CHAPTER-5

(Discussion)
DISCUSSION

Algae play an important role in aquatic ecosystem. They are the primary producers of food chain in an aquatic ecosystem and provider of world biggest photosynthetic biomass. They grow at any place and any environment where moister and sunlight is available. However, specific algae grow in specific environment and therefore, their distribution pattern, ecology, periodicity, qualitative and quantitative occurrence differs widely.

The abundance and diversity of algal flora in surface water of different water bodies affected by pollution of different origin have been discussed by many workers and a conflicting general impression exists in many research findings. Several reports are now available on occurrence of algae in polluted waters of industrial origin. The diversity of physico-chemical and biological characteristics of industrial effluents is so diverse that each waste water habit requires separate study for proper assessment, evaluation and mitigation.

Moreover, identification of pollutant resistant algal species is very important from its application point of view in biological treatment waste water and effluents. The observation and results obtained in this investigation on Elenga Beel ecosystem with special reference to algal diversity and abundance in relation to water quality has been discussed below. The water body is an abandoned paleo-channel of Kopili River and therefore, elongated in nature and loaded by the effluents of Nagaon Paper Mill.
5.1 ABUNDANCE AND COMPOSITION OF ALGAL FLORA IN PAPER MILL
EFFLUENT AND ELENGA BEEL

The abundance of algal flora in Elenga Beel shows a wide displacement from those occurring in natural unpolluted water bodies. The plankton community of Elenga beel shows a departure from normal conditions. A horizontal variation of algal flora of different classes was observed at different sampling location. In the entire stretch of the beel four groups of algae, namely – Cyanophyceae, Chlorophyceae, Bacillariophyceae and Euglenophyceae was recorded. The data presented in Table-4.1 and Figure 4.8 showed that Cyanophyceae (33.17 %), Chlorophyceae (32.56%), Euglenophyceae (29.07%) and Bacillariophyceae (5.18%) were present in the entire stretch of the Beel. and their detailed species wise fluctuation trend of these four groups of algae can be visualized in Table 4.1 (Chapter-4).

The knowledge of plankton species composition and distribution with time and space are of great value especially in any running water system. Plankton distribution and abundance are affected by seasons and variations of physico-chemical variables (Ezra and Nwankwo, 2001). In this investigation, station E and S1 has perfect positive correlation between them (r = 1.000) and did not allow large number of species to encounter. A significant decline of species number was noticed in these stations. Gradual increase of species number was observed from S2 to S6 due to dilution or increase the distance from point of effluent discharge in the water body. Phytoplankton numbers also registered higher during non-rainy season at all the stations. The phytoplankton population’s count was comparatively higher in summer (39.57%) and low during rainy (28.50%) season. Similar type of observation was recorded by Sadguru et al. (2002) while working on Caveri River with reference to pollution.
It is clear from the results presented in Table 4.1 that at the sampling stations E and S₃ characterized with polluted water by the paper mill effluent favours the growth of *Cyanophyceae* and *Euglenophyceae* as compared to the algal groups — *Chlorophyceae* and *Bacillariophyceae*. The *Chlorophyceae* and *Bacillariophyceae* were dominating at sample location S₄ to S₆ which agrees with the findings of Sudhakar and Venkateswarlu (1991a), Venkateswarlu (1969) in Godavari River affected by paper mill effluents.

Nandan and Ahar (2005) showed that the algal genera, *Euglena, Oscillatoria, Scenedesmus, Navicula, Nitzscia and Microcystis* are the species found originally in polluted water bodies. Similar genera were also recorded in the Beel. According to Round (1965), the presence of epilethic and epiphytic algae are excellent indicators of water pollution. In the present investigation, occurrence of *Phormidium, Oscillatoria and Ulothrix* as epilethic algae and *Gomphenoma* as epiphytic were recorded. *Oscillatoria* was recorded as largest in numbers among *Cyanophyceae* indicating the presence of pollutants of biological origin which agreed with the observation of Gadag et al. (2005). The abundance of *Navicula, Oscillatoria and Euglena* were maximum at station E, S₁, S₂ and S₃ indicating the presence of highest degree of organic pollutants. Lightly polluted station S₆ was characterized by the abundance of green algal flora followed by diatoms and flagellates which complies with the results of Verma and Mohanty (994); More and Nandan, (2000); Nandan and Aher, (2005); Tas and Gonulal (2007). It has been reported that excessive growth of certain algal genera viz. *Scenedesmus, Anabaena, Oscillatoria and Melosira* is the indicator of nutrient enrichment of water bodies (Kumar, 1990; Zargar and Ghosh, 2006). In our study similar algae were recorded except *Melosira*. 

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The qualitative and quantitative study of phytoplankton has been utilized to assess the water quality of different water bodies by different workers (Shekhar et al. 2008). Phytoplankton diversity responds rapidly to the changes in the aquatic environment. The dominance of class Chlorophyceae in sample station S5 and S6 might be due to high dissolved oxygen, fair range of pH, alkalinity and total hardness as supported by our physico-chemical data [Table 4.4] of the water samples. Bajpai and Agaker (1997) reported that green algae (Chlorophyceae) prefer water with high concentration of dissolved oxygen. In the present study highest number of green algae were encountered in Station S5 and S6 where DO level was high [Table 4.4]. Moreover, DO value was found to be positively correlated with green algae (Chlorophyceae) as given in Table 4.2 i & ii.

The variations of physico-chemical parameters greatly influence the variation of phytoplankton population. During rainy season, phytoplankton’s counts were declined along with the physico-chemical parameters. Similar observation has also been reported by Pundhir and Rana (2002). The occurrence of higher percentage of phytoplankton in Beel beel during summer is mainly due to the change in physical properties of water rather than chemical condition of the beel as supported by Davika et al (2006). It has been observed that Spirogyra is a major component of phytoplankton in the beel. The occurrence of various species of Spirogyra indicates the eutrophic nature of water bodies as supported by Bajpai and Agaker (1997).

The abundance of Cyanophyceae in paper mill effluents is attributed to favourable contents of oxidizable organic matter and less dissolved oxygen, high BOD and COD (Venkateswarlu, 1991; Boominathan, 2005; Vijayakumar et al. 2005). They suggest that Cyanophyceae grow luxuriantly with great variety and abundance in water
with less DO and oxidizable organic matter. In the present study, the waste water from paper mill showed considerable amount of nitrates and phosphates, with increased level of BOD and COD along with very low DO and turbidity [Table 4.4]. This could be the reason for the flourishing growth of Cyanophyceae in effluents and their sequent decline in unpolluted or low organically polluted stations (S5 and S6).

Fogg et al. (1973) inferred that the correlation between the abundance of planktonic cyanobacteria (also called as Cyanophyceae) and high concentration of dissolved organic matter may be due to the depletion of oxygen. Similarly, Mittal and Senger (1989) concluded that the low temperature, turbidity and total dissolved solid enhance the growth of green algae. Sarojini (1996) and Tara and Bodhke (2002) have observed that high turbidity, pH, bicarbonate, orthophosphate, alkalinity and chloride may be responsible for the Cyanophycean growth and bloom. Kaur et al. (2001) stated that Euglena was found in polluted sites as he studied at Jaipur and these could be considered as pollution tolerant species. The basic process of phytoplankton production depends on temperature, turbidity and nutrients (Sukumaran and Das 2002). In the present study, temperature, turbidity and nutrients found to have significant correlation (p<0.01 or p<0.05) with phytoplankton’s count [Table 4.2i & ii]. Thus, from the foregoing discussion, it is concluded that physico-chemical character of water together with biological monitoring provides converging lines of evidences for evaluation of phytoplankton’s compositions in polluted habitats as in case of some other studies (Cairns and Dickson, 1971; James and Evison, 1979). On the basis of our result it becomes apparent that the changes of algal community of Elenga Beel was attributed to i) seasonal variation ii) high load of pollutants from paper mill and iii) relative adaptability and resistance of nuisance algal flora to pollutants.
5.2 Physico-chemical Characteristics of Paper mill Effluent and Water Quality of Elenga Beel

The physico-chemical parameters of effluent and water quality of Elenga beel at different sampling stations and seasons were incorporated in Table 4.4&4.5 and Figure 4.9 (i-xv). The correlations among the physico-chemical parameters as well as their correlations with phytoplankton abundance during different seasons and their inter-station correlations are presented in Table 4.6(i&ii) and Table 4.7. From the results it is evident that the effluent of the paper mill is coloured and characterised by high temperature, pH, high range of oxidizable matter, sulphates, BOD, COD, TDS, TSS, SS, EC, TN, and TP. The effluent was highly depleted in Dissolved Oxygen and Turbidity.

Water temperature plays an important role in studying the distribution, metabolism and life history of aquatic organisms (Hines, 1978). Increased temperature creates a chain of chemical reaction on water which ultimately reduces the solubility of oxygen in water leading to oxygen depletion in water (Venkateswarlu, 1969). In the present study, water temperature was observed in the range from 26°C-30°C throughout the beel with slight variation with seasons. The water temperature recorded at station E-S4 was higher than the temperature recorded at S5 and S6, which may be due to the effect of effluent entered in the water body. A comparison of algal population with water temperature reveals that higher temperature favours the growth of Cyanophyceae and Euglenophyceae, while low temperature enhanced Chlorophycean growth. This observation agrees with the findings of Sudhakar and Venkateswarlu (1991) who also observed 27 unit’s variation in algal number with a change of one unit of temperature. In the present study positive correlations of temperature with Cyanophyceae (r = 0.530)
and *Euglenophyceae* (r =0.703) and negative correlation with *Chlorophyceae* (r=-0.722) and *Bacillariophycea* (r = -0.856) have been observed. Moreover, the combine effect of fluctuation of temperature in the entire stretch of the Beel during all seasons was significant with the fluctuation of concentration of phytoplankton (r = -0.821, P< 0.05). But individual effects of temperature on different classes of algae are different. Temperature has positive correlation with *Cyanophyceae* (r = 0.530) and *Euglenophyceae* (r = 0.703) and has negative correlation with *Chlorophycea* (r= -0.722) and *Bacillariophycea* (r = - 0.856) [Table-4.2(i & ii)].

The high temperature range (28°C-30°C) in sample station E to S₃ enhanced the growth of *Cyanophycea* and *Euglenophycea* while low temperature range (26°C-27°C) at sample stations S₅ and S₆ favours *Chlorophyceae* and *Bacillariophyceae*. Similarly, Mittal and Senger (1989) also concluded that low temperature enhanced the growth of green algae. Gonzalves and Joshi (1946) observed positive correlation of temperature with *Cyanophyceae*. Kaur *et al.* (2001) established that temperature is the major factor influencing species richness and diversity. In our study species diversity was found to be high in station S₅ and S₆ where temperature recorded was very low (26°C to 27°C) [Table 4.10]. Mahadev and Hosmani (2004, 2005) observed that *Cyanophyceae* are highly tolerant organisms and prefer to grow at higher temperature and in slight alkaline condition.

According to Webb (1982) variation in pH due to chemical and other industrial effluents make the water unsuitable for recreational purpose, rearing fish and other aquatic life. Nelson (1978) opined that pH ranging from 5-9 has no direct effect on most of organisms. But according to Ellis (1937) the tolerance level of most of organisms to alteration of pH is quite narrow. Hence, survival of aquatic organism under extreme
condition creates serious problems. The pH value above 8.8 is harmful for algal growth. The pH of NPM effluent (untreated) is higher than 9.0. But the annual mean value of pH of treated effluent of Nagaon Paper Mill released to Elenga beel was recorded as 8.5 also indicates the enrichment of alkaline effluents. In our present findings, the pH values of water decreases away from the effluent discharge site from 8.5 at station E to 7.5 at station S6 [Table 4.5]. Moreover, the values of pH were recorded high in summer (S) and low in rainy (R) season at all stations. Though the combined effect of pH on phytoplankton’s abundance showed negative correlation (r = -0.769, p<0.05), the effect of pH on individual different groups of algae showed both positive and negative correlations. *Cyanophyceae* (r = 0.477) and *Euglenophyceae* (r = 0.659) showed positive correlation and *Chlorophyceae* and *Bacillariophyceae* showed negative correlation with temperature [Table 4.2 I &ii]. The higher values of pH affected the algal flora and enhanced the growth of blue green and *Euglenoides* which can survive well in alkaline water. This finding is in conformity with the findings of Kaushik *et al.* (1991) who observed similar abundance of algae in polluted water. The positive correlation between PH and phytoplankton’s groups has been reported by Laxminarayana (1965).

Dissolved oxygen (DO) is an important factor in water quality determination. It reflects the physical and biological processes prevailing in the waters body (Shivanikar *et al.*, 1999) and its depletion affects the total system of a water body. In an aquatic ecosystem, flora and fauna can survive only in the presence of adequate dissolved oxygen. Singh and Singh (2001), while studying the water quality of river Ami noticed a high degree of water quality degradation due to changes in values of dissolved oxygen mainly due to the discharge of paper mill effluent. Medhi *et al.* (2011) also noticed low
level of DO in Nagaon paper mill effluents. In the present study dissolved oxygen (DO) level was found to be low at all stations. But, oxygen depletion was not uniform at different stations and seasons. As compared to rainy season, DO was very low during winter and summer. Station S6, which is located far away from the effluent discharge site, showed comparatively higher values of dissolved oxygen. Depletion of dissolved oxygen is an important aspect of water quality. A direct relationship among dissolved oxygen (DO) and different groups of algae have been observed by various workers. Verma and Mahanty (1995), Sarkar and Choudhury (1999) observed positive correlation between DO and phytoplankton abundance. In our study the combine effect of DO with total phytoplankton abundance is positive ($r=0.772$). The individual effect of DO is negatively correlated with Cyanophyceae ($r=-0.736$) and Euglenophyceae ($r=-0.848$) while positively correlated with Chlorophyceae ($r=0.846$) and Bacillariophyceae ($r=0.964$) [Table 4.2i&ii]. The result indicates that low DO of paper mill effluent enhanced the abundance of Cyanophyceae and Euglenophyceae in highly polluted zone whereas high DO influence Chlorophyceae and Bacillariophyceae in low organically polluted zone. Similar type observations were made by Saxena and Chauhan (1993) in river Yamuna and Reemol (2004) in Muvattupuzha River.

BOD is the measurement of biologically oxidizable organic matter present in water. The increased level of BOD and COD indicate the nature of chemical pollution. High amount of BOD and COD cause oxygen depletion which leads to the suffocation of aquatic life (Verma et al., 1984). These two parameters are interrelated and show inverse correlation with DO. Generally in summer, BOD value increases due to biological activity with elevated temperature (Palharya et al., 1993). In the present study, the highest annual mean value of BOD and COD were recorded at station E.
(396.33mg/ml and 553mg/ml) and lowest BOD and COD values were recorded in S6 (167mg/ml and 147mg/ml) respectively [Table 4.4]. The gradual reduction of BOD and COD towards downstream was due to self purification of water by microbial decomposition of the pollutants. Higher BOD and COD values observed during summer are in conformity with the results of Reemol (2004). In the present study, the BOD and COD showed negative correlation with phytoplankton ($r = -0.788$ and $r = -0.879$) but showed positive correlation with Cyanophyceae ($r = 0.776$; $r = 0.918$) and Euglenophyceae ($r = 0.655$; $r = 0.861$) [Table 4.2I & 4.2II]. This indicates that Euglenophycean and Cyanophycean algae can grow abundantly in paper mill effluent loaded water body having higher range of BOD and COD. Similar type observation was also reported by Venkateswarlu (1991) while working on Cyanobacterial diversity in paper mill effluent.

Alkalinity is an important parameter which determines the sum total of the constituents of water that is necessary for raising the pH. Natural, alkalinity helps to buffer pH changes which are important criteria for growth of aquatic organisms. In the present investigation, the values of alkalinity at different sites were high during summer season followed by steep fall during rainy period. The low alkalinity during rainy and post rainy periods in all the seven stations may be due to dilution effect (Jain et al, 1996). Similar observations were also recorded by Reemol (2004) in Cochin estuary. In the present study, the highest alkalinity (322mg/ml) was recorded at station E, while the lowest alkalinity (161mg/ml) was recorded at Stations S6. Negative correlation has been observed between total alkalinity and total phytoplankton population ($r = -0.757$), but alkalinity showed positive correlation with Cyanophycean ($r = 0.785$) and Euglenophycean ($r = 0.962$) algae respectively [Table 4.2I & 4.2II]. This indicates that
increase in total alkalinity due to the discharge of paper mill effluent enhances the abundance of *Cyanophyceae* and *Euglenophyceae* in the water body, while the population of other groups of algae decreases.

The Total dissolved solids (TDS) affect the water quality by increasing the density of water and thereby retarding the palatability of water. The values of TDS were found to be the highest at Station E (1311 mg/ml) and the lowest at station S₆ (385 mg/ml). Seasonal variation showed higher values of TDS during rainy and summer seasons due to addition of runoff, sewage and effluents to the beel. The high level of TDS, especially from station E to station S₃ indicated the input of ionic substances along with NPM effluent. Spatial distribution of phytoplankton population showed that TDS has negative correlation with total phytoplankton density (r = -0.791). However, TDS showed positive correlation with *Cyanophyceae* (r = 0.705) and *Euglenophyceae* (r = 0.867) [Table 4.2 I & 4.2 ii]. The higher value of TDS in rainy and summer season was observed by Gupta and Singh (2000), and Reemol (2004).

Natural waters may contain high quantities of Suspended Solids (SS). Suspended solids present in water may be due to inorganic impurities, accumulated gases, clay, silt, bits of bark, phytoplankton and other microscopic organisms. Higher amount of suspended solids might affect the quality of water and makes it unfit for aquatic plants growth (Manheim, 1970). In the present study, the total suspended solids (TSS) found to vary with sampling location and seasons. The highest amount (3.91 mg/l) of TSS was recorded at station E and minimum at station S₆ (1.76 mg/l). The highest amount of TSS discharged by Nagaon Paper Mill imparted brown colouration of water as well as reduced transparency particularly at sampling station E and S₁. A reduction of photosynthetic activity, reduced growth of primary producers, reduces abundance
and compositions of aquatic flora in habitats altered by high TSS was also reported by Clausen (1973). In our study, negative correlation (r = -0.771) of TSS with total phytoplankton count was found, which supports the observation of Clausen (1973) [Table 4.2 & Figure 4.8A].

Electrical conductivity (EC) denotes the capacity of a substance or solution to pass electrical current through it. The measurement of conductivity gives us an estimate of ionic substance present in water or the degree of mineralization of water. Investigation on conductivity revealed that its value decreases away from the effluent discharge site. The maximum value (1.340 mhos/cm) was observed at station E and minimum value (0.90 mhos/cm) at station S₆. The high value of conductivity at E indicated the presence of large amount of ionic substance in water Kakati (1991), but the lower level of conductivity in S₆ may be due to dilution or self-purification properties of the water body. Trivedy and Goel (1984), Dutta and Baissya (1997) suggested that the water having conductivity more than 2.00 mhos/cm is unsuitable for plant growth. In our present study, conductivity was less than the prescribed limit. Hence it would not affect plant growth. Negative correlation of conductivity was obtained with total phytoplankton counts (r = -0.786). However conductivity of water showed positive correlation with Cyanophyceae (r = 0.699) and Euglenophyceae (r = 0.883) [Table 4.2 i & 4.2 ii].

Turbidity is an important physical parameter which has a significant bearing on productivity of aquatic ecosystem (Kuriyan, 1974). According to Trivedy and Goel (1986) turbidity of all water resources ranged between 18-31 NTU (Nepholometric Turbidity Unit). However, maximum permissible limits recommended by them are 25 NTU. In the present study, lowest turbidity was recorded in station E (133 NTU) and...
highest at Station S₆ (452NTU). The turbidity of water was found to be less in summer and maximum in rainy which complies with the results obtained by Singh et al. (1991). Turbidity increases in downstream station S₅ and S₆ as distance increases from the effluent discharge point. In the present study, turbidity has positive correlation with total phytoplankton counts \((r = 0.750)\), but has negative correlation with Cyanophyceae \((r = -0.700)\) and Euglenophyceae \((r = -0.815)\) [Table 4.2i&ii]. The result indicated that decrease in turbidity of paper mill effluent may reduce the production of phytoplankton at upstream of the beel. Similarly increase in turbidity in downstream may increase the abundance of algae.

The excess amount of nutrients (P and N) that are discharged into aquatic systems sometimes might cause eutrophication and this would lead to various changes in algal community structure (Parnell, 2003). Although pulp and paper mill effluents are deficient in nitrogen and phosphorus, urea and superphosphate were used in biological treatment to feed the microorganisms. As a result, the entry of N and P in waste water of pulp and paper mill effluents and their subsequent release into natural ecosystem may cause serious problem for aquatic flora and fauna. In the present study, the highest amount of total nitrogen (5.07ppm) was recorded in station S₃ and the lowest (2.04ppm) was recorded in station S₆. Similarly, the highest amount of total phosphorus (1.02ppm) was recorded at station E, while the lowest (0.24ppm) was recorded at station S₆. Higher concentration of nitrogen at station S₃ may be due to the mixing of agricultural sewage from the nearby agricultural field where plenty of fertilizers were used by the farmers for crop production along with effluent irrigation (Dutta and Baissaya, 1997; Medhi et al., 2011). Total phytoplankton count shows negative correlation with total Nitrogen \((r = -0.691)\) and total Phosphorous \((r = -0.888)\)
has [Table 4.2i&ii]. The ratio of N/P was below 7 in polluted zones covering stations E to S₄ which stimulate *Cyanophycean bloom* and exhibited eutrophic nature of the Beel water. A positive correlation of TN ($r = 0.655$) and TP ($r = 0.646$) with *Cyanophyceae* was noticed.

Industrial and domestic water are the main source of sulphate for aquatic pollution. The pulp and paper mill waste water contains huge amount of sulphate because majority of pulp mill adopt sulphite processes. In our study the highest amount of sulphate was recorded in station E (168 ppm) and lowest was recorded in S₆ (83ppm) with respect to sulphate Nagaon paper mill have been able to reduce their amount below permissible limit (IS 400). The highest amount sulphate (443mg/l) in NPM effluents was recorded by Medhi *et al.* (2011). A negative correlation ($r = -0.851$) between sulphate and total phytoplankton count was observed.

Hardness was recorded highest at station E (610ppm) and lowest in Station S₆ (156ppm). It was low at all stations during rainy season. Nerra *et al.* (2001) reported that hardness of water was an indication of water pollution. In my study hardness was found not to exceed the IS permissible limit 600ppm except station E. Medhi *et al.* (2011) also observed hardness of NPM below permissible limit. Hardness was found to be negatively correlated ($r = -0.756$) with total algal counts.

### 5.3 Pollution Indices for Assessment of Water Quality and Biota

Two basic approaches were used to evaluate the effect of pollution on aquatic life. The first is to make a qualitative assessment of the presence or absence of algae in known polluted water body and then an understanding of the responses of various species to certain pollutants. The second approach is to make a qualitative analysis
of number of individual, species and structure (abundance and composition) of the aquatic community affected by pollutants and then compare with reference information. In many of the monitoring survey, the collected individual specific data are converted to some short of scale or index based on which the pollution status of a given water body can be well understood.

In the present study, three indices namely Palmer’s Pollution Index (PPI), Shannon Weaver Diversity Index (H) and Trophic State Index (TSI) were applied for evaluation of pollution status of Elenga Beel. The former two indices are of biological origin and the later one is of physico-chemical in nature. The total scores of each individual index were given in Chapter 4 [Table 4.8, 4.9, 4.10, & 4.11 and Figure 4.10, 4.11, 4.12 (i, ii & iii). The correlation coefficient (r) values of each individual index corresponding to each physico-chemical parameters were given in Table 4.12 of Chapter 4.

**Palmer pollution Index (PPI):** In the entire stretch of the beel, the algal genus index value for all stations was higher than the species index value. Again, the number of pollution tolerant genera was found to be higher than the numbers of pollution tolerant species [Table4.8 & 4.9]. The occurrence of higher value of genus index in polluted water was supported by Shaji and Patel (1991), Adhikari (1997), Baruah (1995), Nandan and Patil (1994), Jafari and Gunale (2006). Based on physico-chemical data [Table-4.4], station E was identified as more polluted than the rest of other stations. But here value of genus index was recorded as lower than the index value of station S1, S2, and S3 [Table-4.8]. This may be due to pollutants interaction and saprobic condition of this station. In such a situation, palmer pollution may not be accurately applicable (Adhikari,1997). In saprobic condition the number of tolerant genera and species may thrives well in good, but the number of pollution index genera
and species may be low. Similar type of observations was also noticed by Barua (1995), Adhikari and Sarma (1995), Adhikari (1997), Rana and Palria (1988) while working on bio-monitoring of industrial effluents on different water bodies.

A perusal of Figure 4.12(iii) reveals that palmer pollution index showed their maximum value in summer and minimum in rainy and winter season coinciding with algal population [Figure 4.8B]. The lowering of PPI index value in rainy and winter seasons may be due to low phytoplankton's population with high nutrient content during rainy and winter seasons. Similar observations were recorded by Saikia and Bordoloi (1994), Sahu et al., (1996).

The increase of phytoplankton's population along with PPI index in summer season might be due to temperature effect on water and biota. Temperature was found to be negatively correlated with total phytoplankton \((r = -0.821)\) [Table-4.7]. But correlation coefficient \((r)\) analysis between palmer's pollution index and temperature \((r = 0.767, p<0.044)\) [Table: 4.12] showed a positive correlation which support the observation of temperature effect during summer season. Similarly, in summer temperature is negatively correlated with TN \((r = -0.586)\) and TP \((r = -0.720)\). Nutrients like N and P attained its maximum values during the rainy and winter seasons as compared to summer due to inflow of rainwater. This is in conformity with the result of Singh (1993), Mishra and Yadav (1978).

The algal flora of Elenga beel were subjected to Palmer's Pollution Index (Palmer, 1969) for rating water quality. The result revealed that the station E, S₁, S₂, S₃ were highly polluted having index value above 20 indicating high organic pollution. Whereas station S₄, S₅ and S₆ has index value below 20 indicating moderate to low organic pollution. These findings again are in conformity with the observed value of physico-chemical and phytoplankton data as given in Table 4.8 and 4.1. Thus, the study
reveals that the computations of physico-chemical parameters along with the biological information of a water body exhibit converging lines of evidences for the evaluation of polluted habitats which is also supported by some other studies (Cairns and Dickson, 1971; James and Evison, 1979; Rana and Palria, 1988; Adhikari, 1995; Dubey et al, 2011).

Another important observation is that in palmer’s list some algal genera like Anabaena, Nostoc, Gleocapsa, Euastrum was not included as pollution tolerant species. But in the present it was observed that they can also tolerate organic pollution to some extent as compared to others. Baruah (1995) and Adhikari (1997) also considered Anabaena as pollution tolerant and fixed their index value at 1.

**Shannon Diversity Index (H):** The diversity index is an important tool in assessing the pollution level of a water body. The basic principle behind the application of diversity index is that polluted water bodies harbour low species diversity compared to unpolluted water bodies. Minimum number of species can thrive in polluted water bodies, where as the number of species is in higher in unpolluted water bodies. Based on this theory and applying the formula of Shannon and Weaver diversity index, the average algal diversity value for different sample sites of Elenga Beel was computed for all the seasons of the year and presented in the Table4.10 and Figure 4.10. The Shannon index calculated for Station E and S₁ was less than<1.00 (Table 4.10) indicating high organic pollution. From station S₂ to S₄ the index value increases slightly and lies in the range 1.00 to 2.00 indicating moderate pollution. From station S₅ to S₆ the value of the index was found in the range 2.00 to 3.00, which is an indication of low pollution level. Thus, almost all the sampling stations of the Beel from sites E to S₄ show higher degree of pollution level, while sites S₅ and S₆ show moderate to low pollution level.
Further, pollution level was not uniform at all the stations and during all the seasons. The results reflect that in the entire stretch of the beel, the value of diversity index increased with decreasing pollution load in the downstream direction which is in conformity of the observations of Nandan and Patel (1986), Barua (1995), Adhikari (1997), Ramakrishnan (2003), Mathivanon et al (2007) Dash (1996) and Khan (1991). The gradual increase in species diversity towards downstream with simultaneous decrease of pollution load may be due to dilution or self-purification of water in the beel due to bacterial decomposition of organic pollutants. Tarzwell and Gaufin (1953) demonstrated that organic waste were decomposed by the action of bacteria at septic zones and recovery zones which may be the reason for the gradual building up of the phytoplankton population in this zones. This is reflected in this study also showing low value of Shannon index (0.89) near the effluent discharge site (station E) and highest mean value (2.81) of Shannon index at the furthest sampling site (station S6) from the effluent discharge point.

Low values of Shannon index were recorded during rainy season and higher value in summer season at all the sites [Table 4.10]. This may be due to downpour of rainfall in the rainy season. Adesalu and Nwankwo (2008) and Rajagopal et al (2010) also reported that the low value of Shannon’s index for phytoplankton population in rainy season is due to dilution of medium, water loss through outlet and silting. Bajpai and Agakar (1997) reported that the species diversity would be low following disturbances such as flood, regular inflow and out flow of water. The correlation analysis between Shannon index and physico-chemical parameters [Table 4.12] showed that Shannon diversity is negatively correlated with most of the chemical parameter of water. But a positive correlations with pH (r = 0.337), TSS (r = 0.941), Turbidity (r = 0.979) and DO (r = 0.957) were observed. This means that the water quality parameters...
such as temperature, pH, turbidity and dissolved oxygen play a vital role in altering the phytoplankton species diversity.

**Trophic State Index (TSI):** The trophic level of an ecosystem is generally evaluated from the content of nitrogen, chlorophyll, transparency and biological parameters. The total nitrogen (N) and phosphorus (P) ratio (TN/TP) is considered as an important parameter in calculating the Trophic State Index of an ecosystem. In this study, the TN/TP ratio is utilized to ascertain TSI based on which wetland can be classified. For this Carlson’s equation as given in Chapter 3 were used. The TSI values computed from the equation are given in Table 4.11. Higher values of TSI (60-100) were recorded at station E to S₄ which indicated eutrophic nature of the water body. The lower values of TSI (<60) at station S₅ to S₆ is the indicative of oligotrophic nature of the beel. In Elenga Beel, both nitrogen and phosphorus act as limiting factors to some extent for phytoplankton growth. The relative abundance of **Cyanophyceae** and **Bacillariophyceae** were closely related to N: P ratio. In this investigation, **Cyanophycean algae** was found to be dominant at stations E to S₄ where N: P <7:1. **Bacillariophyceae** was dominant at station S₅ and S₆ (N: P > 7:1). Similar results were also obtained by Tonno and Noges (2003), and Havenes et al. (2003). It was observed that in all the sampling site of Elenga Beel TN/TP ratio is <10:1 which indicates that the ecosystem is nitrogen limited with much more phosphorus that is found in natural wetland. Although paper mill effluent (untreated) is deficient in nitrogen (N) and phosphorous (P), solution of urea and super phosphate are added in the ratio \( \text{BOD: N: P=100:5:1} \) for biological treatment of effluents in aerated lagoon or polishing pond system to feed the microorganisms (Kalita et al., 2002). This may be the reason for entry of excess amount of N and P nutrients into the beel which may lead to excessive growth of BGA at station E to S₄ leading to eutrophic state of water.
The occurrence BGA in station E to S₃ was also evident from algal data as shown in Table 4.1. The result presented in the table indicates that Elenga Beel is shifting from oligotrophic to eutrophic state of water body due to entry of effluents from Nagaon Paper Mill. The TSI value of station E to S₄ was in eutrophic state where as stations S₅ and S₆ were in oligotrophic state. Lowering of TSI at station S₅ and S₆ may also be due to the self-purification process or dilution of beel water. Berthon et al. (1996) states that bloom of Cyanobacteria are due to the drop of N/P ratio below 7, which is the threshold level for algae. When the ratio reaches below 5, algae collapse giving way to cyanobacteria which accept low N/P ratio. In this study, the ratio on N/P is <5 at Station E which support Cyanobacterial growth in paper mill effluents as observed by Venkateswarlu (1991).

5.4 GROWTH RESPONSE OF ALGAE TO PULP AND PAPER MILL EFFLUENT:

The algal growth experiment was conducted using different concentration of paper mill effluent to determine the effect of paper mill effluent on Oscillatoria chlorina and Scenedesmus quadricauda in terms of % stimulation (+) or % inhibition (-) of chlorophyll a, carotene and biomass content over the control at 21 days incubation period of time. This was accomplished by a range finding test in laboratory controlled condition. The result showed that paper mill effluents were stimulatory (+) as well as inhibitory (-) to the growth of test organisms [Table 4.13 - 4.14 & Figure 4.13-4.19]. A stimulatory (+) effect at lower concentration and an inhibitory (-) effect at higher concentration was noticed. The effect of concentrations on test algae were species specific. Blue green algae (Oscillatoria chlorina) showed highest stimulation at 80% concentration whereas green algae (Scenedesmus quadricauda) showed highest stimulation of growth at 40% effluent concentration over the control. Our findings
slight vary with the findings of palria (1991), Adhikari (1997) and Dash and Mishra (1999). Adhikari (1997) conducted bioassay of \textit{O.chlorina} using refinery effluent and observed maximum percentage stimulation (+) of chlorophyll content at 100% effluent concentration enriched with basal nutrient medium. Similarly Dash and Mishra (1999) in another experiment using paper mill effluent observed significant growth of green algae (\textit{Westiellopsis ptolifica}) at 100% effluent enriched with sewage.

Many workers reported negative impact of higher concentrations of industrial effluents on growth of algal chlorophyll. They argued that at higher concentration pigment production was hampered due to absorption of bio-available contaminants by algal cells from the effluents. The increase of pigment content in lower concentrations of effluents and decrease in higher concentration was recorded by Smith et al., (1988), Kobbia et al., (1995); Aidar et al.,(1997), Bindu Alex (2005). Reemol (2004) in his experiment reported both stimulatory and inhibitory effect of distillery effluent on algal growth at higher and lower concentrations respectively which agree with our present findings.

In the present study the enhanced growth of blue green (\textit{Oscillatoria chlorina}) at higher concentration (80% +BM) of paper mill effluent may be attributed to excess amount oxidizable organic matter, nutrients, low DO, high \text{pH}, temperature which favoured the growth of \textit{Cyanophycean} algae. The enhanced growth in Cyanophycea at higher concentration of PME in culture condition also exhibited similar trend of abundance in field observation. Which supports that blue green can survive well in highly polluted station E-S3 as compared to downstream station S5 and S6 [\textbf{Table 4.1}]. Green algae are opposite to this character. From the above it is apparent that different species of algae have differential toxicity to industrial chemicals. Patil (1998) in his studies with spent wash noticed that lower concentration of effluent stimulated the
growth *Spirulina* and *Oscillatoria* species, while higher concentration inhibited the growth. Wong et al. (1995) demonstrated that industrial effluents can cause stimulation and toxicity and structural damages to algae. The increased cell division of test algae in lower concentration may be due to the inducing effect of various ingredients present in it. Nitrate and phosphate present in effluent may act as growth promoting factor at lower concentration. The inhibitory effect of effluents at higher concentration may be due to changing of pH, low DO, high BOD and COD and increased concentration of other parameters.

Chlorophyll the 'pigment of life' plays a major role in growth of plant. It is found abundantly in all algae and a universal component of all classes of algae and is considered as the most useful in productivity and growth studies. The presence of pigments is a characteristic feature of any photosynthesizing cells. The plant pigment includes a number of chlorophyllous forms like chlorophyll a, chlorophyll b, and non-chlorophyllus pigment like carotene. The photosynthetic rate per unit chlorophyll is considered as indicator of the physiological state of an algal community (Perry et al., 1981). Thus the changes in pigment content will adversely affect the photosynthetic rate and thus will lead to an unbalanced physiological state.

The present study revealed that *O. chlorina* and *S. quadricauda* differ in their toxicity to pulp mill effluent. *O. chlorina* can tolerate higher higher concentration of paper mill effluents where as *S. quadricauda* tolerate low concentration. In both algae optimum growth takes place on 21 day of incubation beyond which their growth decline. The ANOVA summary (*Table 4.15 &4.16*) showing the effect of paper mill effluents on Chlorophyll a, biomass and carotenoid contents of *O. chlorina* and *S. quadricauda* exhibited significant difference of their growth between concentrations and treatment days of which 21 day incubation as final yield.

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