spring) and wet season (monsoon and post monsoon). From the regression analysis, a negative correlation was observed between water current and algal productivity in all the sites during wet season (fig. 6.3a) and positive correlation during dry seasons (fig. 6.3 b). In site 2, mainly this relationship was significantly high ( $r^2 = 0.49$ ;  $p = 0.0001$ ). On the contrary, the correlation between algal productivity with total nitrogen and phosphorus (fig. 6.4 to fig. 6.7) was positive during dry season (in S1,  $r^2 = 0.005$  for P and  $r^2 = 0.004$  for TN; in S2,  $r^2 = 0.07$  for P and  $r^2 = 0.57$  for TN; in S3,  $r^2 = 0.07$  for P and  $r^2 = 0.001$  for TN ; in S4,  $r^2 = 0.05$  for P and  $r^2 = 0.105$  for TN) and negative during wet season

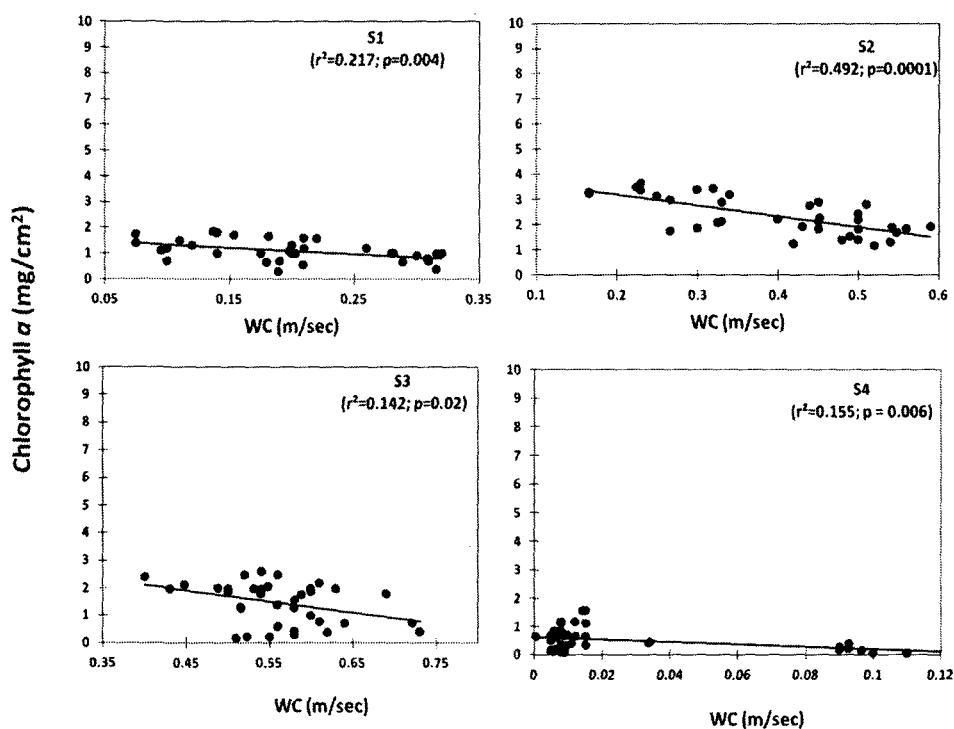
in all the sites (in S1,  $r^2= 0.04$  for P and  $r^2=0.01$  for TN ; in S2,  $r^2= 0.03$  for P and  $r^2=0.002$  for TN ; in S3,  $r^2= 0.10$  for P and  $r^2=0.001$  for TN ; in S4,  $r^2= 0.59$  for P and  $r^2=0.000$  for TN) although the correlation was not significantly strong except that in site 4 where a significant correlation was observed with phosphorus ( $r^2 = 0.596$ ;  $p= 0.0001$ ) during wet season (fig. 6.7). In site 2 also, the relationship between total nitrogen and chlorophyll *a* was significantly high ( $r^2=0.57$ ;  $p=0.0001$ ) during dry season (fig. 6.5).

### **6.3.3. Elemental composition of periphyton:**

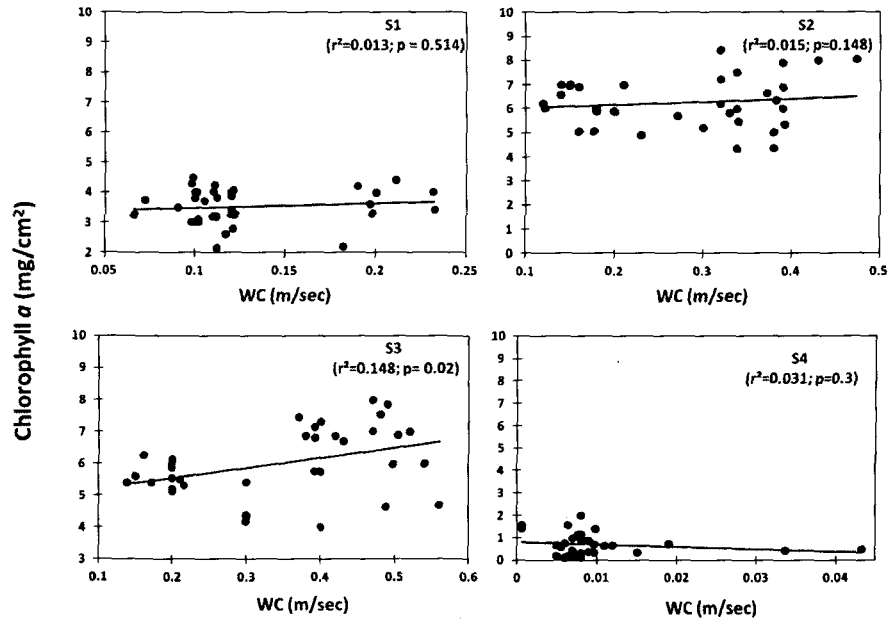
To evaluate the potential impact of periphyton on nutrient retention, nutrient contents (N, P, C, Ca, Mg, K and Na) accumulated in the biomass of periphytonic algae collected from two sites (S2 and S3) and in two seasons (winter and spring) were compared with nutrient concentrations in water column and in sediments of the river (Table 6.2). While comparing the different nutrient content from three different media, i.e., water, sediment and algal biomass, nitrogen content was found to be many fold and significantly higher in the algal biomass than the concentration in water and sediment in both the sites and seasons. Similar trend was observed in case of phosphorus, carbon and sodium concentration where those nutrient concentrations were more in algal biomass. Calcium and magnesium on the other hand were significantly higher in water compared to sediment and algal biomass whereas potassium was significantly higher in sediment than that of water and algal biomass. While comparing the



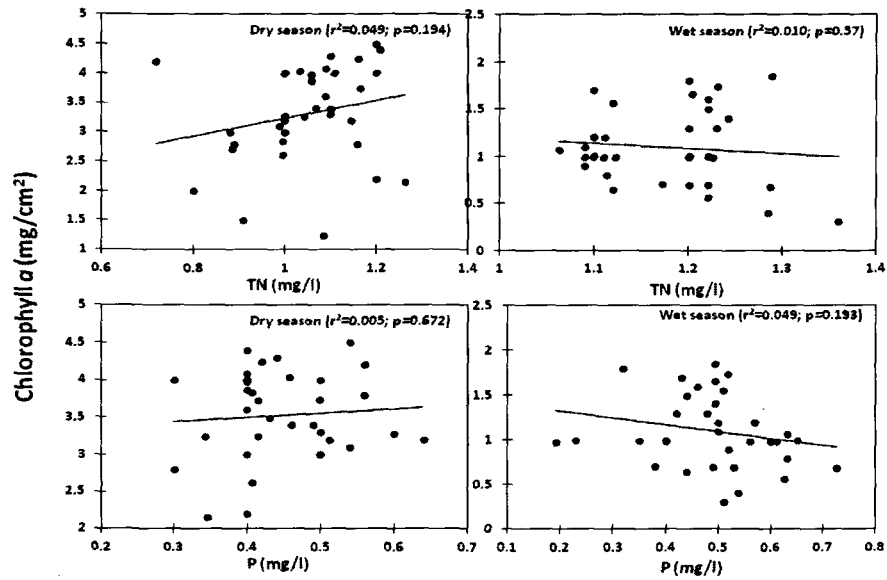
relationship between periphytic productivity (chlorophyll *a*) to nitrogen, phosphorus and carbon content in the periphytic algal biomass, a strong correlation could be established. Increase in chlorophyll *a* content in algal biomass was attained as the percentage of phosphorus ( $r^2 = 0.92$ ,  $p = 0.001$ ), nitrogen ( $r^2 = 0.95$ ,  $p = 0.0001$ ) and carbon ( $r^2 = 0.70$ ,  $p = 0.0001$ ) increased in the periphytic biomass mainly in site 2 (fig. 6.8 a). In site 3 (fig. 6.8 b), this strong correlation was observed only between carbon and chlorophyll *a* ( $r^2 = 0.77$ ,  $p = 0.0001$ ), but not with phosphorus ( $r^2 = 0.00005$ ,  $p = 0.98$ ) and nitrogen ( $r^2 = 0.08$ ,  $p = 0.38$ ).



**Figure 6.3a: Regression of periphytic chlorophyll *a* (mg/cm<sup>2</sup>) with water current (m/sec) in four study sites during wet season.**



**Figure 6.3b: Regression of periphytic chlorophyll *a* (mg/cm<sup>2</sup>) with water current (m/sec) in four study sites during dry season.**



**Figure 6.4: Regression of periphytic chlorophyll *a* (mg/cm<sup>2</sup>) with TN (mg/l) and P (mg/l) of ambient water in site 1 during dry and wet season.**

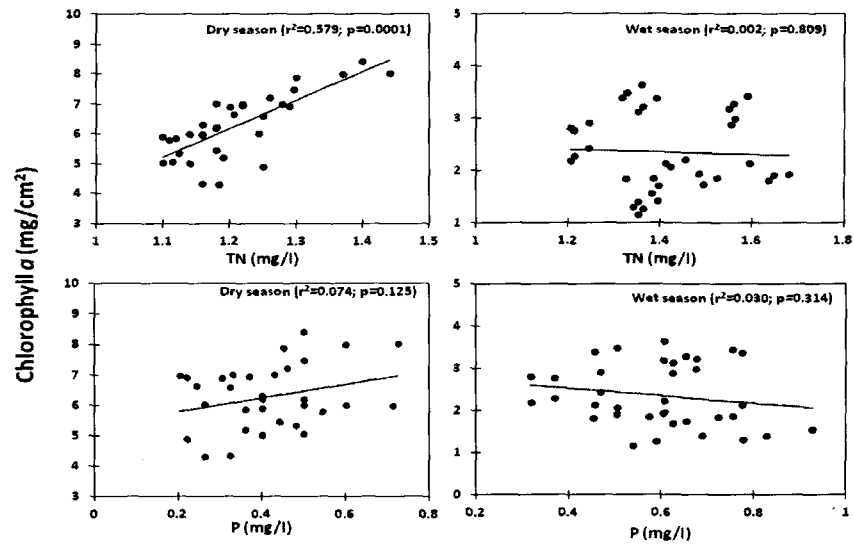


Figure 6.5: Regression of periphytic chlorophyll *a* (mg/cm<sup>2</sup>) with TN (mg/l) and P (mg/l) of ambient water in site 2 during dry and wet season.

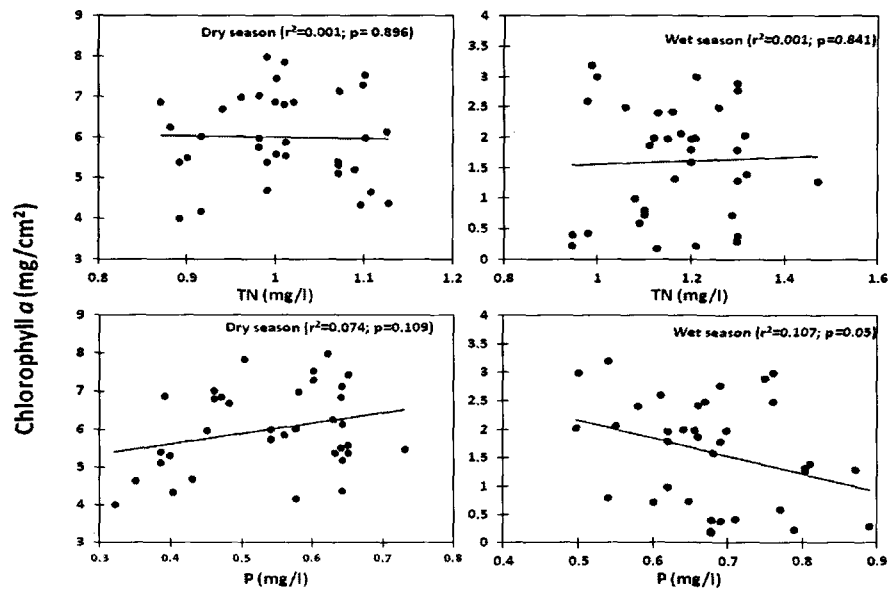


Figure 6.6: Regression of periphytic chlorophyll *a* (mg/cm<sup>2</sup>) with TN (mg/l) and P (mg/l) of ambient water in site 3 during dry and wet season.

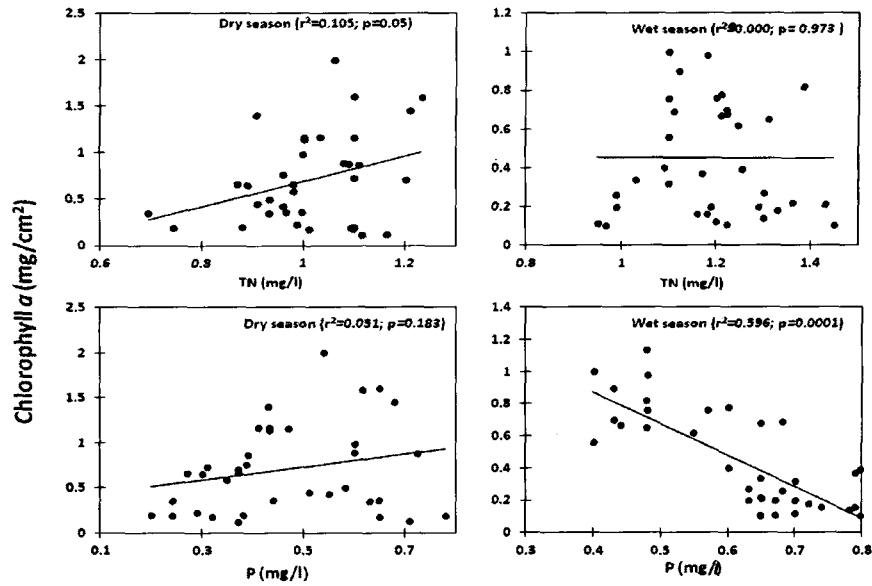
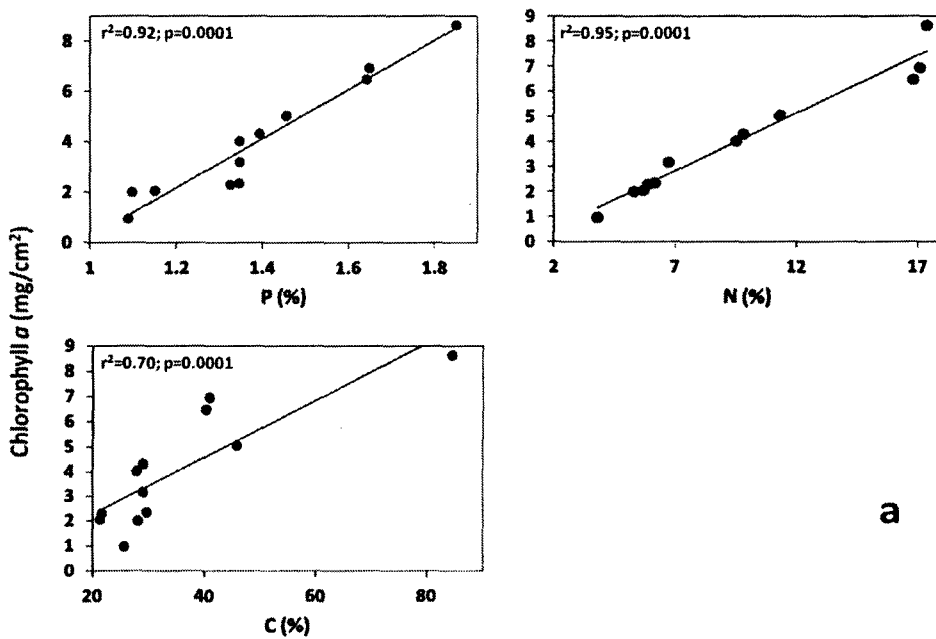
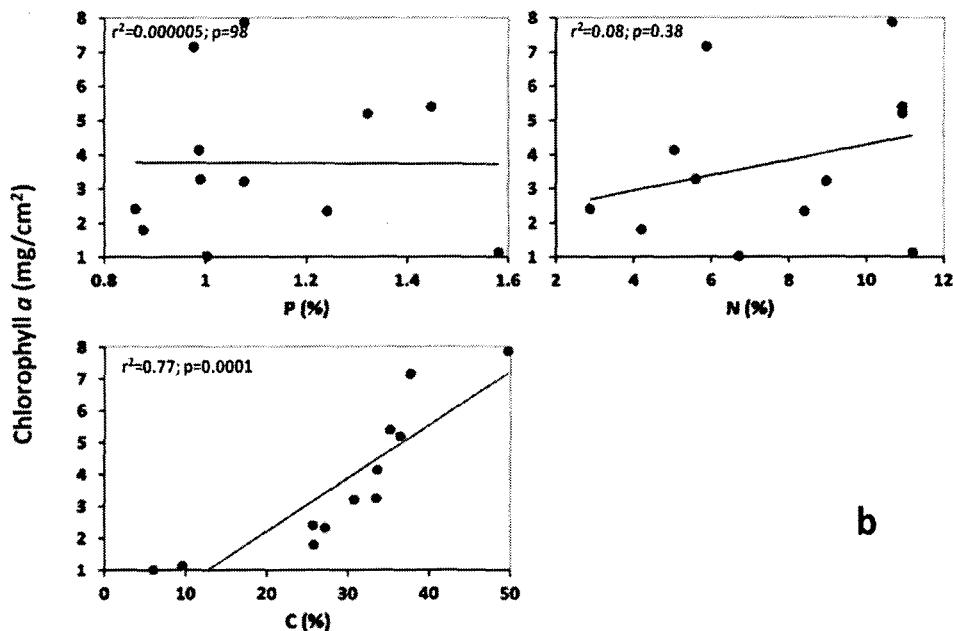


Figure 6.7: Regression of periphytic chlorophyll *a* (mg/cm<sup>2</sup>) with TN (mg/l) and P (mg/l) of ambient water in site 4 during dry and wet season.



a

Figure 6.8a: Regression of periphytic chlorophyll *a* (mg/cm<sup>2</sup>) content with percentage of P, N and C content of periphytic algal biomass in site 3.



**Figure 6.8b: Regression of periphytic chlorophyll *a* (mg/cm<sup>2</sup>) content with percentage of P, N and C content content of periphytic algal biomass in site 3.**

#### 6.3.4. Nutrient Limitation of algae:

It has already been found that different level of nutrients played a major role in algal productivity. Among the different nutrients, relative availability of N and P or co-availability of N and P especially their ratio in the water play major role in controlling algal productivity. TN (total nitrogen) of river water was highest during July (0.76 to 1.61 mg/l) and lowest during October (0.54 to 1.23 mg/l). Maximum TN (nitrate+nitrite) was obtained from site 2 during July (1.61 mg/l). PO<sub>4</sub> (phosphate) was maximum during October (0.53 to 0.64 mg/l) and minimum during July (0.22 to 0.34 mg/l). Maximum PO<sub>4</sub> was obtained from site 3 and 4. Nitrogen: Phosphorus (N: P) atomic ratio in site 1 ranged from 2.71:1 to

8.8:1; in site 2, it ranged from 2.61:1 to 10.45:1; in site 3, it ranged from 1.81:1 to 5.23:1 and in site 4, it ranged from 4.54:1 to 14.13:1. Maximum N: P ratio was recorded from site 4 during July (14.13:1).

**Table 6.2: Elemental nutrient content in water, sediment and algal biomass. Different letters indicates significant different from each media at  $p < 0.05$ .**

<b>S2</b>						
	<b>Winter</b>			<b>Spring</b>		
	<b>Water</b>	<b>Sediment</b>	<b>Algae</b>	<b>Water</b>	<b>Sediment</b>	<b>Algae</b>
<b>N(ppm)</b>	c0.39± 0.16	a1.22± 0.21	b65906.66 ±25097	c0.31± 0.18	a1.13± 0.25	b126466.66 ±51123.3
<b>P(ppm)</b>	a3900± 1600	a4800± 190	b14500± 2600	c2900± 150	a7100± 230	b13200± 1900
<b>TC (%)</b>		a 4.03± 0.11	b28.2± 1.42		a5.36± 1.21	b42.40± 12.11
<b>Ca(ppm)</b>	c14.41± 2.01	a2.99± 0.86	b1.13± 0.95	c16.44± 2.42	a5.00± 0.89	b1.77± 0.54
<b>Mg(ppm)</b>	b7.12± 2.84	a3.44± 1.72	ab4.77± 2.08	a11.79± 4.75	a7.04± 0.68	a5.47± 2.73
<b>K(ppm)</b>	a 10.12 ±1.87	50.8± 3.11b	39.6± 8.29c	a12.04± 2.01	b65.2± 7.26	b55± 12.49
<b>Na(ppm)</b>	a17.07± 2.46	b19.4± 2.07	c44.5± 7.09	a19.76± 2.98	b17.6± 2.7	c49.5± 9.89
<b>S3</b>						
	<b>Winter</b>			<b>Spring</b>		
	<b>Water</b>	<b>Sediment</b>	<b>Algae</b>	<b>Water</b>	<b>Sediment</b>	<b>Algae</b>
<b>N(ppm)</b>	c0.38± 0.04	a0.85± 0.06	b60666.66 ±16485.95	c0.25± 0.09	a1.04± 0.23	b91600.00± 32423.23
<b>P(ppm)</b>	c3800± 400	a6400± 2100	b11700± 2900	b2100± 900	a9100± 3600	a10500± 1300
<b>TC (%)</b>		a7.06± 2.04	b26.52± 8.08		a7.98± 2.07	b31.81± 7.17
<b>Ca(ppm)</b>	c17.74± 2.3	a5.66± 2.65	b1.07± 0.14	c19.01± 3.10	a9.66± 3.02	b1.49± 0.36
<b>Mg(ppm)</b>	c6.39± 0.72	a4.52± 0.51	b2.65± 0.32	ab14.05± 12.58	a4.00± 0.91	b2.76± 0.14
<b>K(ppm)</b>	a9.31 ± 1.04	b57± 11.86	b61.8± 12.71	a9.98± 1.20	b58.4± 13.63	b48± 17.10
<b>Na(ppm)</b>	a15.2 ± 1.76	b46.2± 5.58	b58.6± 7.25	a17.92± 2.01	b33.2± 9.41	b46.4± 4.85

In the present study, N: P atomic ratio was found to be consistently low, i.e., less than the Redfield ratio in all the sites (Table 6.3). Low N: P atomic ratio thus clearly indicated that the river water was in nitrogen limited condition. Addition of nitrogen into the test water raised the chlorophyll *a* content in the test alga significantly specially at high nitrogen level, i.e., 2 mg/l in most of the treatments. In those treatments where water was collected from site 3 and 4 during October, the increase was not significant. Addition of phosphorus also increased the chlorophyll *a* in both low and high doses but the increase was not significant. High concentration (2 mg/l of N + 0.5 mg/l of P) of N+P added into the test alga yielded much higher productivity, 2-3 folds higher value than the control (fig. 6.9 to 6.12).

**Table 6.3: TN, PO<sub>4</sub> and N: P ratio of river water at different sites collected in three different periods representing three seasons. J=January; O=October; F=February; *p* <0.05.**

Parameters	S1				S2			
	J	O	F	<i>p</i>	J	O	F	<i>p</i>
TN (NO <sub>3</sub> +NO <sub>2</sub> mg/l)	1.03	0.64	0.81	0.002	1.61	0.74	0.84	0.00002
PO <sub>4</sub> (mg/l)	0.24	0.53	0.25	0.03	0.33	0.61	0.23	0.002
N:P	8.31	2.71	8.8	0.009	10.45	2.61	8.54	0.0007

Parameters	S3				S4			
	J	O	F	<i>p</i>	J	O	F	<i>p</i>
TN (NO <sub>3</sub> +NO <sub>2</sub> mg/l)	0.76	0.54	0.94	0.002	1.28	1.23	0.93	0.21
PO <sub>4</sub> (mg/l)	0.32	0.64	0.29	0.003	0.22	0.63	0.51	0.0005
N:P	5.23	1.81	8.6	0.01	14.13	4.85	4.54	0.003

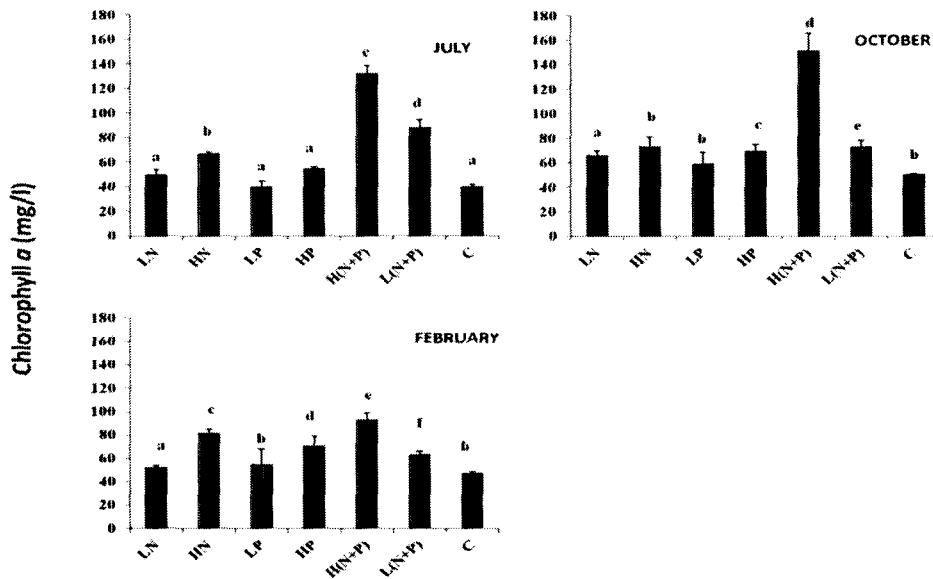


Figure 6.9: Chlorophyll *a* content in *Scenedesmus obliquus* cultured in only river water and river water supplemented with different levels of N and P in different seasons in site 1. Error bar indicates standard deviation. Different letter indicates significant different from the control mean at  $p < 0.05$ .

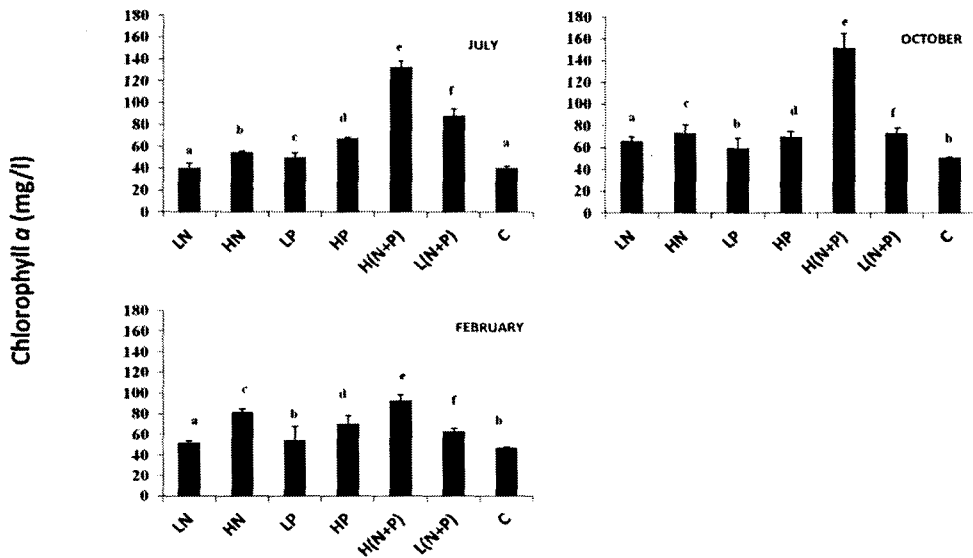


Figure 6.10: Chlorophyll *a* content in *Scenedesmus obliquus* cultured in only river water and river water supplemented with different levels of N and P in different seasons in site 2. Error bar indicates standard deviation. Different letter indicates significant different from the control mean at  $p < 0.05$ .

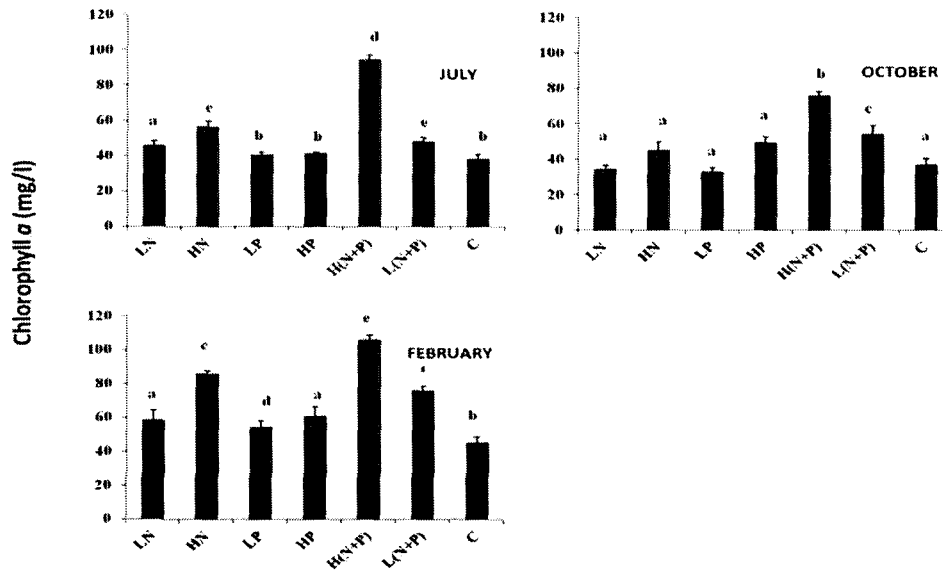


Figure 6.11: Chlorophyll *a* content in *Scenedesmus obliquus* cultured in only river water and river water supplemented with different levels of N and P in different seasons in site 3. Error bar indicates standard deviation. Different letter indicates significant different from the control mean at  $p < 0.05$ .

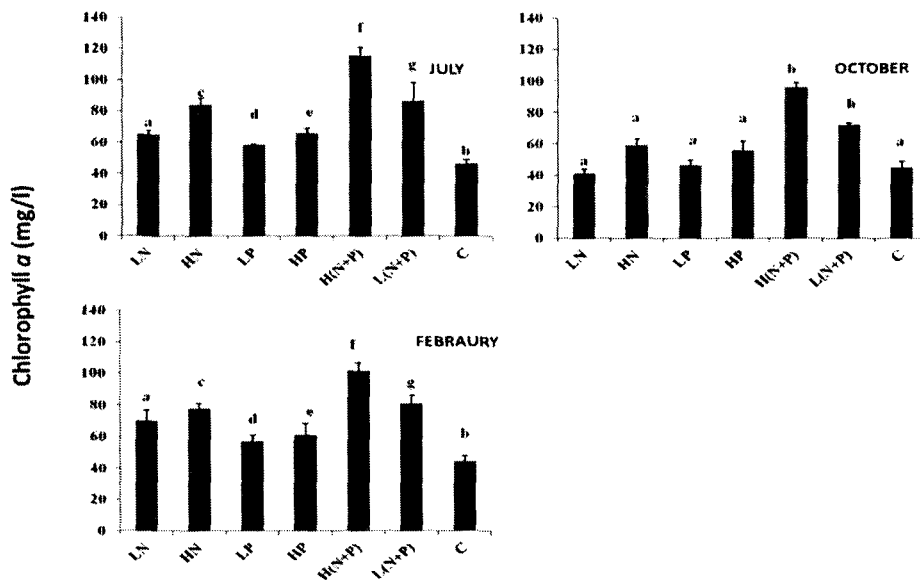


Figure 6.12: Chlorophyll *a* content in *Scenedesmus obliquus* cultured in only river water and river water supplemented with different levels of N and P in different seasons in site 4. Error bar indicates standard deviation. Different letter indicates significant different from the control mean at  $p < 0.05$ .

#### 6.4. DISCUSSION

The algal productivity in Umiew river followed a seasonal pattern, i.e., higher productivity in dry winter and spring seasons and low in wet monsoon and post monsoon seasons. This trend has also been observed and reported by many authors from tropical streams (Mosisch & Bunn, 1997; Moschini *et al.*, 2000; Vercellino & Bicudo, 2006; Borduqui *et al.*, 2008; Davies *et al.*, 2008) and from many other parts of monsoonal Asia (Bishop, 1973; Dudgeon, 1982, 1999, 2000; Yang *et al.*, 2009). It is well documented that among the factors that affect algal biomass, rainfall is the most important one which induces high velocity of current and reduces the algal standing crop. This is reflected in the present study where inversed regression was observed between chlorophyll *a* content and water current. Many workers from different parts of the world reported the same trend in different lotic systems (Power & Stewart, 1987; Grimm & Fisher, 1989; Stevenson, 1990; Ghosh & Gaur, 1994; Bergey & Resh, 2006). A significant decline in algal productivity due to high velocity of current during monsoon has been reported by many workers where they explained the decline in productivity or algal biomass as a result of dislodgement of filamentous algal groups due to increase in flow rate and also reported that excessive drag disturbances caused by higher water velocity resulted in the dominance of benthic diatoms group during monsoon season (Sagar, 1986; Biggs & Close, 1989; Biggs & Hickey, 1994; Biggs *et al.*, 1998; Biggs *et al.*, 2005).

According to Welch *et al.*, (1988) and Horner *et al.*, (1983) benthic algal chlorophyll *a* content from an unpolluted river systems varied within a range of 0.1-0.15 mg/cm<sup>2</sup>. Chlorophyll *a* content more than that indicated that the water system was at risk. The amount of chlorophyll *a* content of periphytic algae in the present study ranged from 0.16 to 0.59 mg/cm<sup>2</sup> in three sites (S1, S2 and S3) having much higher values than 0.15 mg/cm<sup>2</sup>. Algal biomass ranging from 0.47 to 0.62 mg/cm<sup>2</sup> was also reported by Munn *et al.*, (2010) from agricultural stream where they related the high biomass to coarse-grained substrate (rocks). High chlorophyll *a* content value obtained in the present study also may be related to the presence of huge rocks and rocky nature of the substrata which supported the growth of many filamentous algae with higher biomass.

Biggs and Shand, (1987) also reported approximately 15 times greater benthic algal biomass in Clutha river from hard substrate (e.g. rock) than that on fine-grained sediments. Seasonal variations in algal productivity with high values of chlorophyll *a* content in winter and spring could thus be related to the abundant growth of filamentous green algae during that period where the velocity of current was least (Biggs *et al.*, 2005). Apart from current velocity, light and nutrients were the other key determinants controlling the algal community structure, their productivity and nutrient dynamics in flowing ecosystems (Hill & Knight, 1988; Hill *et al.*, 1995; Quinn *et al.*, 1997). Many workers have reported an increase in algal productivity in lotic communities with increase in nutrient level in ambient water (Horner *et al.*, 1983; Hill *et al.*,

1992; Dodds *et al.*, 1997; Biggs, 2000; Stelzer & Lamberti, 2001; Dodds *et al.*, 2002; Tank & Dodds, 2003; Kiffney *et al.*, 2004; Von Schiller *et al.*, 2007). In the present study, relating to the algal productivity with nutrient concentrations particularly nitrogen and phosphorus in ambient water, it was observed that during dry seasons (winter and spring), the algal productivity was significantly high compared to wet seasons (monsoon and post monsoon) although the nutrient levels of ambient water was low. The occurrence of this condition could be due to high nutrient uptake by algal periphytons and thereby reducing the concentration of nutrients in the ambient water during that period. In winter and spring, i.e., in low flow period, a linear increase in cellular nutrient content (N, P and C percentages) was also observed with increase in algal biomass production, i.e., chlorophyll *a* content in periphytons. This kind of situation with low soluble nutrient concentrations in water but high periphyton biomass has been reported from shallow cobbly streams in New Zealand (Biggs, 1995). Therefore, the concentrations of dissolved nutrients measured in the ambient water mainly reflected the nutrients that are left over after the periphytons had taken the nutrients (Biggs, 2000a). In streams with rare floods and long accrual periods (>100 days), a relatively small increase in dissolved nutrients greatly increased the frequency of high biomass accumulation (Biggs, 2000).

Low nutrient level and shaded condition formed by riparian vegetation on the banks of the narrow river could be the important factors responsible for low algal production in site 1 compared to site 2 and 3. Lowe *et al.*, (1986); Hill

and Knight, (1988) reported four to five times higher productivity in open area of river compared to shaded area created by tree canopy. According to River Continuum Concept proposed by Vannote *et al.*, (1980) the benthic algal biomass increased downstream from headwater to mid catchment as the channel widened and shading got reduced and then decreased in the lower regions of the catchment as depth and turbidity increased. Same is true in the present study where algal productivity was significantly low in upstream (site 1), which is the source of the river and also in site 4 located downstream of the river, where the river appears like a reservoir with stable flow and very high depth and width and low light availability due to construction of a dam. Algal productivity in the mid region of the river i.e., in site 2 and site 3 was significantly higher. The absence of coarse rocks and suitable substrata for the accrual of periphytons particularly the green filamentous form might be the other possible reason for low productivity in upstream and downstream of the river. According to Langdon, (1988), filamentous green algae required more light than diatoms or other groups. However, increased irradiance not only increased algal biomass but also changed the composition of the periphyton assemblages by promoting the growth of filamentous green algae (Steinman *et al.*, 1989; Hill, 1996). Substantial growth of green filamentous algae (*Spirogyra* sp. and *Oedogonium* sp.) in site 2 and 3 of the river reduced the availability of nutrients to downstream sites by taking up the nutrients in inorganic form and releasing it back to river water in organic form (Tate, 1990; Mulholland, 1992).

As observed in the present study the elevated nutrient contents in algal biomass compared to ambient water and sediments were also reported by Steven *et al.*, (2001) in southeastern Ohio and Godwin *et al.*, (2009) in temperate streams. In addition, a number of research studies are available where nutrient/metal concentration in the algal biomass have been reported to be much higher than that in ambient water concentrations (Rai *et al.*, 1981; Lawrence *et al.*, 1998, Das & Ramanujam, 2011). The high nutrient accumulating capacity of periphytons in the river, especially nitrogen, might be the reason for the low N content in the river which made it a limiting nutrient for the growth of other algal groups. Increased nitrogen, phosphorus and carbon concentration in algal biomass in site 2 might be due to input of nutrients from the catchment agricultural area in the form of fertilizers through runoff into the river (Kendall *et al.*, 2001). High percentage of total carbon content in the algal biomass was the primary source of organic matter in the river (Wetzel *et al.*, 1997; Frost *et al.*, 2002; Wilson *et al.*, 2003). High potassium content in the sediments than water and algal biomass indicated that the sediments are rich in potassium but algal assemblages present in the system are poor absorber of potassium. Similar reasons might be applicable for calcium and magnesium as the level of those two have been found to be lower in algal biomass than its concentration in the ambient water and sediments. The high nutrient content in algal biomass as observed in the present study thus indicated that algal assemblages in the river

could be able to support other biotic groups as good source of food for macro invertebrates, fishes and other aquatic organisms which feed on them.

Based on Redfield atomic ratio, the N: P ratio in Umiew river has been found to be low indicating the nitrogen limiting condition of the river. The bioassay results supported this contention as algal growth was enhanced by nitrogen supplementation to the river water. Nitrogen limiting condition has also been reported from many streams (Bothwell, 1988, 1989; Stanley *et al.*, 1990; Peterson *et al.*, 1993; Edwards *et al.*, 2000; Francoeur, 2001; Capps *et al.*, 2011). Talling and Lemoalle, (1998) and Lewis, (2000) reported that N limitation may be more common in tropical systems than in temperate ones. Earlier, Ghosh and Gaur, (1990) reported phosphorus limitation in streams of this region. Phosphorus had been considered as the primary limiting nutrient in many fresh water ecosystems (Vollenweider 1968; Borchardt, 1996; Notestein *et al.*, 2003) and in most fresh water ecosystems, concentration of phosphorus was less than that of nitrogen (Wetzel & Likens, 2006). The addition of both nitrogen and phosphorus to the test material showed even better response as the chlorophyll *a* content was 2-3 times higher in high N+P set than the control set indicating that not only nitrogen which is indicated by Redfield ratio but phosphorus in the river water is also limited. Many in-situ experiments in lotic systems has been conducted worldwide which showed that a combination of nitrogen and phosphorus together enhanced algal biomass production than where it was given singly (Bothwell, 1985; Hershey *et al.*, 1988; Panand Lowe, 1994; Dodds *et al.*,

1997; Winter & Duthie, 2000). Increased biomass with nitrogen addition in bioassay experiments suggested that nitrogen deficiency was one of the important factors that is limiting algal productivity in Umiew river. From the present study it can be confirmed that the standing crop of algae in the river at present is low and below nuisance level. It clearly indicated that if level of nutrients particularly nitrogen is enhanced due to increased anthropogenic activities along the catchment of the river, it may however effectively enhance algal biomass production which eventually might led to eutrophication. Thus, the knowledge regarding the nutrient level in the water and its relationship to algal biomass production could be utilized for formulating effective water management programme.

## CHAPTER 7

### EFFECT OF WATER CURRENT ON ALGAL COLONIZATION

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#### 7.1. INTRODUCTION

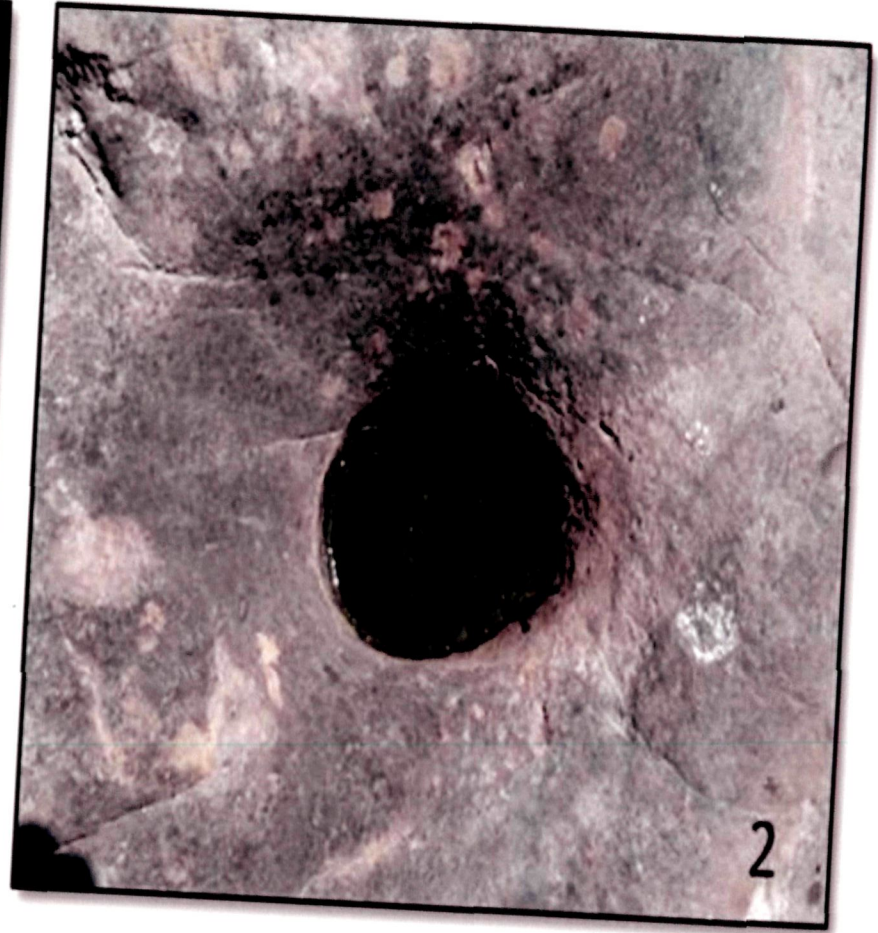
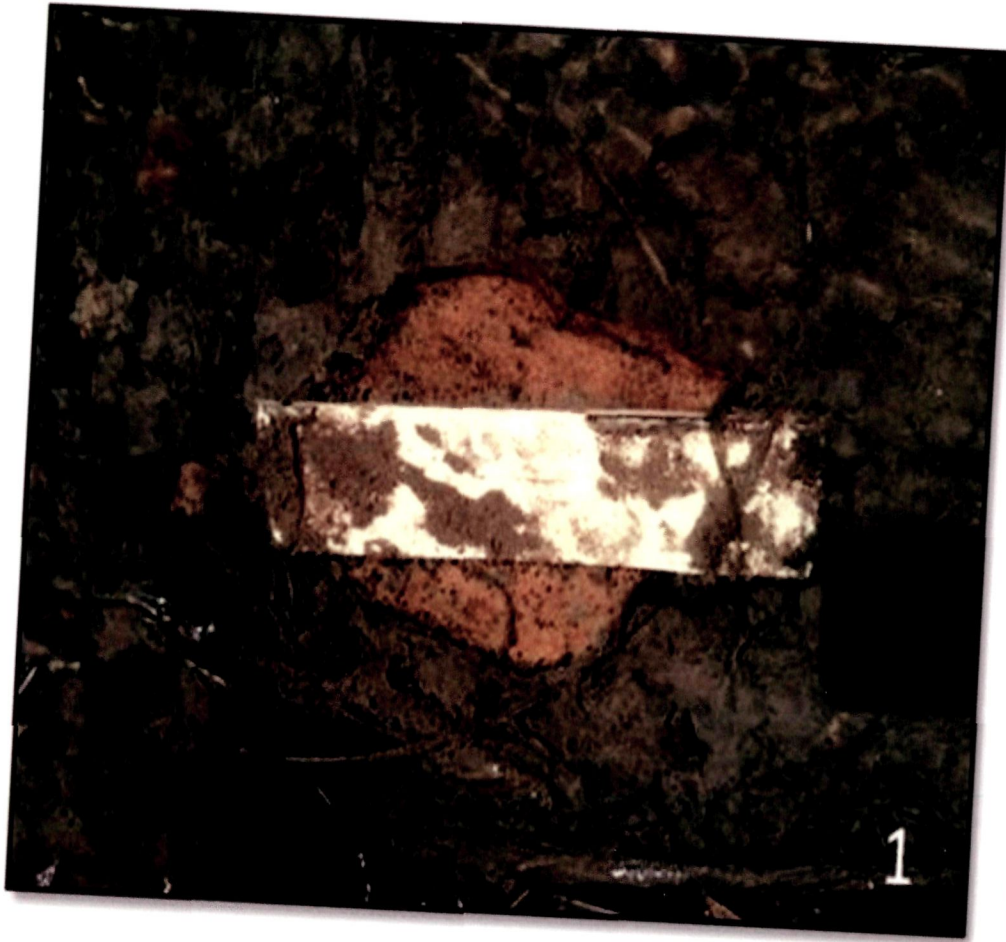
In riverine systems, velocity of current varies spatially and temporally over a range of scales and influences benthic algal biomass via several mechanisms (Hart & Finelli, 1999). Current velocity can have both positive and negative effects on the biomass and composition of stream algal communities (McIntire, 1966; Reisen & Spencer, 1970; Stevenson, 1984; Lamb & Lowe, 1987; Horner *et al.*, 1990; Poff *et al.*, 1990; Uehlinger, 1991; Stevenson, 1996). Increasing velocity can either positively influence biomass production by increasing nutrient availability through reduced thickness of the laminar boundary layer or negatively by increasing shear stress on algae. A positive effect of high current on benthic algal nutrient uptake and growth has been hypothesized for several decades (Whitford & Schumacher, 1961; McIntire, 1966; Riber & Wetzel, 1987; Sanford & Crawford; 2000, Larned *et al.*, 2004). Current velocity can influence macro invertebrate grazing (Opsahl *et al.*, 2003, Wellnitz & Poff, 2006) and grazing can affect directly benthic algal composition, physiognomy, and indirectly, resistance to sloughing (DeNicola & McIntire, 1990; Pringle, 1990;

Rosemond *et al.*, 1993; Biggs & Hickey, 1994, Biggs *et al.*, 1998; Darcy-Hall & Hall, 2008)

In lotic ecosystems, high and low flows have the potential to alter ecosystem structure and function profoundly through scour and accrual of epilithon. Variations in discharge and flow velocity influence the flux of nutrients to periphytic communities and shape algal community structure (Biggs & Thomsen, 1995, Dodds *et al.*, 1996, Biggs *et al.*, 1998; Dodds & Biggs, 2002; Francoeur & Biggs, 2006). Spatial variation in flow can be well manifested in differences between pools and riffles, which have very different benthic flow characteristics. In tropical streams and rivers, especially in North-East India this type of study is scanty (Ghosh & Gaur, 1998). In order to know the effect of current on various periphytic algae, the present study has been carried out by allowing the periphytic algal colonization on ceramic tiles at different flow regimes.

## **7.2. MATERIALS AND METHODS**

The experiment was set up in dry season (first week of February to second week of March) where no rainfall was recorded in order that there was not much fluctuation in the water current. The experiment was done following the method given by Ghosh and Gaur (1991). For this experiment, artificial substrates were horizontally placed and oriented parallel to the water current, 5 cm beneath the water surface. The artificial substrates were made up of ceramic tiles (10cm X



**Ceramic tile place in riffle zone (1) and pool (2)**

4cm) which were fixed on the upper side of a brick. The ceramic tiles were placed in the riffle zone under three flow conditions *i.e.* low flow (8 to 12.5 m/sec), moderate flow (18 to 25 m/sec) and high flow (50 to 68 m/sec) and also in the pool (no flow). Altogether 60 tiles were placed in the fields with 3 replicates each.

After the experiment was set up, the periphytons were allowed to colonize the ceramic tiles. At weekly intervals, three replicate substrata were retrieved from each riffle and pool habitat and the tiles were carefully placed into the plastic bag and brought to the laboratory for further studies. In the laboratory, the samples were divided into two equal parts. One part was used for quantitative analysis and the other part was used for chlorophyll *a* estimation. Chlorophyll *a* was estimated spectrophotometrically by following the methods of Strickland and Parson, (1972). Algal samples were observed as fast as possible under Olympus microscope (BX41) and photographed with the help of digital camera directly fitted to the microscope. Preservation, enumeration and identification were done following standard methods (as given in chapter 5). The total number of species and cells were calculated per cm<sup>2</sup>. At the same time, physico-chemical parameters of the water were also studied at weekly interval as mentioned in chapter 4.

One way ANOVA was performed for different environmental variables to test whether they differed significantly in different flow regimes and multivariate statistical analyses (Canonical Correspondence Analysis) was

performed using XLSTAT 2009 to relate the abundance of different dominant species to different environmental variables at different flow regimes. In order to avoid the interaction of less important species in CCA, only those species which showed relative abundance of more than 5% were taken into account.

### **7.3. RESULTS**

Water parameters of the river showed variations between pool and riffle zone. pH value ranged from 6.1 to 6.75 but did not show significant difference between two microhabitats. Electrical conductivity ranged from 53.33 to 96.66  $\mu\text{S}/\text{cm}$  and found to be significantly high in the pool. Dissolved oxygen was more in the riffle zone and low in the pool with a range of 4.37 to 8.64 mg/l. Nitrate and phosphate values were higher in the pool compared to that of riffle zone. The nitrate concentration ranged from 0.62 to 1.45 mg/l where as phosphat ranged from 0.22 to 0.53 mg/l. All the environmental parameters except pH when subjected to ANOVA were found to be different among different flow regime at  $p < 0.05$ . Detailed water chemistry is provided in Table 7.1.

The periphytic algal assemblages encountered under different flow regimes included members of Bacillariophyceae, Euglenophyceae, Cyanophyceae, Chlorophyceae, Chrysophyceae and Cryptophyceae. 83 algal species were encountered during the study, of which 40 species belonged to Bacillariophyceae, 27 species to Chlorophyceae, 9 species to Euglenophyceae, 5

species to Cyanophyceae, and one species each to Chrysophyceae and Cryptophyceae respectively.

**Table 7.1: Water parameters at different flow regime; HF= high flow; MF= moderate flow; LF= low flow; P =pool; *p*-value indicates mean differences in the entire flow regime (one way ANOVA).**

Variables	HF	MF	LF	P	<i>p</i> -value
WC (cm/sec)	50-68±9	18-25±3.0	8-12.5±2	No flow	0.000006
pH	6.65±0.08	6.10±0.70	6.27±0.45	6.75±0.14	0.1908
EC (µS/cm)	53.33±5.77	59.66±0.57	73.33±20.81	96.66±20.81	0.0320
DO (mg/l)	8.64±0.61	7.82±0.57	6.65±0.34	4.37±0.85	0.0001
NO <sub>3</sub> (mg/l)	0.80±0.14	0.95±0.08	0.62±0.04	1.45±0.32	0.0029
PO <sub>4</sub> (mg/l)	0.22±0.06	0.24±0.01	0.23±0.03	0.53±0.15	0.0057

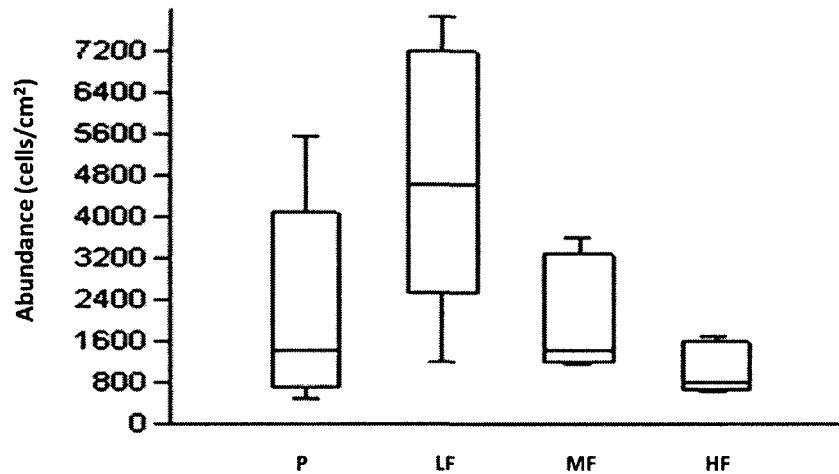
Diatoms were the most dominant group in the riffle zone, whereas in the pool, green algae were the most dominant one, in which *Spirogyra varians* (Hassall) Kutzling, *Euglena mutabilis* Schmitz and *Scenedesmus obliquus* (Turpin) Kutzling were the dominant species which contributed maximally to the total cell abundance. *Spirogyra varians* (Hassall) Kutzling was mainly found in the pool as an unanchored floating mat. Many species were common to both the microhabitats, but 13 species were encountered only from the pool. Twenty species were found only in low flow and *Pinnularia braunii* (Grunow) Cleve was found only in high flow zone. *Synedra acus* Kutzling, *Synura* sp. and *Pithophora* sp. were present only in moderate flow.

**Table 7.2: List of algal species in artificial ceramic tiles in different flow regimes after 5 week incubation.**

<b>CHLOROPHYCEAE</b>	<b>LF</b>	<b>HF</b>	<b>MF</b>	<b>P</b>
<i>Ankistrodesmus falcatus</i>	+	-	-	+
<i>Characium</i> sp.	+	-	-	-
<i>Chlamydomonas</i> sp.	+	-	-	+
<i>Closteriopsis acicularis</i>	+	-	+	-
<i>Closterium abruptum</i>	+	-	-	-
<i>Closterium attenuatum</i>	-	-	-	+
<i>Closterium rostratum</i>	+	-	+	-
<i>Closterium striolatum</i>	+	-	-	-
<i>Closterium venos</i>	+	-	+	-
<i>Cosmarium australe</i>	+	-	-	-
<i>Cosmarium polygonum</i>	-	-	-	+
<i>Cosmarium subcrenatum</i>	+	-	-	-
<i>Gonotozygon kinahanii</i>	+	-	-	-
<i>Hyalotheca</i> sp.	+	-	+	+
<i>Maugeatia</i> sp.	+	+	+	-
<i>Microspora</i> sp.	-	-	+	-
<i>Monoraphidium contortum</i>	+	+	-	-
<i>Oedogonium</i> sp.1	+	-	-	+
<i>Oedogonium</i> sp. 2	+	-	+	+
<i>Pithophora</i> sp.	-	-	+	-
<i>Scenedesmus abundans</i>	+	-	-	-
<i>Scenedesmus dimorphos</i>	+	-	+	+
<i>Scenedesmus obliquus</i>	-	-	-	+
<i>Scenedesmus opoliensis</i>	-	-	-	+
<i>Spirogyra varians</i>	+	+	+	+
<i>Staurastrum punctulatum</i>	+	-	+	+
<i>Stigeoclonium glomeratum</i>	+	-	-	+
<b>BACILLARIOPHYCEAE</b>				
<i>Achnanthes brevipes</i> var. <i>intermedia</i>	+	+	+	+
<i>Amphora</i> sp.	+	-	-	-
<i>Caloneis</i> sp.	+	-	+	-
<i>Craticula cuspidata</i>	-	-	-	+
<i>Cymatopleura solea</i>	-	-	+	+
<i>Cymbella minuta</i>	+	+	-	-
<i>Cymbella naviculiformis</i>	+	-	+	+
<i>Cymbella ventricosa</i>	-	-	-	+
<i>Eunotia minor</i>	+	-	+	-
<i>Eunotia pectinalis</i>	+	-	-	-
<i>Fragillaria biceps</i>	+	-	+	+
<i>Gomphonema gracile</i>	-	-	+	+
<i>Gomphonema olivaceum</i>	+	-	-	-
<i>Gomphonema parvalum</i>	+	-	-	+

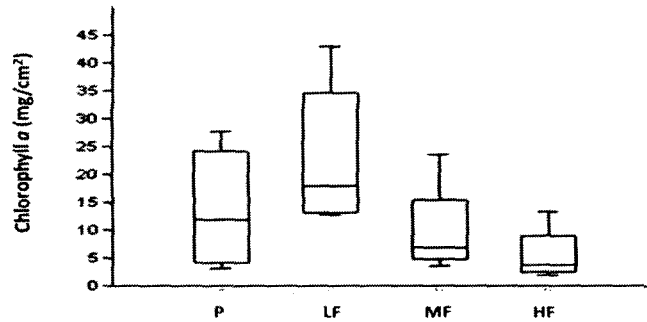
<i>Gomphonema septa</i>	+	-	-	-
<i>Gomphonema sphaerophorum</i>	-	+	+	-
<i>Navicula cryptocephala</i>	+	+	+	+
<i>Navicula dubia</i>	+	-	-	-
<i>Navicula gastrum</i>	+	-	-	-
<i>Navicula gracilis</i>	+	-	-	+
<i>Navicula lamii</i>	+	-	-	-
<i>Navicula major</i>	+	-	+	-
<i>Navicula radiosa</i>	-	-	+	+
<i>Navicula reinhardtii</i>	+	-	-	-
<i>Navicula sphaerophora</i>	+	+	+	+
<i>Navicula viridis</i>	-	+	+	+
<i>Neidium irridis</i>	+	-	-	-
<i>Nitzschia acicularis</i>	+	-	-	-
<i>Nitzschia amphibia</i>	+	-	+	+
<i>Nitzschia palea</i>	+	+	+	-
<i>Pinnularia biceps</i>	-	-	-	+
<i>Pinnularia braunii</i>	-	+	-	-
<i>Pinnularia brebissonii</i>	-	-	-	+
<i>Pinnularia gibba</i>	+	-	-	-
<i>Pinnularia mesolepta</i>	+	-	-	+
<i>Pinnularia viridis</i>	+	+	-	+
<i>Sellaphora pupula</i>	+	-	+	-
<i>Synedra acus</i>	-	-	+	-
<i>Synedra ulna</i>	+	+	-	+
<i>Synedra ulna oxyrhynchus</i>	+	-	-	-
<b>EUGLENOPHYCEAE</b>				
<i>Euglena gracilis</i>	-	-	-	+
<i>Euglena mutabilis</i>	-	-	-	+
<i>Euglena polymorpha</i>	+	-	-	+
<i>Lepocynclis ovum</i>	+	-	-	+
<i>Phacus</i> sp.	-	-	-	+
<i>Trachelomonas abrupta</i>	+	-	-	-
<i>Trachelomonas dubium</i>	-	-	-	+
<i>Trachelomonas volvocina</i>	+	-	+	-
<b>CYANOPHYCEAE</b>				
<i>Leptolyngbya</i> sp.	+	-	+	-
<i>Oscillatoria amphibia</i>	-	-	-	+
<i>Oscillatoria bourelly</i>	+	-	+	-
<i>Oscillatoria planktonica</i>	-	+	+	-
<i>Oscillatoria tenuis</i>	+	-	+	+
<b>CHRYSOPHYCEAE</b>				
<i>Synura</i> sp.	-	-	+	-
<b>CRYPTOPHYCEAE</b>				
<i>Chilomonas</i> sp.	+	-	-	-

Significant variations in cell abundance were observed among four flow regimes ( $p < 0.022$ ) in which maximum individuals were recorded at low flow regime with an average number of 4828 individuals/cm<sup>2</sup> and minimum individuals were recorded at high flow regime with an average number of 1072 individuals/cm<sup>2</sup>. At the pool, average cell abundance was 2208 individuals/cm<sup>2</sup> while that at moderate flow was 2072 individuals/cm<sup>2</sup> (fig.7.1).



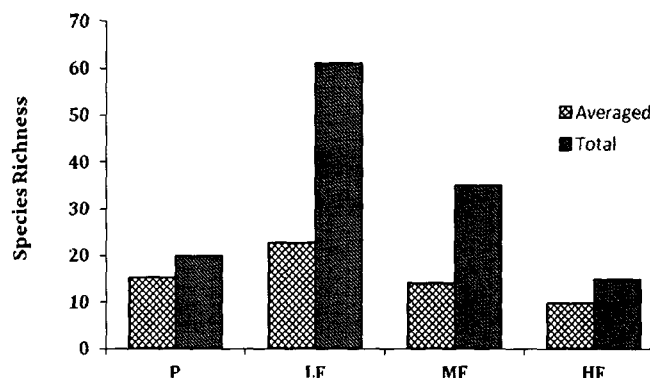
**Figure 7.1: Cell abundance/cm<sup>2</sup> in different flow regimes. P, LF, MF and HF indicates pool, low flow, moderate flow and high flow respectively.**

Similarly, chlorophyll *a* content was maximum at low flow regime with an average production of 22.64 mg/cm<sup>2</sup>, although the variation among different flow regimes was not significant ( $p < 0.233$ ). Minimum chlorophyll *a* content was recorded at high flow regime with an average value of 5.31 mg/cm<sup>2</sup>. At the pool and moderate flow regimes, the average chlorophyll *a* content was 13.78 mg/cm<sup>2</sup> and 9.40 mg/cm<sup>2</sup> respectively (fig.7.2).



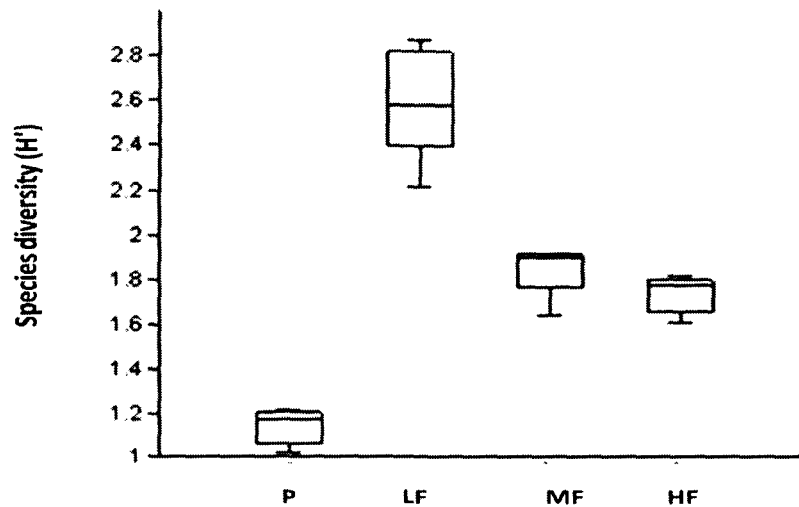
**Figure 7.2: Chlorophyll *a* content (mg/cm<sup>2</sup>) in different flow regimes. P, LF, MF and HF indicates pool, low flow, moderate flow and high flow respectively.**

Throughout the entire study period, total number of species colonizing the ceramic tiles was maximum at low flow with 61 species and an average of 22 species, whereas the lowest value was recorded at high flow with 15 species and with an average of 9 species. At the pool and moderate flow regime, the total species richness was 40 and 35 species with an average number of 15 and 14 species respectively (fig. 7.3). The variation in species richness among different flow regimes was not significant ( $p < 0.577$ ).



**Figure 7.3: Average and total species richness (species/cm<sup>2</sup>) in different flow regimes. P, LF, MF and HF indicates pool, low flow, moderate flow and high flow respectively.**

Shannon wiener diversity index ( $H'$ ) was significantly high at low flow regime ( $p < 0.030$ ) with an average value of 2.57 and low at the pool with an average value of 1.16 (fig. 7.4). At the high flow regime, the average index value was 1.77 whereas in moderate flow it was 1.89.



**Figure 7.4: Species Diversity in different flow regimes at different time period. P, LF, MF and HF indicates pool, low flow, moderate flow and high flow respectively.**

CCA biplot (fig. 7.5) based on different environmental variables and algal abundance data varied significantly in different flow regimes ( $p < 0.0001$ ). The Eigen values for the first and second axes in the CCA biplot was 0.66 and 0.38 respectively. The first two axes for environmental variable explained 90.61% of the variance in the periphytic algal colonization, indicating that pH, EC,  $PO_4$ ,  $NO_3$ , DO and WC played a major role in the colonization of periphytic algal community. Moreover, all the three riffles zones (LF, MF, and HF) were

explained by axis 2 whereas, pool (P) alone was explained by axis 1. It also explained that among the different environmental variables pH, EC, PO<sub>4</sub>, NO<sub>3</sub> influenced significantly the species composition in the pool, while WC and DO significantly influenced the species distribution in the riffle zone.

**Table 7.3: List of algal species with their species code indicated in CCA ordination diagram.**

<b>Algal species</b>	<b>Sp. Code</b>
<i>Achanthes subssesilis</i>	Ac.sub
<i>Chilomonas</i> sp.	Chi
<i>Cymbella minuta</i>	C.min
<i>Cymbella naviculiformis</i>	C.nav
<i>Euglena gracilis</i>	Eug.gra
<i>Eunotia minor</i>	E.min
<i>Gomphonema parvalum</i>	G.par
<i>Gomphonema sphaerophorum</i>	G.sph
<i>Hyalotheca</i> sp.	Hya
<i>Navicula cryptocephala</i>	N.cry
<i>Navicula gracilis</i>	N.gra
<i>Navicula reinhardtii</i>	N.rein
<i>Navicula sphaerophora</i>	N.spha
<i>Nitzschia amphibia</i>	Nit.amp
<i>Nitzschia palea</i>	Nit.pal
<i>Oedogonium</i> sp.1	Oed.1
<i>Oedogonium</i> sp.2	Oed.2
<i>Oscillatoria bourelly</i>	Os.bour
<i>Oscillatoria planktonica</i>	Os.plan
<i>Oscillatoria tenuis</i>	Os.ten
<i>Pinnularia viridis</i>	Pi.vir
<i>Scenedesmus obliquus</i>	Sc.obl
<i>Sellaphora pupula</i>	Se.pup
<i>Spirogyra varians</i>	Spi.var
<i>Staurastrum punctulatum</i>	St.punc
<i>Stigeoclonium glomeratum</i>	Sti.glo

From CCA biplot, it was clearly understood that most of the species showed affinity for low flow regime, whereas only a few species which included

*Oscillatoria planktonica* and several diatoms like *Navicula sphaerophora* Kutzing, *Pinnularia braunii* (Grunow) Cleve, *Achnanthes brevipes* Agardth var. *intermedia* (Kutzing) Cleve, *Gomphonema parvulum* (Kutzing) Kutzing, *Gomphonema sphaerophorum* Ehrenberg and *Navicula viridis* Kutzing showed preferences for moderate and high flow velocity. *Spirogyra varians* (Hassall) Kutzing and various unicellular algae like *Euglena mutabilis* Schmitz, *Scenedesmus obliquus* (Turpin) Kutzing and *Chilomonas* sp. were the only few species found in high abundance in the pool. *Navicula cryptocephala* Kutzing and *Cymbella naviculiformis* (Auerswald) Cleve showed preferences for moderate to low flow velocity but the abundance of former species was higher than that of the latter.

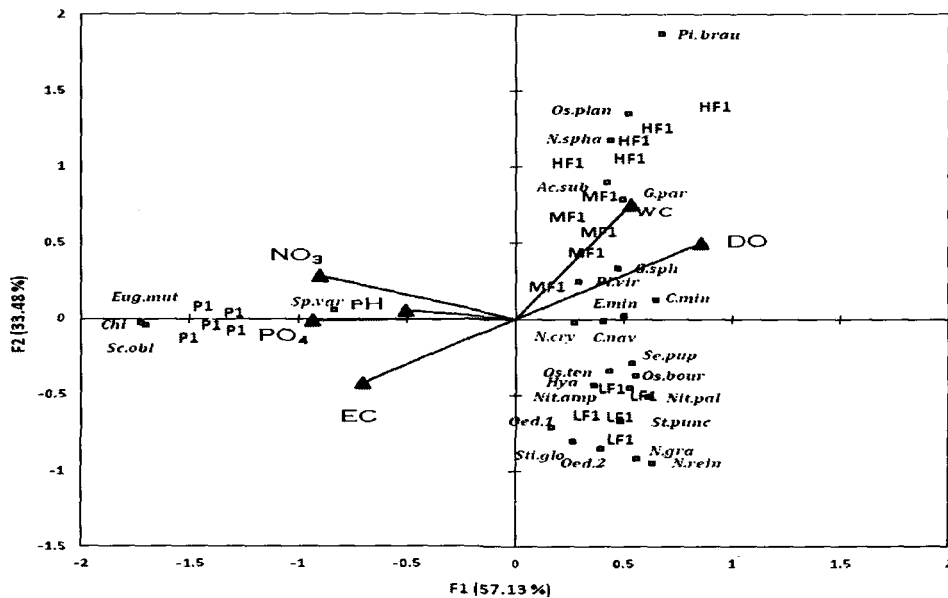


Figure 7.5: CCA ordination diagram of environmental gradients correlated with algal colonization in different flow regime. List of species code was given in Table 7.3.

#### 7.4. DISCUSSION:

The present study suggested that velocity of current played a significant role in the colonizing pattern of periphytic algae in the river Umiew. In addition, factors like nutrients mainly nitrate and phosphate, electrical conductivity, dissolved oxygen and pH played major role in determining algal composition and their abundance in lotic system. In the present study, maximum colonization was observed on artificial substrata kept in low flow regime indicating that a low flow of water was necessary for periphytic algal colonization in streams and rivers. This trend was congruent to several results reported by McIntire, (1966); Raisen and Spencer, (1970); Stevenson, (1983); Steinman and McIntire, (1986). On the contrary, Ghosh and Gaur, (1998) reported greater number of species from substrata kept in the pool. Greater cell abundance in slow current velocity was reported by Lamb and Lowe, (1987). According to Biggs, (1996) steady flow of water generally promoted the accumulation of algal biomass in streams. Similar pattern was also observed by Potapova *et al.*, (2005). The dominance of diatoms in the riffle zone was similar to the observations of Oemke and Burton, (1986). The accumulation of *Navicula cryptocephala* Kutzing in high abundance in low flow indicated the preference of that species in low velocity of current for colonization. Similar finding was also observed by Plenkovic Moraj *et al.*, (2008). The decrease in algal biomass and species richness at the pool remained unexplained, but it could be attributed to factors such as increased herbivore activity (Steinman, 1996; Ronald *et al.*, 2003), sloughing due to stress and

reduced metabolic activities due to detritus and sediment accumulation (Ghosh & Gaur, 1991). The occurrence of *Spirogyra varians* (Hassall) Kutzing, a filamentous green algae, *Euglena mutabilis* Schmitz and *Scenedesmus obliquus* (Turpin) Kutzing in the pool may be due to high nutrient availability that appeared to be the main controlling factor, while variations in flow velocity seemed to have much less impact on the growth of periphytons. This was also explained by CCA in which PO<sub>4</sub> NO<sub>3</sub>, pH and EC showed relatively strong positive correlation with the respective species abundance. This finding was also similar to the findings of Suren *et al.*, (2003) who suggested that nutrient availability was the limiting controller of biomass development, rather than the flow velocity in New Zealand. Under high flow conditions periphytic algae were subjected to different conditions of removal from the substrata. It might be through direct shear removal, abrasion or physical scouring due to bed disturbances leading to dramatic declines in benthic algal biomass (Power & Stewart, 1987; Biggs & Close, 1989; Grimm & Fisher, 1989; Stevenson, 1990; Bergey & Resh, 2006). This might be the reason for reduced cell abundance, diversity, richness and chlorophyll *a* production in high flow regimes. Significant impact of high flow velocity on reducing the abundance of benthic algal mats as well as changing the community composition in stream was demonstrated by Stanish *et al.*, (2011) in a dry valley stream. A negative relationship between water flow rate and algal biomass or cell numbers in fresh water rivers were observed by Antoine and Benson Evans, (1982); Heiskary

and Markus, (2001); Ahearn *et al.*, (2006). Another reason for the low biomass in those tiles kept at high flow regime might be due to the poor nutrient concentration in the ambient water. Humphrey and Stevenson, (1992) reported that rise in water current could stimulate algal growth in nutrient-rich waters but inhibit it in nutrient-poor streams.

This study showed an inverse relationship between high current velocity and periphytic colonization. The study also showed that formation of small pools within the river bed created different microhabitats where nutrients could accumulate and enhanced luxuriant algal growth. Thus from this experiment it could be concluded that if sediment load like quarrying and nutrient enrichment into the river in the form of runoff continues to take place at high intensity, it would obstruct the proper flow of the river thereby creating pool-like habitats that would accumulate nutrients and might lead to eutrophication.

## CHAPTER 8

### GENERAL DISCUSSION

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Diversity and productivity of algal communities in any lotic system is governed by the physico chemical characteristics of the ambient water prevailing in that particular area (Buzzi, 2002; Celekli & Kulkoyluoglu, 2007; Pilkaitite & Razinkovas, 2007) and the trophic level of water in turn plays an important role in governing the structure of algal assemblages in that system (Vilbaste & Tru, 2003). The amount of algae present in any water body indicates the status and health of that system (Guy, 1992). Deterioration in physical and chemical parameters in freshwater systems due to various anthropogenic activities along the river course affect the growth and production of algal communities and bring serious threat to the ecosystems (Dallas & Day, 2004; Palmer *et al.*, 2004, 2005).

In the present study variations observed in physical and chemical parameters of water collected from different points of river Umiew clearly indicated that anthropogenic activities like deposition of agricultural waste in site 2 resulted in increase in conductivity, nitrogen and phosphate level and deposition of remains of lime quarrying in site 3 resulted in higher turbidity, pH, calcium, magnesium and silica content and all those factors together has lead to a change in water quality of the river. But the detailed analysis of water for

different parameters together indicated that the river is oligotrophic with low level of nutrients.

Algal communities of Umiew river showed temporal and spatial variations. Presence of rocky bed, boulders, pebbles etc in site 1, 2 and 3 in the river provided more surface area for attachment and therefore favored the growth of many periphytons compared to phytoplanktons. Green algae and diatoms were the dominating algal groups in the river. Bacillariophyceae group was the dominant one in site 1, 3 and 4 whereas Chlorophyceae group was dominant in site 2. In many fresh water lotic systems, dominance of green algae and diatoms were found to be a common feature (Hynes, 1970; Temel, 2006; Saadet & Sahin, 2009; Sahin *et al.*, 2010; Baba *et al.*, 2011; Negi *et al.*, 2012). Presence of large number of desmids in the river indicated oligotrophic status of the river (Vidyavati, 2007; Yasmin *et al.*, 2011) Occurrence of more diatoms in the river was probably due to the presence of adequate concentration of silica in the water which aided in frustules formation (Wetzel & Likens, 2006). Slightly acidic to alkaline pH (5.30 to 7.46) of water might be responsible for the small contribution of blue green algae to the total algal assemblages of the river (Maurice *et al.*, 1987; Shapiro, 1997). Okogwu and Ugwumba, (2009) reported a strong relationship between cyanobacterial abundance and pH in river floodplain of Nigeria. The occurrence of very less number of Chrysophycean algae could be attributed to low pH and low nutrient condition of the water. Similar findings had also been reported by Kristiansen, (2005) and Nedbalova *et al.*, (2006) in

forested lake. The occurrence of Dinophycean group (*Ceracium hirundinella* and *Woloszynskia sp.* R.H.Thompson) in site 3 and 4 might be due to its adaptability to hard and turbid water with high calcium-ion concentrations and low level of inorganic nutrients (Bellinger & Sigee, 2010).

Among the four study sites, diversity and cell abundance was found to be significantly high in site 2 where the agricultural wastes got deposited. Green algae had been found to be the dominant group and the dominance of green algal group in that part of the river could be due to high transparency of water, high light penetration along with the presence of adequate amount of nutrient particularly nitrogen. Notestein *et al.*, (2003) reported an increase in periphytic algal abundance in Floridian streams with increase in nutrient concentration. Yu and Lin, (2009) reported significantly higher algal cell in subtropical mountain streams running close to agricultural area. High turbidity, high velocity of current, low nutrients, high depth, low light penetration were the other factors which led to low cell abundance in other 3 sites. Further CCA also supported the findings where no particular parameters could play significant role in site 1, in site 4, depth was a major factor. High turbidity and velocity of current in site 3 significantly lowered the cell abundance compared to that in site 2. Biggs and Smith, (2002) and Yamada and Nakamura, (2002) reported the negative influence of water current on the taxonomic richness of periphytic algae in streams and rivers.

In any lotic system, algae are the main primary producers and are source of vital energy for secondary consumers including invertebrates and fishes (Sanderson *et al.*, 2009). Primary productivity, the main functional characteristics of a community (Stevenson *et al.*, 1996) showed a seasonal pattern in Umiew river as observed in structural attributes like diversity and abundance. Productivity was higher in dry seasons (winter and spring) and lower in wet seasons (monsoon and post monsoon). Similar trend had also been observed by many earlier workers from different streams of tropical region (Moschini *et al.*, 2000; Vercellino & Bicudo, 2006; Borduqui *et al.*, 2008) and from many other parts of Asian Monsoonal (Dudgeon, 1999; Yang *et al.*, 2009). The algal productivity in Umiew river was contributed maximally by periphytons as the phytoplanktons could not maintain their population due to high velocity of current. Algal standing crop was governed by velocity of current which in turn was controlled by rainfall. An inverse relationship was thus established between chlorophyll *a* content of algal assemblages and velocity of current. Similar results had also been reported by many workers in different lotic systems (Power & Stewart, 1987; Grimm & Fisher, 1989; Stevenson, 1990; Ghosh & Gaur, 1994; Bergey & Resh, 2006). Significant decline in algal productivity during monsoon was due to dislodgement or removal of filamentous algae by high velocity of current. Biggs and Hickey, (1994); Biggs *et al.*, (1998); Biggs *et al.*, (2005) reported the same phenomenon in different rivers and stream in New Zealand. Primary productivity (chlorophyll *a* content) in the present case was

high compared to that reported from many other streams and rivers (Horner *et al.*, 1983; Welch *et al.*, 1988; Ghosh & Gaur, 1994). Similar high primary productivity as observed in the present case was also reported by Uehlinger, (1991) from pre alpine river and by Munn *et al.*, (2010) from agricultural stream of the United States. High productivity was obtained from site 2 and 3 because of the presence of huge and coarse-grained rocks which supported the growth of many filamentous algae with high biomass. Biggs and Shand, (1987) also reported approximately 15 times greater benthic algal biomass in Clutha river from hard substrate (e.g. rock) than that on fine-grained sediments.

Increase in productivity of algae due to increase in nutrient levels in water in rivers and streams have been reported by many workers (Biggs, 2000; Stelzer & Lamberti, 2001; Dodds *et al.*, 2002; Tank & Dodds, 2003; Von Schiller *et al.*, 2007). In the present study, the nutrient levels in ambient water particularly nitrogen and phosphorus was low during dry seasons, but the algal productivity was significantly high. This could be due to high nutrient uptake by periphytic algae which reduced the concentration of nutrients in the ambient water during that period. This condition was also supported by a linear increase of cellular nutrient content (N, P and C) in algal biomass with increase in productivity during winter and spring. This kind of situation with low soluble nutrient concentrations in water but high in biomass of periphytic algae had been reported from shallow cobbly streams in New Zealand (Biggs, 1995). Therefore, the concentrations of dissolved nutrients measured in the ambient water mainly

reflected the nutrients that were left over after the periphytons had taken (Biggs 2000a). Minimum productivity in site 1 and site 4 which are upstream and downstream sites of the river might have followed a River Continuum Concept proposed by Vannote *et al.*, (1980) which stated that benthic algal biomass increased downstream from headwater to mid catchment as the channel widened and shading got reduced and then decreased in the lower regions of the catchment as depth and turbidity increased.

Dissolved inorganic nutrients were mainly sequestered by periphytic and benthic algae (Stevenson *et al.*, 1996). Many researchers reported that the nutrient/metal concentration in the algal biomass was many times higher than in ambient water (Rai *et al.*, 1981; Lawrence *et al.*, 1998, Das & Ramanujam, 2011). The high nutrient accumulating capacity of periphytons in the river especially nitrogen, might be the reason for the low nitrogen content in the river which made it a limiting nutrient for the growth of other algal groups. High total carbon content in the algal biomass compared to sediments of the river indicated that the periphytic algae were the primary source of organic matter in the river (Wetzel *et al.*, 1997; Frost *et al.*, 2002; Wilson *et al.*, 2003). High Potassium content in the sediments compared to that in water and in algal biomass indicated that the sediments in the river are potassium rich and periphytic algae are poor absorber of potassium. Similar reasons could be applicable for calcium and magnesium.

It is established that among the different nutrients, nitrogen and phosphorus especially their ratio in the water play major role in controlling algal productivity. N: P atomic ratio also known as Redfield ratio generated for river water in the present case had been found to be low ( $< 16:1$ ) in all the 4 sites and in all the seasons indicating the nitrogen limited nature of the river. The nitrogen limiting condition had been reported in many streams worldwide (Bothwell, 1988, 1989; Stanley *et al.*, 1990; Peterson *et al.*, 1993; Edwards *et al.*, 2000; Francoeur, 2001; Capps *et al.*, 2011). It was further reported that nitrogen limitation of flowing water was more common in tropical systems than in temperate ones (Talling & Lemoalle, 1998; Lewis, 2000). To confirm the same, laboratory experiments performed with different doses of nitrogen and phosphorus on algal culture which clearly indicated that supplement of nitrogen singly or with phosphorus to the river water increased algal growth. Addition of both high nitrogen and phosphorus singly and also in combination to the river water showed better response where the chlorophyll *a* content in algal biomass was 2-3 times higher compared to that of control. Many in-situ experiments in lotic systems have demonstrated that combination of nitrogen and phosphorus together enhanced algal biomass production than when it was given singly (Bothwell, 1985; Hershey *et al.*, 1988; Pan & Lowe, 1994; Dodds *et al.*, 1997; Winter & Duthie, 2000). The manifold increase in productivity with addition of phosphorus along with nitrogen thus indicated that though phosphorus was not

detected as a limiting nutrient according to Redfield ratio but the level phosphorus was low for algal growth.

In riverine ecosystem, velocity of current varies spatially and temporally over a range of scales, and influences benthic algal biomass via several mechanisms (Hart & Finelli, 1999). In Umiew river, velocity of current played a significant role in the colonizing pattern of periphytic algae. Maximum colonization was observed on substrata kept in low flow regimes which indicated that low flow was necessary for periphytic algal colonization in the river. The similar trend has been reported in several other streams (McIntire, 1966; Raisen & Spencer, 1970; Stevenson, 1983; Steinman & McIntire, 1986).

## CHAPTER 9

### SUMMARY AND CONCLUSION

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Analysis of physico chemical parameters of water in selected sites showed that the water quality of Umiew River ranged from slightly acidic to mildly alkaline (5.30 to 7.46). An acidic pH was recorded from site 1 and alkaline pH was recorded from site 3. Water temperature showed seasonal variation where maximum temperature was recorded in spring (24.8°C) and minimum in winter (11.3°C). Water turbidity was maximum in site 3 with a range of 0.09 to 0.33 NTU and in site 1, 2 and 4 it remained almost the same (0.01 to 0.07 NTU) throughout the study period. A significant temporal variation in velocity of current was observed. Velocity of current was high in site 2 and 3 in rainy season with a mean value of 0.51 to 0.53 m/sec and the minimum flow was recorded in site 4 with an average value of 0.01 m/sec. Conductivity ranged from 16 to 126  $\mu\text{S}/\text{cm}$ , dissolved oxygen ranged from 4.07 to 8.64 mg/l, nitrogen ranged from 0.21 to 1.39 mg/l, phosphate varied from 0.13 to 0.52 mg/l and were maximum in site 3. Calcium, ranged from 7.63 to 24.3 mg/l, magnesium ranged from 3.04 to 12.36 mg/l and silica content ranged from (2.74 to 5.79 mg/l) and were maximum in site 3. Detailed analysis of water for different water parameters though varied in between sites and seasons but all put together indicated that the river is oligotrophic with low level of nutrients. Using

a hierarchical cluster analysis based on the physico chemical parameters of river water, two main clusters were formed in which site 4 formed a separate cluster which indicated that in site 4, along with change in width and depth in the river water parameters like high pH, low velocity of current separated the site from other three sites.

Periphytic algae contributed 89-93% of the total algal community and only 7-12 % was contributed by phytoplanktons. Totally, 346 algal species spreading over 8 families were recorded from 4 selected sites in different seasons during the entire study. Out of total taxa 151 species were recorded from Chlorophyceae, 112 species from Bacillariophyceae, 55 species from Cyanophyceae, 20 species from Euglenophyceae, 3 species from Chrysophyceae and 2 species from Xanthophyceae, Dinophyceae and Cryptophyceae respectively. Dinophyceae group was recorded only from site 3 and 4 while Cryptophyceae was recorded from site 1, 2 and 4. Both planktonic and periphytic cell abundance was maximum during spring when water current was minimum in all the sites. Planktonic cell abundance (individuals/l) was more in site 4 with 75 to 1920 individuals/l whereas in other three sites it was almost similar (45 to 635; 120 to 575; 105 to 580 individuals/l in site 1, 2 and 3 respectively). *Cyclotella* sp. a centric diatom and *Scenedesmus obliquus* a green alga were the most dominant planktonic species which contributed more towards the cell abundance in site 4 and 2 respectively. Planktonic species diversity (H') ranged from 0.06-2.3 with a maximum value recorded from site 1 during post

monsoon. Periphytic cell abundance was significantly high in site 2 with a range of  $18.5 \times 10^2$  to  $613.65 \times 10^2$  cells/ml. In site 1, it varied from  $56.12 \times 10^2$  to  $410.95 \times 10^2$  cells/ml. In site 3, it ranged from  $58.3 \times 10^2$  to  $405.6 \times 10^2$  cells/ml whereas in site 4 it ranged from  $40.23 \times 10^2$  to  $460.97 \times 10^2$  cells/ml.

A distinct seasonal variation in periphytic species diversity and richness was obtained in Umiew river in which the maximum value was recorded from site 2 in spring. In site 1, 2, 3 and 4 the species richness was 173, 229, 205 and 154 respectively and diversity index ranged from (1.71 to 2.53), (1.93 to 3.37), (1.88 to 2.55) and (1.39 to 2.46) respectively. No marked temporal and spatial variation in the dominance and evenness indices could be obtained during the study period. Bacillariophyceae was the most dominant group in site 1, 3 and 4 whereas in site 2 it was dominated by Chlorophyceae. *Navicula* was the most abundant taxon from Bacillariophyceae with 21 species, *Cosmarium* with 27 species from Chlorophyceae, *Oscillatoria* and *Euglena* with 14 and 9 species from Cyanophyceae and Euglenophyceae respectively. *Woloszynskia* sp. and *Ceracium hirundiniella* was the only representative from Dinophyceae whereas *Dinobryon sertularia*, *Mallomonas* sp. and *Pedinella* sp. represented Chrysophyceae. *Chilomonas paramecium* and *Cryptomonas* sp. were the representatives from Cryptophyceae and *Tribonema* sp. and *Characiopsis* sp. were from Xanthophyceae. Canonical correspondence analysis demonstrated that most of the species are cosmopolitan. Environmental variables like water current, turbidity, pH and depth were the main factors influencing the periphytic

algal growth. *Ankistrodesmus falcatus*, *Spirogyra pratensis*, *Cosmarium constrictum*, *Navicula tripunctata* *N. radiosa*, *Synedra ulna* and *Euglena gracilis* showed preference to nitrogen and dissolved oxygen. *Navicula lanceolata*, *Surirella elegans*, *S. robusta*, *Cymbella cistula*, *C. tumida* and *Gomphonema parvalum* were influenced by high water current, turbidity, silica and calcium. *Oedogonium* sp preferred high current velocity and *Oscillatoria curvicep* showed preference for high pH and phosphate. From the hierarchical cluster analysis, as obtained for water quality analysis, site 4 formed a separate cluster which indicated that it is dissimilar from the other three sites considering algal diversity where planktonic diatom species like *Cyclotella pseudostelligera* Hustedt and *Achnanthes brevipes* Agardth var. *intermedia* (Kutzing) Cleve were recorded in abundance.

Productivity in both phytoplanktonic and periphytic algal assemblages were at its peak in spring and minimum in monsoon to post monsoon season. Productivity of phytoplankton was maximum in site 4 with a range of 0.05 to 0.36 mg/l whereas in the other three sites (site 1, 2 and 3) it was relatively low owing to fast flowing water and ranged from 0.01 to 0.08 mg/l. No significant variation was observed among the sites. Significant seasonal variation in productivity in periphytic algae was observed among the sites. Highest productivity was recorded in site 2 (1.2 to 5.9 mg/cm<sup>2</sup>) and site 3 (0.73 to 5.21 mg/cm<sup>2</sup>) and minimum from site 4 (0.16 to 0.82 mg/cm<sup>2</sup>). In site 1 it ranged from 0.64 to 3.65 mg/cm<sup>2</sup>. During dry period (winter and spring), it was

observed that the river bed was covered with a turf of filamentous green algae particularly *Spirogyra* sp. in site 2 and *Oedogonium* sp. in site 3. Significant positive correlation between productivity in dry seasons and velocity of current and negative correlation between productivity in wet season and velocity of current ( $r^2 = 0.14$  to  $0.49$ ;  $p = 0.0001$  to  $0.02$ ) have been established in all the four sites ( $r^2 = 0.01$  to  $0.14$ ;  $p = 0.02$  to  $0.51$ ). A positive correlation was also observed between productivity and total nitrogen and productivity and phosphorus during dry season (S1,  $r^2 = 0.005$  and  $0.004$ ; S2,  $r^2 = 0.07$  and  $0.57$ ; S3,  $r^2 = 0.07$  and  $0.001$  and S4,  $r^2 = 0.05$  and  $0.105$  respectively) and negative correlation during wet season in all the sites (in S1,  $r^2 = 0.04$  and  $0.01$ ; S2,  $r^2 = 0.03$  and  $0.002$ ; S3,  $r^2 = 0.10$  and  $0.001$ ; S4,  $r^2 = 0.59$  and  $0.0001$  respectively).

Different nutrient content in algal biomass was compared to the nutrients present in two media i.e. water and in sediment, nitrogen content was found to be many fold and significantly higher in the algal biomass than the concentration in water and sediment in different sites and in different seasons. Similar trend was observed in case of phosphorus, carbon and sodium concentrations where concentrations of these nutrients were higher in algal biomass. Calcium and magnesium on the other hand were significantly higher in water compared to sediment and algal biomass whereas potassium was significantly higher in sediment than that in water and algal biomass. A strong relationship between periphytic productivity (chlorophyll *a* content) to nitrogen, phosphorus and carbon content in the periphytic algal biomass could be established. Increase in

chlorophyll *a* content in algal biomass was attained as the percentage of phosphorus ( $r^2 = 0.92$ ,  $p = 0.001$ ), nitrogen ( $r^2 = 0.95$ ,  $p = 0.0001$ ) and carbon ( $r^2 = 0.70$ ,  $p = 0.0001$ ) increased in the periphytic biomass mainly in site 2. In site 3 this strong correlation was observed only between carbon and chlorophyll *a* ( $r^2 = 0.77$ ,  $p = 0.0001$ ), but not with phosphorus ( $r^2 = 0.00005$ ,  $p = 0.98$ ) and nitrogen ( $r^2 = 0.08$ ,  $p = 0.38$ ).

It is established that among the different nutrients, relative availability of nitrogen and phosphorus or co-availability of nitrogen and phosphorus especially their ratio in the water played major role in controlling algal productivity. N: P atomic ratio also known Redfield ratio of Umiew river was found to be low (<16:1) in all the sites which indicated that the river was nitrogen limited. Therefore, to know the effect of different levels of nitrogen and phosphorus nutrients on the algal productivity in the river an experiment was carried out in the laboratory. Addition of nitrogen into the test water raised the chlorophyll *a* content of the test alga significantly specially at high nitrogen level i.e. 2 mg/l in most of the treatments. Addition of phosphorus also increased the chlorophyll *a* content in both low and high doses but the increase was not significant. Combination of high concentration of nitrogen and phosphorus added into the test alga yielded much higher productivity, 2-3 folds higher than those given singly. The manifold increase in productivity with addition of phosphorus along with nitrogen thus indicated that though phosphorus was not

detected as a limiting nutrient according to Redfield ratio but the level phosphorus was low for algal growth.

In the present study it was found that velocity of current played one of the most important role in controlling the diversity and productivity of algal assemblages in Umiew river. To study the role of velocity of current on algal colonization and growth, artificial substrata (ceramic tiles) were placed in different micro habitats of the river like pool formed within the river (with no flow current), different riffle zones (high flow, moderate flow and low flow). The artificial tiles were incubated for 5 weeks. From this experiment, it was found that variation in water current was highly significant among the entire flow zones ( $p < 0.0000006$ ). 13 species were encountered only from the pool, 20 species were found only in low flow and *Pinnularia braunii* was found only in high flow zone. *Synedra acus*, *Synura* sp. and *Pithophora* sp. were present only in moderate flow. Species diversity, richness, cell abundance and productivity were significantly high in low flow and minimum in high flow. Diatoms were the most dominant group in the entire riffle zone, whereas in pool, *Spirogyra varians*, *Euglena mutabilis* and *Scenedesmus obliquus* were the most common and dominant species which contributed maximally to the total cell abundance. This experiment thus confirmed that low flow in a lotic system supports diverse algal assemblage.

It can be concluded from the present study that though the river water varied in different physiochemical parameters at different sites the overall water

quality was oligotrophic with low nutrient levels favoring the growth of algae, the primary producers of the river. Algal assemblages in river Umiew has been found to be diverse. Recording of 346 algal species from the river representing different groups indicated the richness of riverine algal flora of the region. The presence of 71 species of desmids in the river and occurrence of chrysophytes like *Dinobryon* sp. and *Mallomonas* sp. indicated the nutrient poor condition of the river. Maximum numbers of algal species were recorded in the area of the river where it runs through agricultural land and receive agricultural runoff during monsoon. This observation clearly indicated that deposition of agricultural waste into the nutrient poor river did not affect the algal assemblages adversely but it enhanced the growth of algae by increasing species richness and diversity and productivity. Dominance of Chlorophyceae and Bacillariophyceae members, their even distribution further confirmed the unpolluted nature of the river. Deposition of remain of lime quarrying in Umtynngar increased calcium level in the river. Presence of calciphilic species like *Ceracium hirundinella* and *Woloszynskia* sp. in site 3 and 4 belonging to Dinophyceae and calcium loving diatoms like *Cymbella* and *Achnanthes* indicated the higher level of calcium in that particular site of the river. It further increased the turbidity of the water which adversely affected the algal assemblages. Thus the present study clearly indicated that shifting of remains of lime quarrying as sand and silts from the catchment area to the river mainly obstructed the flow of

water and light penetration in dry seasons has resulted in adverse effect on the structure and function of algal communities.

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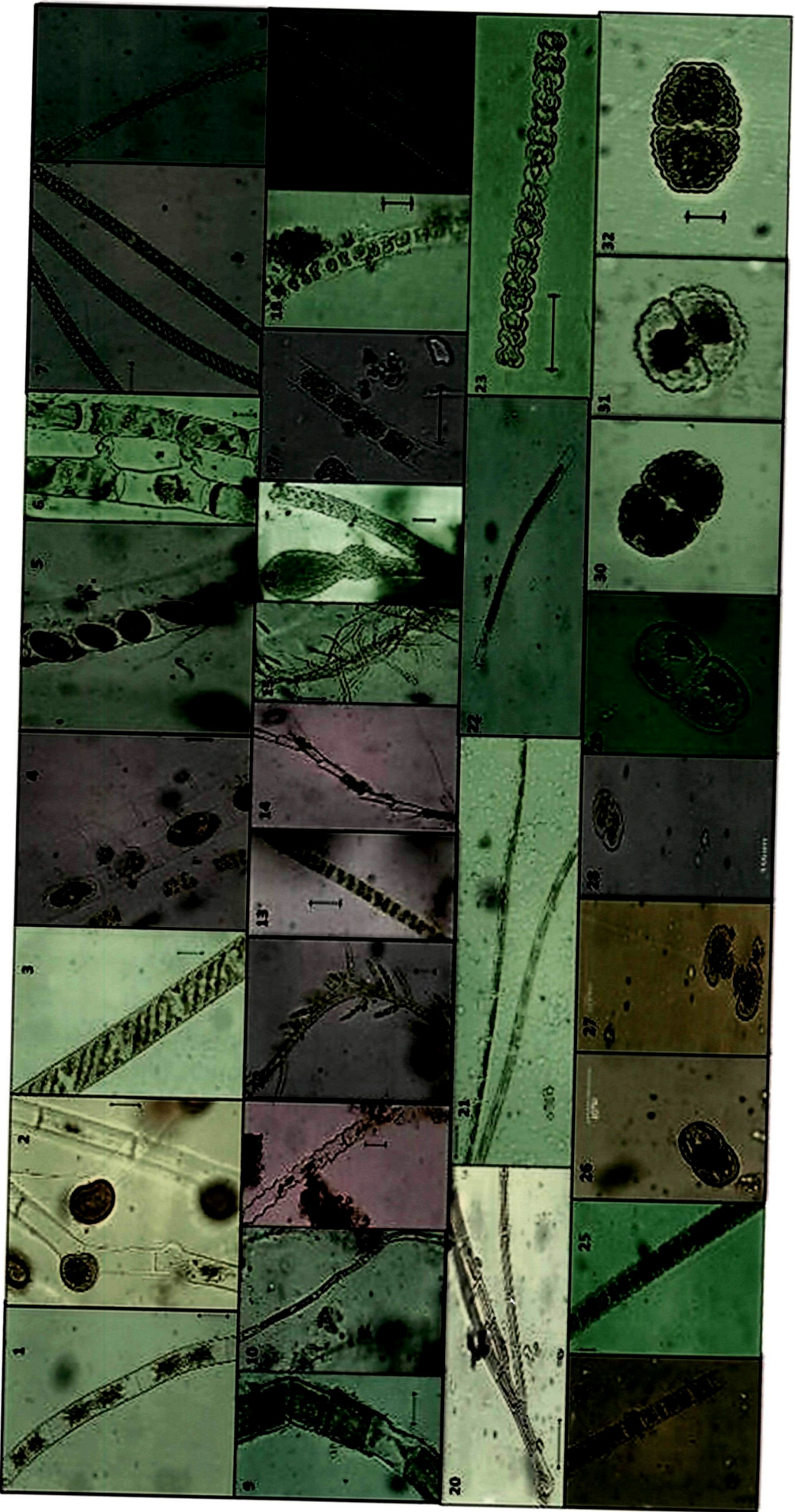
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## PLATE-1

Fig. 1-2. *Zygnema pectinatum*; Fig. 3-4. *Spirogyra pratensis*; Fig. 5-6 *Spirogyra varians*; Fig. 7. *Spirogyra* sp; Fig. 8. *Maugeatia* sp; Fig. 9. *Oedogonium* sp.1; Fig. 10. *Oedogonium* sp 2; Fig. 11. *O. undulatum*; Fig. 12. *Stigeoclonium* sp; Fig. 13. *Ulothrix* sp; Fig. 14. *Bulbocheate* sp; Fig.15. *Chaetophora* sp; Fig. 16. *Pitophora* sp; Fig. 17. *Microspora tumidula*; Fig. 18. *M. irregularis*; Fig. 19. *M. willeana*; Fig. 20. *Cladophora* sp; Fig. 21. *Klebsormidium* sp; Fig. 22. *Gonotozygon kinahanii*; Fig.23. *Spondylosium planum*. Fig. 24 *Desmidium baileyi*; Fig. 25. *Hyalotheca* sp; Fig. 26. *Cosmarium cucurbita*; Fig. 27. *C. undulatum* var. *minutum*; Fig. 28. *C. angulosum*; Fig. 29. *C. impressulum*; Fig. 24. *C. quinarium*; Fig. 30. *C. awadhense*; Fig. 31. *C. sportella*; Scale bar = 10 $\mu$ m.

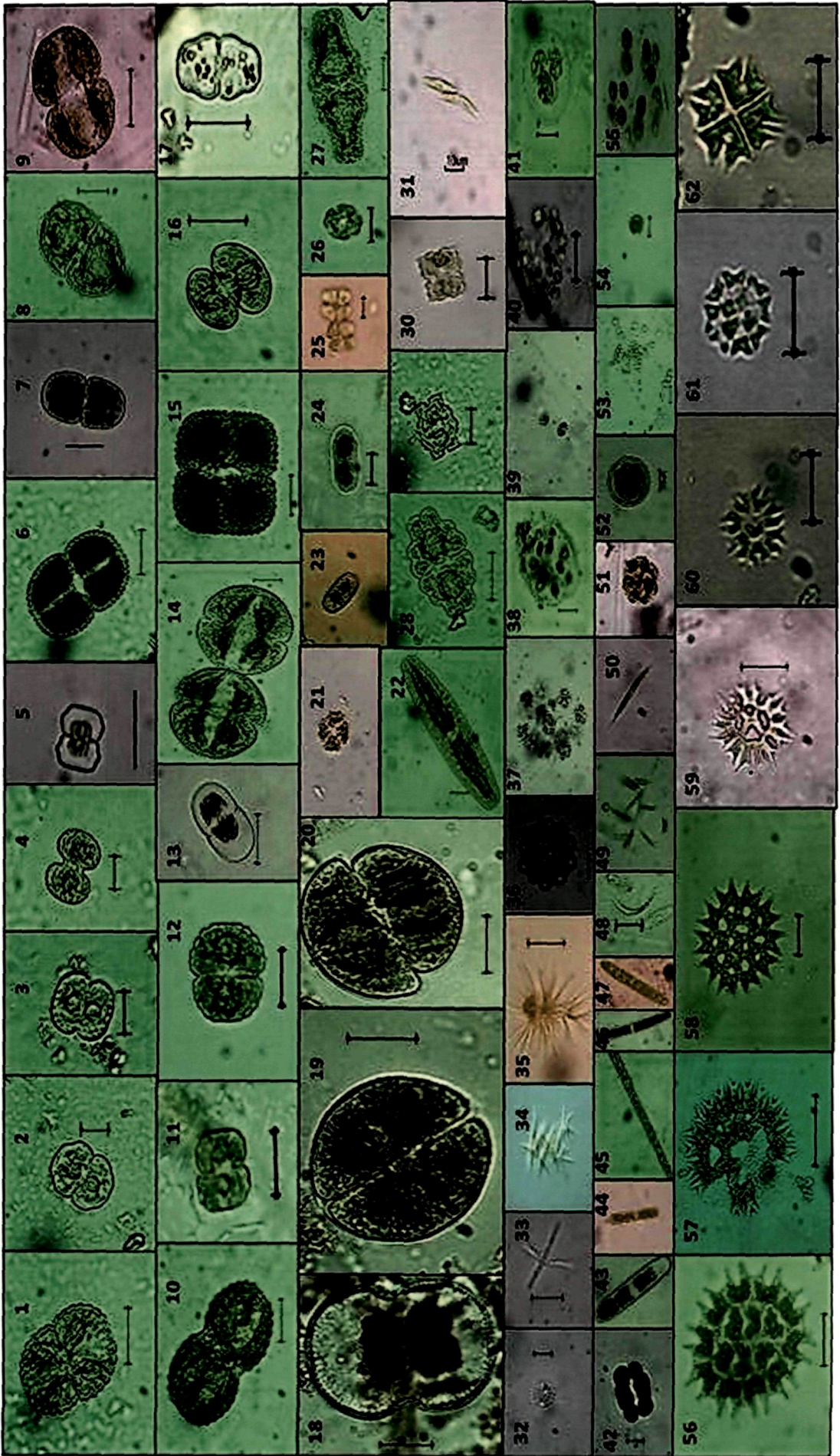
PLATE-1



## PLATE 2

Fig. 1. *Cosmarium speciosum*; Fig. 2. *C. angulosum* var *concinnum*; Fig. 3. *C. punctulatum*; Fig. 4. *C. portianum*; Fig. 5. *C. polygonum* ; Fig. 6. *C. decoratum*; Fig. 7. *C. cucumis*; Fig. 8. *C. circulare* var. *messikimeri* ; Fig. 9. *C. bidentatum* 2; Fig. 10. *C. amaenum*; Fig. 11. *C. meneghinii*; Fig. 12. *C. subcrenatum*; Fig. 13. *C. pseudoconnatum*; Fig. 14. *C. subcirculare*; Fig. 15. *C. quadrum*; Fig. 16. *C. bioculatum*; Fig. 17. *C. hammeri*; Fig. 18. *C. connatum*; Fig. 19. *C. obsolatum* ; Fig. 20. *Cosmarium* sp; Fig. 21. *Tetrastrum glabrum*; Fig. 22. *Netrium digitus*; Fig. 23. *Cylindrocystis subpyramidota*; Fig. 24. *C. brebissonii*; Fig. 25. *Crucigenia rectangularis*; Fig. 26. *C. tetrapedia*; Fig. 27. *Euastrum ansatum*; Fig. 28. *E. sinuosum*; Fig. 29. *E. coralloides*; Fig. 30. *E. dubium*; Fig. 31. *Elakatothrix* sp; Fig. 32. *Golenkinia radiata*; Fig. 33. *Actinastrum* sp; Fig. 34. *Ankistrodesmus falcatus*; Fig. 35. *A. spiralis*; Fig. 36. *Coelastrum cambricum*; Fig. 37. *Coelastrum pseudomicrosporum*; Fig. 38. *Gleocystis vesiculosa*; Fig. 39. *Radiococcus* sp; Fig. 40. *Dictyosphaerium pulchellum*; Fig. 41. *Oocystis gigas*; Fig. 42. *Pandorina* sp; Fig. 43. *Penium margariteceum*; fig. 44. *P. cylindrus*; Fig. 45. *Pleurotaenium ehrenbergii*; Fig. 46. *P. trabecula*; Fig. 47. *Spirotaenia* sp. Fig. 48. *Monoraphidium contortum*; Fig. 49. *M. littorale*; Fig. 50. *M. turtile*; Fig. 51. *Coelastrum microsporum*; Fig. 52. *Chlorococcum* sp; Fig. 53. *Chlorella* sp; Fig. 54. *Chlamydomonas globosa*; Fig. 55. *C. reinhardtii*; Fig. 56. *Pediastrum buryanum* var *cornutum*; Fig. 57. *P. duplex* var *clathratum*; Fig. 58. *P. duplex*; Fig. 59. *P. duplex* var *gracillimum*; Fig. 60. *P. tetras* var *tetraodon*; Fig. 61. *P. tetras*; Fig. 62. *P. tetras* var *excisum*; Scale bar =10µm.

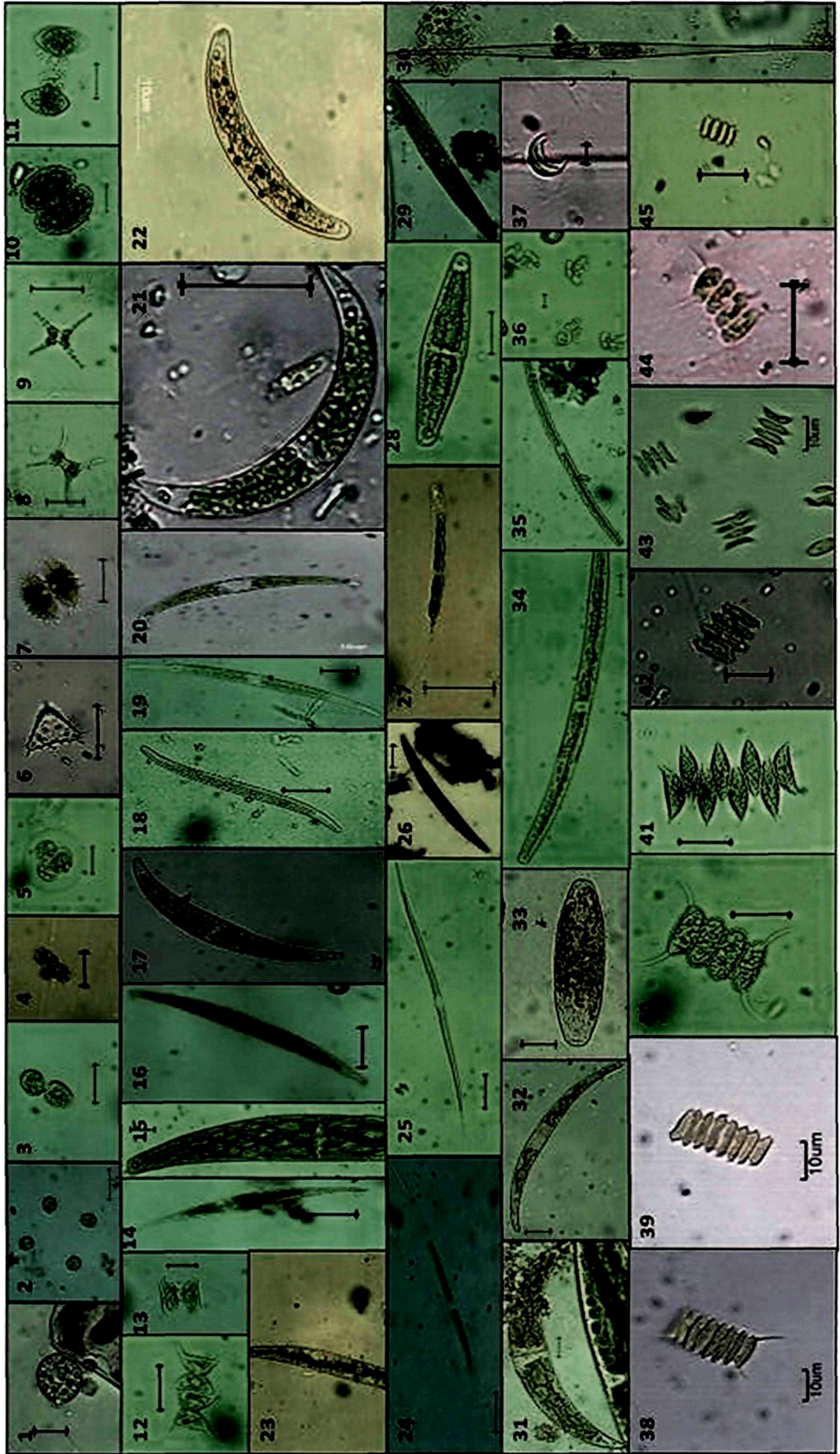
PLATE-2



### PLATE 3

Fig. 1. *Apiocystis* sp; Fig. 2. *Aseterococcus limneticus*; Fig. 3. *Haematococcus* sp; Fig. 4. *Nephrocytium* sp; Fig. 5. *Oocystis gigas*; Fig. 6. *Staurastrum gracile*; Fig. 7. *S. brebissonii*; Fig. 8. *C. chaetoceras*; Fig. 9. *S. tetracerum* 2; Fig. 10. *S. asperum*; Fig. 11. *S. punctulatum* ; Fig. 12. *Staurasdesmus incus*; Fig. 13. *S. triangularis*; Fig. 14. *Closterium rostratum*; Fig. 15. *C. striolatum*; Fig. 16. *C abruptum*; Fig.17. *C. lebleinii*; Fig. 18 *C. sigmoideum*; Fig. 19. *C. gracile* ;Fig. 20. *C. diana*; Fig. 21. *C. incurvum*; Fig. 22. *C. recurvum*; Fig. 23. *C. attenuatum*; Fig. 24. *C. idiosporum*; Fig. 25. *C. acutum*; Fig. 26. *C. angustatum*; Fig. 27. *C. gracillimum*; Fig. 28. *C. navicula*; Fig. 29. *C. acerosum*; Fig. 30. *C.kuetzingii*; Fig. 31. *C. colasporum*; Fig. 32. *C. intermidium*; Fig. 33. *C. closteroides var intermidium*; Fig. 34. *C. directum*; Fig. 35. *C. cornu*; Fig. 36. *Kirchneriella aperta*; Fig. 37. *K. lunaris*; Fig. 38. *Scenedesmus perforates*; Fig. 39. *S. acutiformis*; Fig. 40. *S. quadricauda*; Fig. 41. *S. dimorphos*; Fig. 42. *S. brasiliensis*; Fig. 43. *S. obliquus*; Fig. 44. *S. aculeolatus*; Fig. 45. *S. abundans*; Scale bar = 10µm.

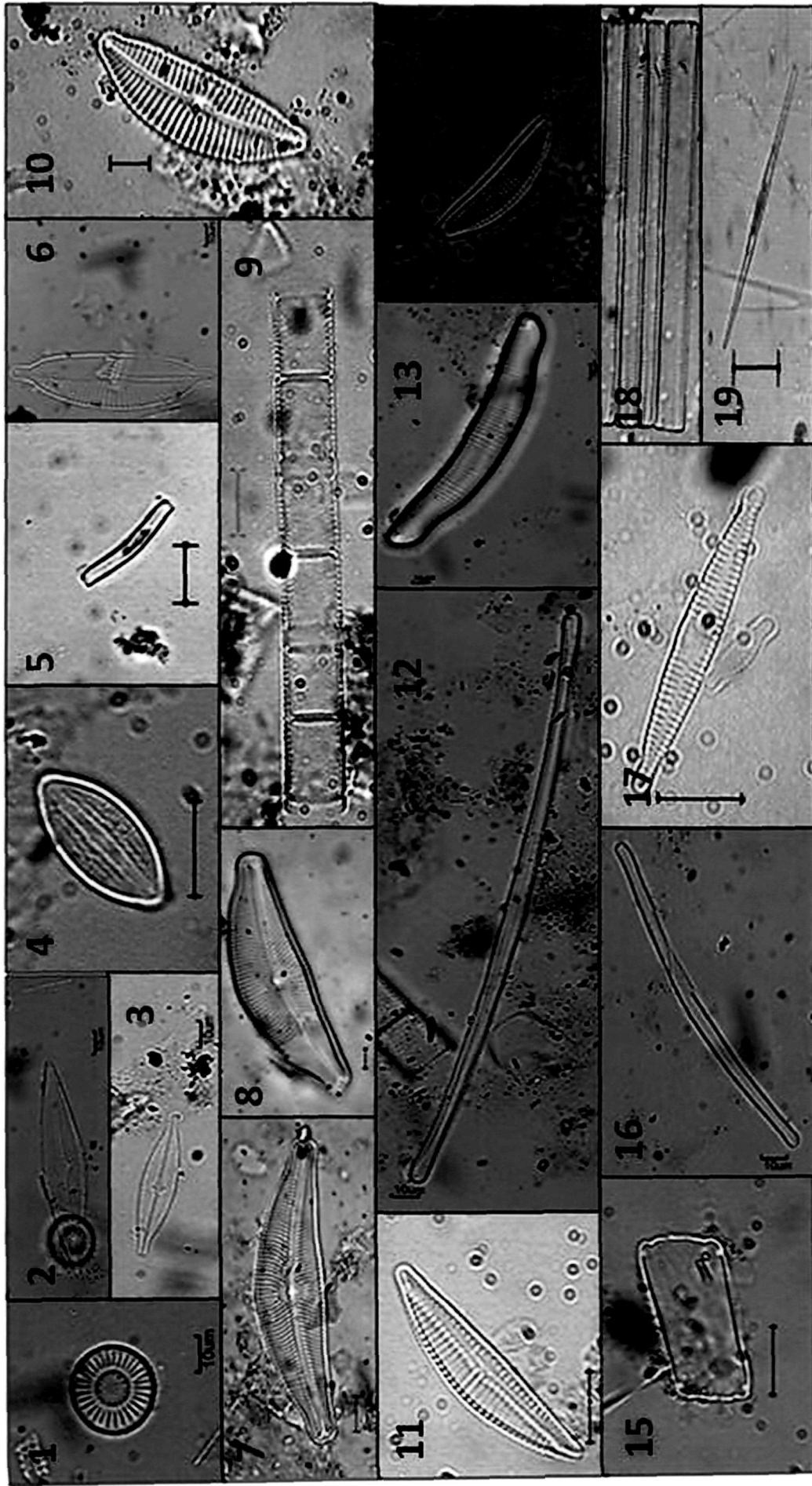
# PLATE-3



#### PLATE 4

Fig. 1. *Cyclostrella pseudostelligera* Fig. 2. *Bachysira serians*; Fig. 3. *B. vitrea*; Fig. 4. *Cocconeis pediculus*; Fig. 5. *Achnanthes* sp; Fig. 6. *Cymbella naviculiformis*; Fig. 7. *C. proxima*; Fig. 8. *C. tumida*; Fig. 9. *Aulocoseira granulata*; Fig. 10. *Encyonema silesiacum*; Fig. 11. *E. neogracile*; Fig. 12. *Eunotia flexuosa*; Fig. 13. *E. pectinalis*; Fig. 14. *E. paludosa*; Fig. 15. *E. major*; Fig. 16. *E. bilunaris*; Fig. 17. *Fragillaria capucina*; Fig. 18. *F. biceps*; Fig. 19. *F. crotonensis*; Scale bar = 10µm

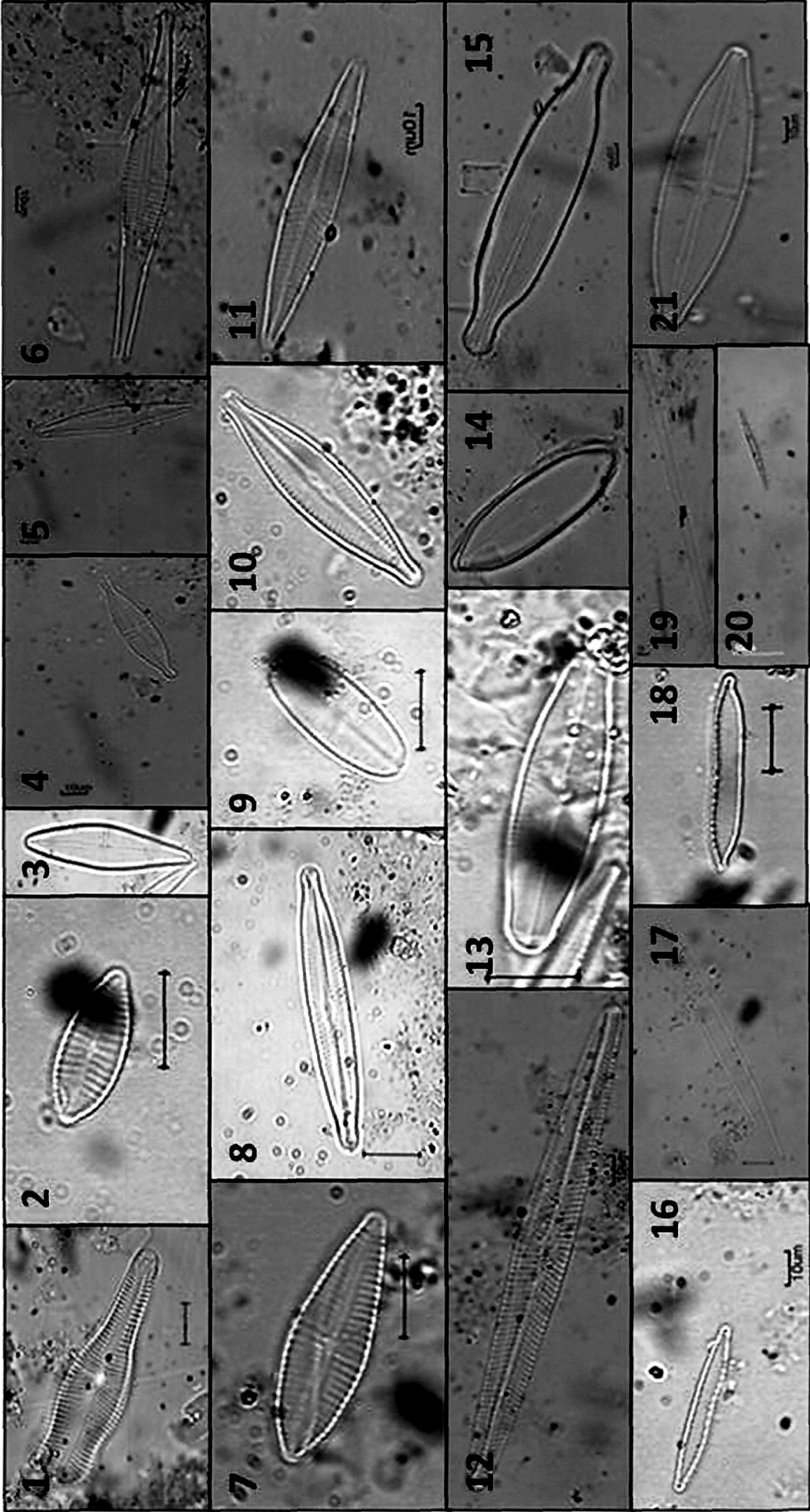
# PLATE-4



## PLATE 5

Fig. 1. *Gomphonema truncatum*; Fig. 2. *G. olivaceum*; Fig. 3. *G. clavatum*; Fig. 4. *G. parvalum*; Fig. 5. *G. gracile*; Fig. 6. *G. septa*; Fig. 7. *G. minutum*; Fig. 8. *Navicula lanceolata*; Fig. 9. *N. minima*; Fig. 10. *N. capitoradiata*; Fig. 11. *N. cryptocephala*; Fig. 12. *N. radiosa*; Fig. 13. *N. protracta*; Fig. 14. *Neidium affine*; Fig. 15. *N. ampliatum*; Fig. 16. *Nitzchia perminuta*; Fig. 17. *N. palea*; Fig. 18. *Hantzchia amphioxys*; Fig. 19. *Synedra ulna*; Fig. 20. *S. capitata*; Fig. 21. *Stauroneis phoenicenteron*; Scale bar = 10 $\mu$ m

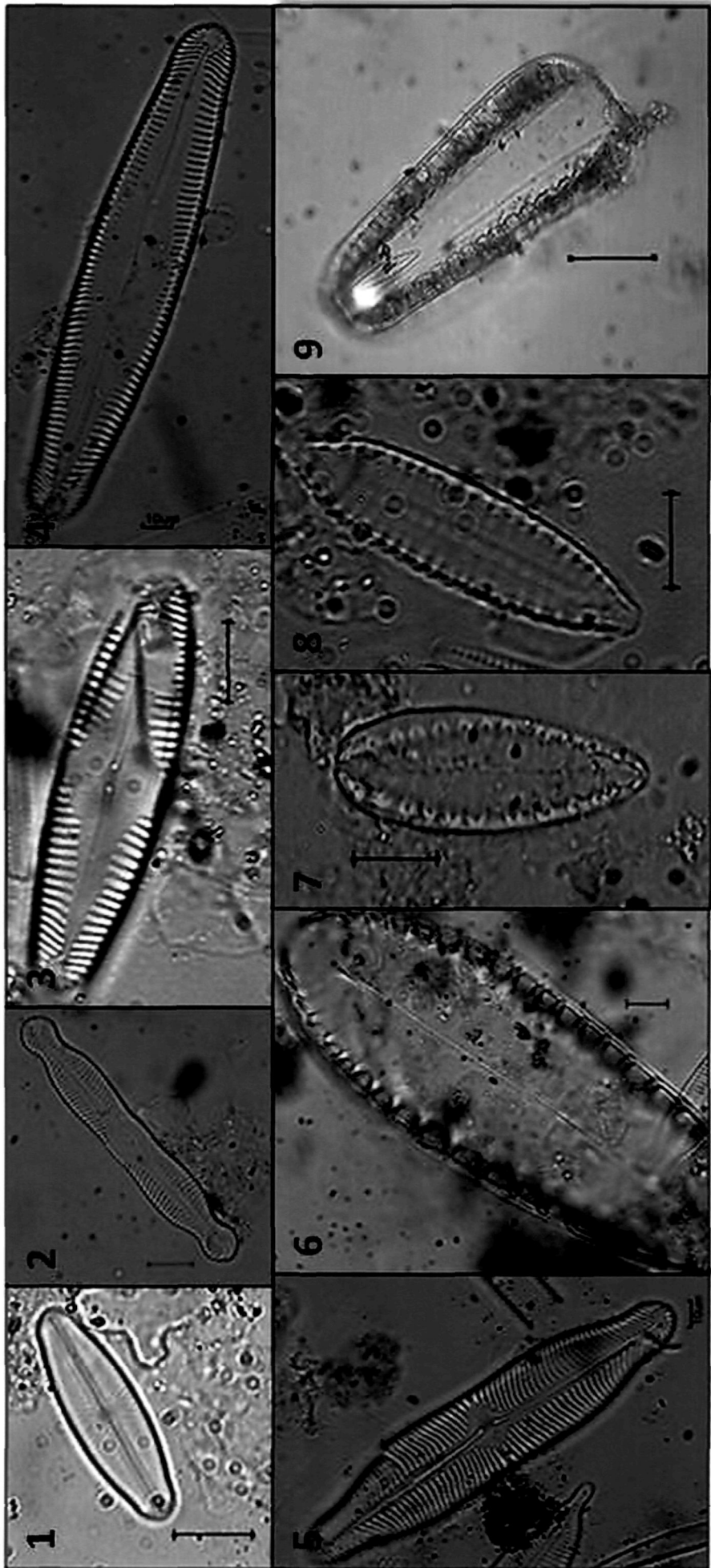
# PLATE-5



## PLATE 6

Fig. 1. *Sellaphora pupula*; Fig. 2. *Pinnularia mesolepta*; Fig. 3. *P. viridis*; Fig. 4. *P. gibba*; Fig. 5. *P. microstauron*; Fig. 6. *Surirella elegans*; Fig. 7. *S. brebissonii*; Fig. 8. *S. linearis*; Fig. 9. *S. robusta*; Scale bar = 10 $\mu$ m

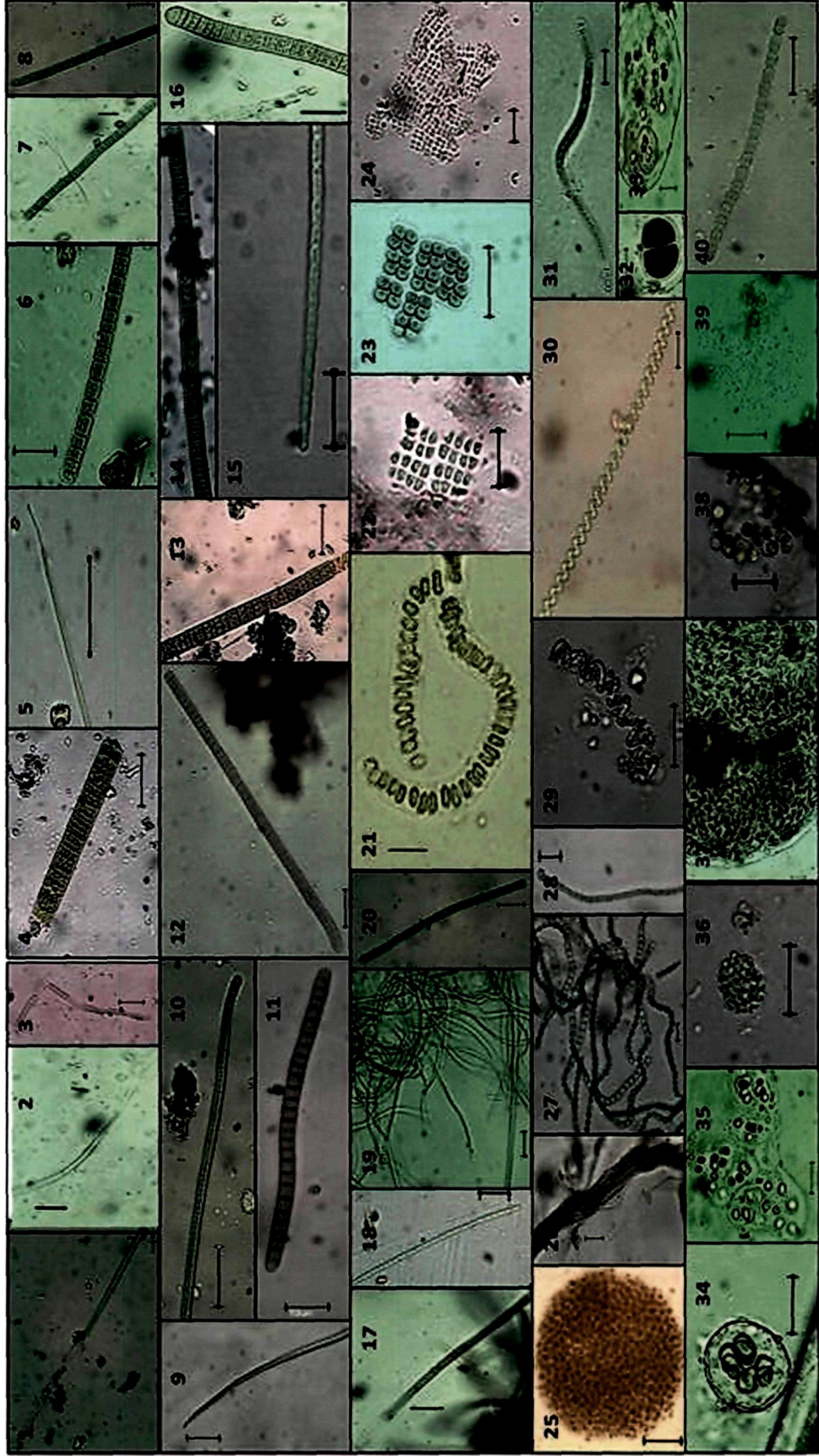
# PLATE-6



## PLATE 7

Fig. 1. *Lyngbya estaurii*; Fig. 2. *L. limnetica*; Fig. 3. *Leptolyngbya sp*; Fig. 4. *Oscillatoria princeps*; Fig. 5. *O. limnetica* ; Fig. 6. *O. pseudogerminata*; Fig. 7. *O. subbrevis* ; Fig. 8. *O. tenuis* ; Fig. 9. *O. acuminata* 2; Fig. 10. *O. agardhii*; Fig. 11. *O. amphibia* ; Fig. 12. *O. chalybya*; Fig. 13. *O. curviceps*; Fig. 14. *O. limosa*; Fig. 15. *O. redekei*; Fig. 16. *O. sancta*; Fig. 17. *Phormidium ambiguum*; Fig. 18 *P. molle*; Fig. 19. *P. tenuis* ; Fig. 20. *P. uncinatum*; Fig. 21. *Johannesbaptistia sp*; Fig. 22. *Merismopedia elegans*; Fig. 23. *M. glauca*; Fig. 24. *M. minima*; Fig. 25. *Microcystis sp*; Fig. 26. *Microcoleus sp*; Fig. 27. *Nostoc coruleum*; Fig. 28. *Nostoc sp*; Fig. 29. *Spirulina sp*; Fig. 30. *S. major*; Fig. 31. *Calothrix sp*; Fig. 32. *Chroococcus turgidus*; Fig. 33. *Gloeocapsa alpina*; Fig. 34. *G. aerogenosa*; Fig. 35. *G. alpina*; Fig. 36. *Aphanothece castagnei*; Fig. 37. *Aphanothece sp*; Fig. 38. *Coelosphaerium sp*; Fig. 39. *Synechococcus sp*; Fig. 40. *Anabaena constricta*; Scale bar = 10µm.

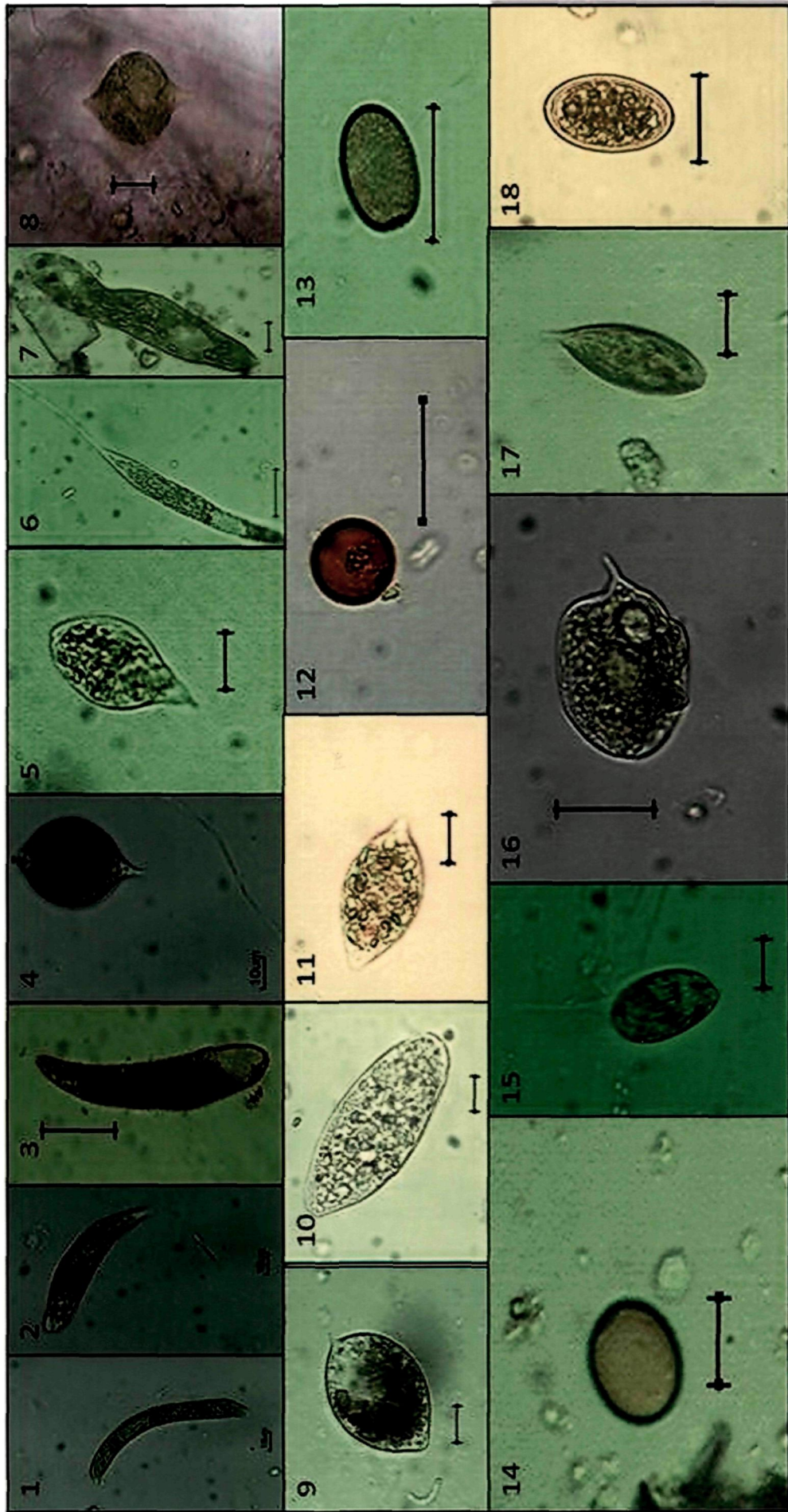
PLATE-7



## PLATE 8

Fig. 1. *Euglena oxyuris*; Fig. 2. *E. mutabilis*; Fig. 3. *E. spirogyra*; Fig. 4. *E. caudata*;  
Fig. 5. *E. polymorpha*; Fig. 6. *E. ehrenbergii*; Fig. 7. *E. acus*; Fig. 8. *E. elastica*; Fig. 9.  
*E. gracilis*; Fig. 10. *E. haematodes*; Fig. 11. *E. proxima*; Fig. 12. *Trachelomonas*  
*volvocina*; Fig. 13. *T. abrupta*; Fig. 14. *T. intermedia*; Fig. 15. *Phacus pyrum*; Fig. 16.  
*P. caudatus*; Fig. 17. *L. steinii*; Fig. 18. *Lepocinclis ovum*; Scale bar: 5µm.

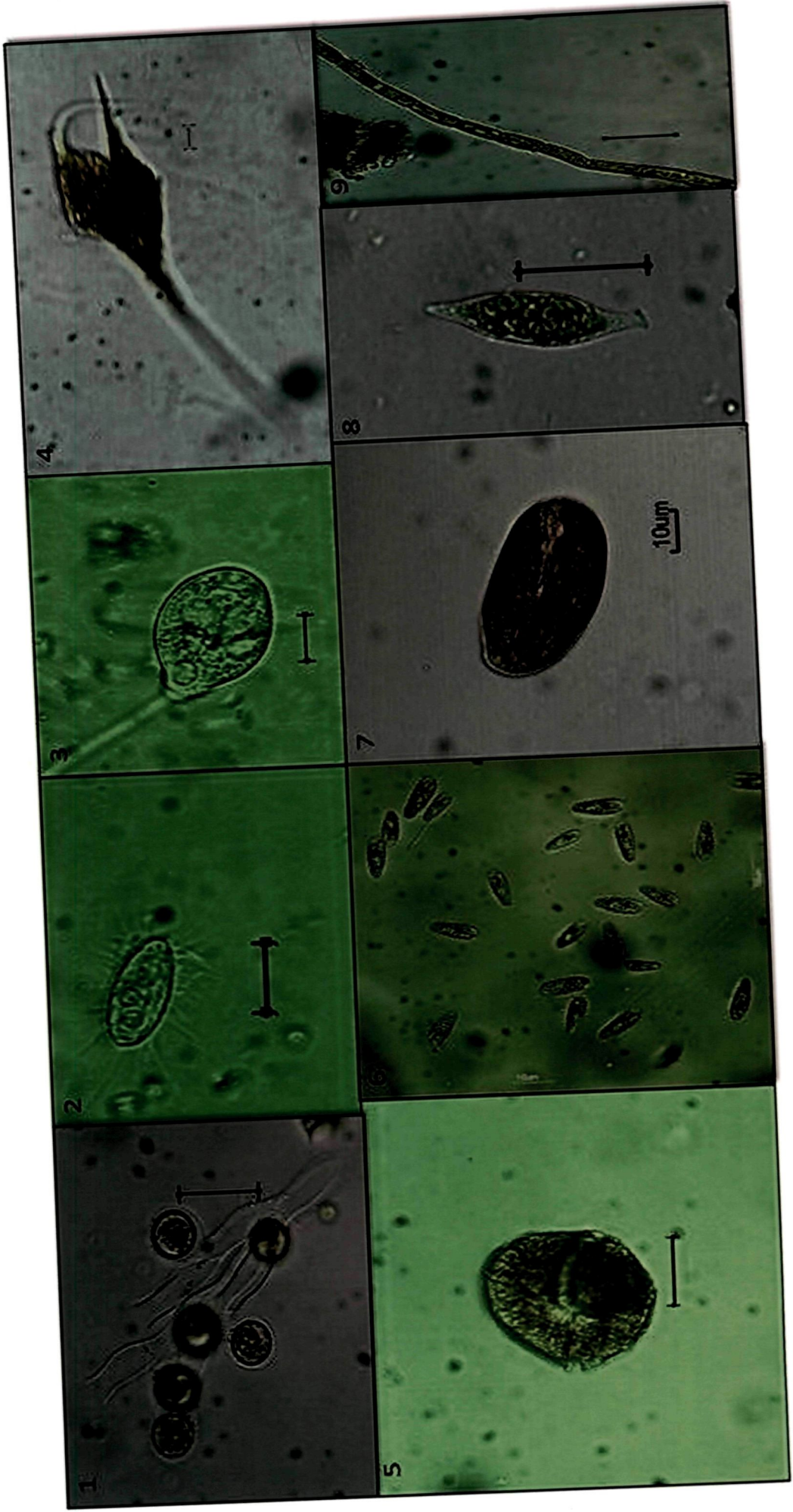
# PLATE-8



## PLATE 9

Fig. 1. *Dinobryon sertularia*; Fig. 2. *Mallomonas* sp; Fig. 3. *Pedinella* sp; Fig 4. *Ceracium hirundiniella*; Fig. 5. *Woloszynskia* sp; Fig. 6. *Chilomonas* sp; Fig. 7. *Cryptomonas* sp; Fig. 8. *Characium* sp; Fig. 9. *Tribonema* sp; Scale bar =10 $\mu$ m.

PLATE-9



## **CURRICULUM VITAE**

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### **Education Qualification**

Ph.D Title: '**Diversity, productivity and nutrient content of algal communities in Umiew river, Meghalaya.**' (Ph.D Reg No.: 1269 of 17.04.2008) Under the Supervision of **Dr. P. Ramanujam**, Department of Botany, North-Eastern Hill University Shillong 793022.

Examination Passed	Board/University	Year of Passing	Div	%
Ph.D.	North-Eastern Hill University (NEHU), Meghalaya		Result Awaited	
M.Sc (Botany)	North-Eastern Hill University (NEHU), Meghalaya	2006	I	63.7
B.Sc (Botany)	North-Eastern Hill University (NEHU), Meghalaya	2004	I	64.2
HSSLC	Meghalaya Board of School Education (MBOSE), Meghalaya	2001	I	60.0
SSLC	MBOSE	1999	II	58.96

#### **Research Article/ Short communication (Published)**

1. Ramanujam P and Siangbood H. (2009). Diversity of algae in Umiew River, Meghalaya. Indian Hydrobiology: 12: (1): 65-73.
2. Siangbood H and Ramanujam P. (2011). A report on thermophilic Cyanophyta (Cyanobacteria) from Jakrem Hot Spring, Meghalaya. International Journal on Algae: 2: (13): 178-185.

#### **Symposium/ Workshop/ Training/Seminar Attended**

- Presented a paper (Poster) titled “Diversity of algae in Umiew river, Meghalaya” in the “96<sup>th</sup> Indian Science Congress Association held at North Eastern Hill University, Shillong, Meghalaya from January 3 - 7, 2009.
- Presented a paper (Poster) titled “Effect of anthropogenic activities on diversity of algae in selected water bodies of Meghalaya” at the “International symposium on phycological research held from 25<sup>th</sup>-27<sup>th</sup> February 2010 at Banaras Hindu University, Varanasi.

- Participated at national symposium on frontiers in bio complexity and biodiversity of plants, 14<sup>th</sup>-15<sup>th</sup> March 2008, Centre for advanced studies in Botany, NEHU.
- Attended a national training programme on “The evolutionary diversification of cyanobacteria: Biochemical, molecular and phylogenetic approaches” held from 14<sup>th</sup>-19<sup>th</sup> July 2009, NBAIM, Mau, UP.
- Attended a workshop on cryptogams from classroom teaching to field application from 11<sup>th</sup>-17<sup>th</sup> December 2009 held in department of Botany, Calcutta University.
- Attended a workshop on statistical methods in medical and health sciences from 19<sup>th</sup>-21<sup>st</sup> February 2009 held in department of statistics, NEHU.

**Hygina Siangbood**

## Diversity of Algal communities in Umiew River, Meghalaya

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### ABSTRACT

The present paper deals with the diversity of algae in Umiew River, an important river in Meghalaya in relation to physico-chemical characters. The physico-chemical parameters of the two selected stations of the river (running source and dammed reservoir) showed marked variations in width, depth, transparency, current velocity, dissolved oxygen and in nutrient contents like nitrate, phosphorus, calcium and magnesium. Totally, 117 species were recorded from station-1 whereas only 46 species were recorded from station 2. Species diversity value was higher in station-1 than station-2 with 0.51 and 0.37 respectively. Bacillariophyceae showed the highest species diversity in both the stations. Relative abundance of different classes in station-1 was 48% (Chlorophyceae), 24% (Bacillariophyceae), 21% (Cyanophyceae) and 7% (Euglenophyceae), whereas in station-2, 49% were (Bacillariophyceae), 31% (Chlorophyceae), 19% (Cyanophyceae) and 1% (Euglenophyceae). *Navicula* with 13 and 7 species from Bacillariophyceae and *Scenedesmus* with 11 and 4 species from Chlorophyceae had been observed as the most dominant genera in station 1 and 2 respectively. 15 species of Desmids were recorded from station-1 whereas only two species were recorded from station-2. High diversity in station-1 compared to station-2 could be attributed mainly to its changes in physical characteristics of the river as well as chemical characteristics due to lime quarrying.

### Introduction

Meghalaya in North Eastern India is one of the important Biodiversity Hotspots. The climate in general is monsoonic with average rainfall of 2200 mm spread over mid May to September with temperature varying from 25°C - 34°C in summer and in winter it varies from 16°C to minimum of 3°C which is considered as very conducive conditions for the growth of algal communities. But very little is known about the algal communities, their diversity in different aquatic habitats. Only a few lakes and streams have been studied (Biswas 1934; Alfred 1978; Ghosh 1991; Rout 1991; Sharma & Lyngdoh 2003, Jena *et al.*, 2006a & b). Reports on the algal communities

of rivers are still deficient. The aquatic habitats of this region are undergoing changes in a very fast pace due to anthropogenic activities. Distributional pattern of different algal communities in general has been treated as good indicator of water quality. Hence, the purpose of this present paper was to study the diversity of algal communities in the river Umiew. River Umiew is one of the most important rivers of Meghalaya which is still considered as clean water body by Central Pollution Control Board (CPCB Annual Reports 2002-2003). This river supplies drinking water to Shillong town and its vicinity. The river stretches to 400 km originating from Shillong peak at an altitude of 1912m and flow upstream through Nongkrem village, East

Khasi Hills District, and downstream via Mawphlang to Bangladesh. At Mawphlang village, the water has been dammed to create a reservoir, Greater Shillong Water Supply (GSWS).

## Materials and methods

### Study site description

Two stations were selected along the river. Station-1 Nongkrem source of the river (Alt-1763 msl, Lat- N 25°30'6.08", E91°54'12.07") where the river is narrow, shallow and clear, running through agricultural fields. Station-2 Mawphlang (Alt-1582 msl, Lat-N25°26'45.2", E91°45'57.8") where river water has been dammed to create a Greater Shillong Water Supply. The depth of the water in this station is very high and it runs in between high hills.

### Methodology

Algae were collected by scraping rocks, pebbles, dead twigs, roots and stems of some macrophytes. Phytoplankton was collected by towing plankton net into the river. The samples were kept in a sample container and preserved with 4% formaldehyde. Quantitative analysis of algae was done by using a light microscope and phase contrast attached with a digital camera which filmed the algae directly from the sample. Algal identification was done according to the monographs of Tiffany and Britton (1952), Prescott (1962), Philipose (1967), Desikachary (1988), and Krishnamurthy (2000). All voucher samples are preserved at Algal laboratory of Botany Department, North Eastern Hill University. Temperature, pH, dissolved oxygen were measured by Deluxe Water and Soil Analysis Kit (Model-191-E) during collection of samples. Water current was measured with the help of a bubbler and stopwatch. Depth was measured with the help

of a long stick and tape, and water transparency was measured with Secchi-disc. All these parameters were measured in field condition. Nutrients like calcium, magnesium, phosphate and nitrates were analyzed in the laboratory one day after collection of sample following APHA (2005). Species diversity was calculated using Shannon-Weaver diversity index (Shannon and Weaver 1963), following the formula

$$H' = -\sum p_i \log p_i$$

Where,

$$p_i = n_i/N$$

$n_i$  = No. of individuals in the  $i^{\text{th}}$  species

$N$  = Total no. of individuals of all the species

## Results

### Physico-chemical factors

A comparison of physical parameters in two important parts of the river station-1 (upstream) and station-2 (huge dammed reservoir - downstream) showed significant variations in width, depth, transparency, current velocity. At upstream the average width was 5.9m and depth was 0.36m whereas it was 70m wide and 95m deep at downstream. Water transparency in station -1 was 100 % as water was very clear and depth was very low but in station-2 transparency was 0.67m. Average water current velocity also differed considerably. In station-1, it was 0.129 m/sec compared to station-2, 0.03 m/sec. There were very little differences in temperature. Average pH value was 6.62 in station-1 and 7.24 in station-2. Dissolved oxygen and nutrients like nitrate and phosphate were higher in station-1 whereas magnesium and calcium was higher in station-2 (Table-1).

### Species composition

117 species from station 1 and 46 species from station 2, mainly belonging to

Table 1. Average value of physico-chemical parameters in the two stations of Umiew River

Variables	Station-1	Station-2
Width(meter)	5.9±0.81 <sup>a</sup>	70.0±10.0 <sup>b</sup>
Depth (meter)	0.36±0.15 <sup>a</sup>	95.0±6.24 <sup>b</sup>
Transparency (meter)	0.36±0.15(100%)	0.67±0.32
Water current (m/sec)	0.129±0.05 <sup>a</sup>	0.035±0.01 <sup>b</sup>
Temperature(°C)	20.00± 2.3 <sup>a</sup>	20.75±3.2 <sup>a</sup>
pH	6.62±0.38 <sup>a</sup>	7.24±0.43 <sup>a</sup>
Dissolve Oxygen (mg <sup>-1</sup> )	8.83±1.07 <sup>a</sup>	5.83±2.16 <sup>b</sup>
Calcium (mg <sup>-1</sup> )	4.92±1.93 <sup>a</sup>	7.43±0.62 <sup>b</sup>
Magnesium (mg <sup>-1</sup> )	31.02±1.51 <sup>a</sup>	33.71±6.32 <sup>a</sup>
Nitrate (mg <sup>-1</sup> )	4.2±0.11 <sup>a</sup>	1.6±0.24 <sup>b</sup>
Phosphate (mg <sup>-1</sup> )	0.27±0.03 <sup>a</sup>	0.18±0.15 <sup>b</sup>

Letter followed by same letter is not significantly different

four major classes of algae were identified. The relative abundance of different classes in station-1 was 48% (Chlorophyceae), 24% (Bacillariophyceae), 21% (Cyanophyceae) and 7% (Euglenophyceae), whereas in station-2, 49% were (Bacillariophyceae), 31% (Chlorophyceae), 19% (Cyanophyceae) and 1% (Euglenophyceae) (Fig. 1).

In station 1, maximum number of species 46 and individuals / ml 8964, were recorded from Chlorophyceae followed by Bacillariophyceae 35 and 4365.8, Euglenophyceae 20 species, but number of individuals/ml recorded was 1374, lesser than Cyanophyceae where species number

recorded was 16 and individuals/ml recorded were 3896.8. In station 2 both the species number and individuals/ml were much lower than station 1. Bacillariophyceae with 20 species and 2089.5 individuals/ml had been found to be the most dominant one followed by Chlorophyceae with 14 species and 1304.9 individuals/ml, Cyanophyceae with 9 species and 796.8 individuals/ml, Euglenophyceae was represented by only 2 species and 286.8 individuals/ml (Fig. 2).

Distribution of algae in Station-1 was found to be more diverse compared to station-2 with total species diversity of 0.51 and 0.37 respectively. Bacillariophyceae showed the

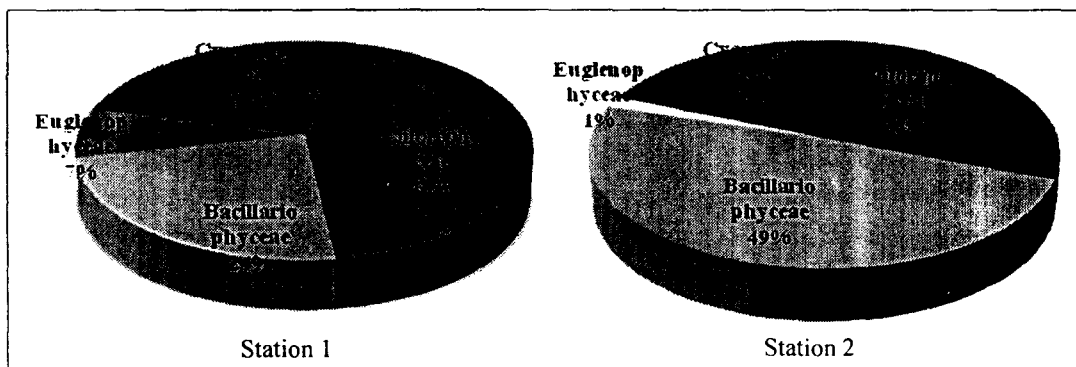


Fig. 1. Distributional pattern of different algal groups in station-1 and station-2

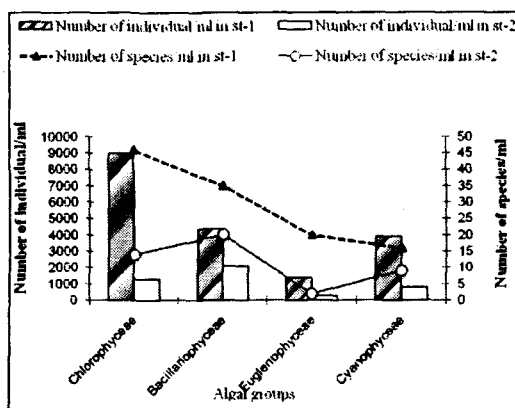


Fig. 2. No. of Species and No. of Individuals/ml in two stations

highest species diversity in both the stations with 1.43 and 1.01 respectively (Table-2)

*Navicula* was found to be the most dominant genus from Bacillariophyceae represented by 13 and 7 species, followed by *Gomphonema* with 6 and 4 species and *Cymbella* with 4 and 2 species in station 1 and 2 respectively. In Chlorophyceae, 15 species of Desmids were found in station-1 whereas only two species were recorded from station-2. *Scenedesmus* was recorded as the most dominant green alga with 11 species in station 1 and 4 species in station 2. 21 species from Euglenophyceae were recorded from station 1 whereas only two euglenoid species were recorded from station 2. From station 1, 14 species of cyanophycean algae were collected, *Oscillatoria* being the most dominant one among them whereas only 6 species of Cyanophyceae were collected from station 2 (Table-3).

## Discussion

High diversity and occurrence of algae from Chlorophyceae and Bacillariophyceae in Umiew river of Meghalaya indicate that the prevailing environmental conditions particularly the physico-chemical parameters are still favorable for the growth

Table 2. Species diversity in two stations

Algal groups	Species diversity	
	Station-1	Station-2
Chlorophyceae	1.37	0.96
Bacillariophyceae	1.43	1.01
Cyanophyceae	0.94	0.63
Euglenophyceae	0.99	0.36
Total diversity	0.51	0.37

of algal communities. Physical characteristics of the river Umiew at the two stations which varied mainly in depth, width, transparency, current velocity, as well as surrounding land use might be responsible for the differences observed in species diversity. Increase in depth resulted in decrease in diversity (Palmer 1980). In the present study, low depth, higher transparency (100%), and higher dissolved oxygen in station-1 might have resulted in higher species diversity compared to station-2. Ariyadej *et al.* (2004) and Tiseer *et al.* (2008) reported the importance of light and dissolved oxygen in algal distribution in Banglang reservoir in Yala Province, Thailand and Nigeria respectively. Species diversity in both the stations was maximum in the class Bacillariophyceae due to greater cell density even though the total number of species from Chlorophyceae was more compared to other classes in station 1. Dominance of Bacillariophyceae had been reported by Ghosh (1991) and Rout (1991) from streams of both forested and deforested areas of Meghalaya. Rout (1991) reported totally 158 species, of which 122 were Bacillariophyceae, 20 Chlorophyceae and 13 members Cyanophyceae from streams of forested area whereas from streams of deforested area, Ghosh (1991) reported only 75 algal species of which 54 belonged to Bacillariophyceae, 13 belonged to chlorophyceae and only 6 belonged to Cyanophyceae. Jena *et al.* (2006)

Table 3. List of algal species recorded from station-1 and station 2

Chlorophyceae	Station-1	Station-2
<i>Ankistrodesmus braunii</i> (Naeg) Brunthaler	+	-
<i>Ankistrodesmus falcatus</i> (Corda.) Ralfs	+	+
<i>Asterococcus</i> sp	-	+
<i>Chaetophora</i> sp	+	-
<i>Charatiopsis</i> sp	+	-
<i>Chlorella vulgaris</i> Beyerinck	+	-
<i>Chlorococcum</i> sp	+	+
<i>Chlorococcus</i> sp	+	+
<i>Closterium acutum</i> (Lyngb.) Brebisson	+	-
<i>Closterium croasdale</i> Nurul Islam	+	+
<i>Closterium navicula</i> Brebisson	+	-
<i>Closterium kuetzingii</i> Brebisson.	+	-
<i>Closterium lebleinii</i> Kuetzing	+	+
<i>Closterium moniliferum</i> (Bory) Ehrenberg	+	-
<i>Coelastrum microsporum</i> Naegeli	-	+
<i>Cosmarium circulare</i> Reinsch	+	-
<i>Cosmarium cucurbita</i> Brebisson	+	-
<i>Cosmarium decoratum</i> W.et. G.S.West	+	-
<i>Cosmarium globosum</i> Bulnheim	+	-
<i>Cosmarium pseudocoronatum</i> Nordst	+	-
<i>Cosmarium pyramidatum</i> Brebisson	+	+
<i>Cosmarium</i> sp	+	-
<i>Cosmarium subcrenatum</i> Hantzsch	+	-
<i>Cosmarium undulatum</i> (Corda) Ralfs	+	+
<i>Desmidium beileyi</i> (Ralfs) Nordst.	+	-
<i>Gonium</i> sp	+	-
<i>Haematococcus</i> sp	+	-
<i>Microspora quadrata</i> Hazen	+	-
<i>Monaraphidium turtile</i> (W&G. West) Kormakóva	+	-
<i>Mougeotia</i> sp	+	-
<i>Oedogonium</i> sp	+	-
<i>Oocystis</i> sp	+	-
<i>Penium cylindrus</i> (Ehr.) Brebesson	+	-
<i>Scenedesmus abundans</i> G.W. Smith	+	-
<i>Scenedesmus acuminatus</i> (Lagerheim)Chodat	+	-
<i>Scenedesmus acutiformis</i> Schi oeder	+	-
<i>Scenedesmus alternans</i> (Reinsch) Borge	+	-
<i>Scenedesmus arquatus</i> Smith	+	-
<i>Scenedesmus bicaudatus</i> (Hansgirg) Chodat	+	+
<i>Scenedesmus bijugatus</i> ((Turpin) Brebesson	+	-
<i>Scenedesmus carinatus</i> ( Lemmermann) Chodat	+	-
<i>Scenedesmus dimorphos</i> (Turpin) Kuetzing	+	+
<i>Scenedesmus hystrex</i> Lagerheim	-	+
<i>Scenedesmus obliquus</i> (Turpin) Kuetzing	+	+
<i>Scenedesmus quadricauda</i> (Turpin) Brébisson	+	-
<i>Sphaeroszma</i> sp	-	-

Table 3. Continued...

	Station-1	Station-2
<i>Spirogyra pratensis</i> Transeau	+	-
<i>Spirogyra varians</i> ( Hass.) Kuetzing	+	+
<i>Staurastrum</i> sp	-	-
<i>Ulothrix subconstricta</i> G.S.West	+	-
<i>Ulothrix zonata</i> ( Weber and Mohr.) Kuetzing	+	-
<i>Volvox</i> sp	+	+
<b>Bacillariophyceae</b>		
<i>Achnanthes</i> sp	+	+
<i>Amphipleura</i> sp	+	-
<i>Cocconeis</i> sp	+	-
<i>Cyclotella meneghiniana</i> Kuetzing	-	+
<i>Cymbella affinis</i> Kuetzing	-	+
<i>Cymbella cistula</i> (Hempr.) Grunow	+	-
<i>Cymbella lanceolata</i> Ehrenberg	+	-
<i>Cymbella naviculiformis</i> Auerswald	+	+
<i>Cymbella tumida</i> (Breb.) V.Heurck	+	-
<i>Diatoma</i> sp	+	-
<i>Fragillaria bicep</i> Grunow	+	+
<i>Frustulia rhomboides</i> (Ehr.) DeToni	+	+
<i>Gomphonema dichotomous</i> Kuetzing	+	-
<i>Gomphonema lanceolatum</i> Ehrenberg	+	-
<i>Gomphonema olivaceum</i> (Lyngb.) Kuetzing	+	+
<i>Gomphonema parvulum</i> Grunow	-	+
<i>Gomphonema sphaerophorum</i> Ehrenberg	+	-
<i>Gomphonema telographicum</i> Kuetzing	+	-
<i>Gomphonema vibrio</i> Ehrenberg	+	+
<i>Melosira granulata</i> (Ehrenberg.) Ralfs	-	+
<i>Navicula accomoda</i> Hust.	+	-
<i>Navicula cuspidata</i> Kuetzing	+	+
<i>Navicula gracilis</i> Ehrenberg	+	+
<i>Navicula kariana</i> Grunow	+	-
<i>Navicula lamii</i> Manguin.	+	-
<i>Navicula lanceolata</i> Kuetzing	+	+
<i>Navicula major</i> Kuetzing	+	+
<i>Navicula microspora</i> Kant & Gupta	+	-
<i>Navicula pupula</i> Kuetzing	+	-
<i>Navicula radiosa</i> Kuetzing	+	+
<i>Navicula reinhardtii</i> (Grunow) Van Heurck	+	-
<i>Navicula rhyncocephala</i> Kuetzing	+	-
<i>Navicula viridis</i> (Nitz.) Kuetzing	+	+
<i>Nitzschia palea</i> (Kutz.) Smith.	+	-
<i>Nitzschia stagnarum</i> (Rabenh.) Grunow	+	-
<i>Pinnularia bicep</i> Gregory	+	-
<i>Pinnularia viridis</i> (Nitz.) Ehrenberg	+	+
<i>Stephanodiscus</i> sp	+	-
<i>Surirella robusta</i> Ehrenberg	+	+

Table 3. Continued...

	Station-1	Station-2
<i>Synedra capitata</i> Ehrenberg	+	-
<i>Synedra ulna</i> (Nitz.) Ehrenberg	+	+
<b>Euglenophyceae</b>		
<i>Euglena acus</i> Ehrenberg	+	+
<i>Euglena caudata</i> Hubner	+	-
<i>Euglena gracilis</i> Klebs	+	-
<i>Euglena haematodes</i> (Ehr.) Lemmermann	+	-
<i>Euglena hemichromata</i> Skuja	+	-
<i>Euglena polymorpha</i> Dangeard	+	-
<i>Euglena proxima</i> Dangeard	+	-
<i>Euglena spirogyra</i> Ehreberg	+	-
<i>Euglena viridis</i> Ehrenberg	+	-
<i>Euglena wangii</i> Chu	+	-
<i>Lepocinclis elongata</i> (Swirenko.) Conrad	+	-
<i>Lepocinclis ovum</i> (Ehr.) Lemmermann	+	-
<i>Lepocinclis</i> sp	+	-
<i>Phacus anomalus</i> Fritsch	+	-
<i>Phacus brevicaudatus</i> (Klebs) Lemmermann	+	-
<i>Phacus caudatus</i> Hubner	+	-
<i>Phacus crenatus</i> Hirano	+	-
<i>Phacus hispidulus</i> (Eickwald) Lemmermann.	+	-
<i>Phacus longicouda</i> (Ehr.) Dujardin	+	-
<i>Trachelomonas armata</i> (Ehr.) Stein	+	-
<i>Trachelomonas hispida</i> (Perty) Stein	+	+
<b>Cyanophyceae</b>		
<i>Anabaena constricta</i> Szafer	-	+
<i>Aphanocapsa endophytica</i> G.M. Smith	+	+
<i>Chroococcus limneticus</i> Lemmermann	+	-
<i>Leptolyngbya</i> sp	-	+
<i>Lyngbya perelegans</i> Lemmermann	+	-
<i>Merismopedia elegans</i> G.M. Smith.	+	+
<i>Microcystis aeruginosa</i> (Kuetz.) Kuetzing	+	+
<i>Oscillatoria agardhii</i> Gomont	+	-
<i>Oscillatoria amphibia</i> C. Agardh	-	+
<i>Oscillatoria articulata</i> (Gardner.) Drouet	+	-
<i>Oscillatoria bornetii</i> Zukal	+	-
<i>Oscillatoria curviceps</i> (Agardh) Gomont	-	+
<i>Oscillatoria limosa</i> (Dillwyn) Agardh	+	-
<i>Oscillatoria pseudogerminata</i> G.M. Smith	+	-
<i>Oscillatoria sancta</i> (Kuetz) Gomont	+	-
<i>Oscillatoria subbrevis</i> Schmidle	+	-
<i>Oscillatoria tenuis</i> C.A. Agardh	+	-
<i>Phormidium ambiguum</i> Gomont	-	+
<i>Phormidium fragile</i> Gomont	-	+
<i>Phormidium purpurascens</i> (Kuetz.) Gomont	+	-
<i>Phormidium uncinatum</i> (Agardh) Gomont	+	-

reported totally 272 species where 121 species were from Bacillariophyceae and 132 species were from Chlorophyceae with 32 genera of desmids and 20 species from Euglenophyceae from different aquatic habitats of North eastern India. *Navicula* had been reported by all as the most dominant genus. 15 desmid genera had been recorded from station-1 and only two genera from station-2. This drastic change in number of desmids in station 2 which is considered as indicator of oligotrophic acidic condition of aquatic systems could be related to change in pH from acidic to alkaline and presence of more calcium which resulted from lime quarrying. Vidyavati (2007) reported great decline in desmid genera due to human interferences and other activities from many natural habitats of Andhra Pradesh. Allyson *et al.* (2006). Jones *et al.* (1993) & Daniel *et al.* (1994) have found that increased amount of nutrients (phosphorus, nitrogen), entering a stream from agricultural runoff increased the growth of algae and other organisms within limiting level and supported high diverse algal communities. In the present study higher level of nitrogen and phosphorus found in station-1 might be another additional factor responsible for higher diversity in station-1 but at the same time the dominance of Bacillariophyceae and Chlorophyceae compared to Cyanophyceae and Euglenophyceae indicate that the level of nutrients are still within limiting level.

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