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Seasonal Variations of Phytoplanktonic Community Structure and Production in Relation to Environmental Factors of the Southwest Coastal Waters of Bangladesh

[1]Md. Mahfuzur Rahman Shah, [2,3]Md. Yeamin Hossain, [1]Momtaz Begum,
[4]Zoarder Faruque Ahmed, [5]Jun Ohtomi, [6]Mohammad Mustafizur Rahman,
[1]Md. Jahangir Alam, [1]Md. Amirul Islam and [5]Bernerd Fulanda
[1]Bangladesh Fisheries Research Institute, Brackishwater Station,
Paikgacha, Khulna 9280, Bangladesh
[2]United Graduate School of Agricultural Sciences, Kagoshima University,
1-21-24 Korimoto, Kagoshima 890-0065, Japan
[3]Department of Fisheries, Faculty of Agriculture,
University of Rajshahi, Rajshahi 6205, Bangladesh
[4]Department of Fisheries Management, Faculty of Fisheries,
Bangladesh Agricultural University, Mymensingh 2202, Bangladesh
[5]Faculty of Fisheries, Kagoshima University, 4-50-20 Shimoarata,
Kagoshima 890-0056, Japan
[6]Aquaculture Research Team, East Sea Fisheries Research Institute, 30-6,
Dongduk, Yongok, Gangnung, Gangwon 210-861, Republic of Korea

Abstract: The present study was carried out to monitor the plankton community structure and productivity, its diurnal and seasonal variations and the influence of physico-chemical factors in the Shibsha River of the southwest coast of Bangladesh from July 2004 to June 2005. A total of 31 phytoplankton species were identified; 17 belong to Bacillariophyceae, seven to Cyanophyceae, five to Chlorophyceae and two to Dinophyceae. Bacillariophyceae appeared to be the dominant group in terms of total species and cell numbers during the period studied. The over all phytoplankton production was significantly ($p<0.05$) higher in June (175.8×10^3 cells L^{-1}) and lower in September (12.0×10^3 cells L^{-1}) attributed to low temperature. Phytoplankton diversity declined to the lowest level in winter and there was a positive correlation with water temperature. The number of phytoplankton species was high (26) in June and quite low (11) in December. Nutrient concentrations including nitrate and phosphate were significantly ($p<0.05$) higher in summer, while lower values recorded in winter. The lowest and highest concentration of Nitrate-Nitrogen (NO_3-N) and Phosphate-Phosphorus (PO_4-P) were 0.7, 0.3, 1.9 and 0.9 mg^{-1}, respectively.

Key words: Phytoplankton, production, southwest coast, Shibsha River, Bangladesh

INTRODUCTION

The temporal variability of populations and communities and the relationship between population and community variability, has received much attention over the past half-century (Vasseur *et al*., 2005). It is well recognized that environments fluctuate in time and space in ways that may be important for community structure and assembly (Beisner, 2001). Large temporal fluctuations

Corresponding Author: Md. Yeamin Hossain, United Graduate School of Agricultural Sciences, Kagoshima University, 1-21-24 Korimoto, Kagoshima 890-0065, Japan Tel: +81-99-286-4152 Fax: +81-99-286-4133

in abiotic forces should alter population vital rates, potentially leading to shifts in population dynamics and interactions (Beisner, 2001). The community-wide response, including changes in diversity and composition, depends on the relative scales of fluctuation in populations and the environment (Connell, 1978).

The plankton community is comprised of the primary producers or phytoplankton and zooplankton; the secondary producers (Battish, 1992). The phytoplankton population represents the biological wealth of a water body, constituting a vital link in the food chain (Boyd, 1982; Hossain *et al*., 2007). Both the qualitative and quantitative abundance of phytoplankton in a fish pond are of great importance in managing the successful aquaculture operations, as they vary from location to location and depth to depth within the same location even within similar ecological conditions (Boyd, 1982; Hossain *et al*., 2007). Phytoplankton is the major primary producer in many aquatic systems and is an important food source for other organisms. Species composition and the seasonal variations of planktonic and benthic forms in freshwaters are dependent on interactions between physical and chemical factors (Çetin and Şen, 2004). Besides, climate has a major influence on water quality and consequently, the biodiversity within the water bodies (Boyd and Tucker, 1998). Good water quality in fish or shrimp ponds is essential for survival and adequate growth (Burford, 1997). In recent years, interest in the ecological role of plankton protests has been increased, particularly for nanoplankton and microzooplankton in the microbial food web (Dupuy *et al*., 2007).

Coastal regions are the most productive ecosystem in the world, exemplified by the fact that coastal and estuarine habitats provide feeding and reproduction ground for approximately 90% of the world's marine fish catch (Bashar *et al*., 2005). Southwest coastal part of Bangladesh is surrounded by world heritage Sundarbans mangrove forest (Rouf, 2006). The Shibsha River is one of the important rivers in the south-west coastal portion, Paikgacha, Khulna, Bangladesh. The river is connected to the Sundarbans mangrove forest and finally drains into the Bay of Bengal. Tidal water of this river is currently used for the shrimp farming activities which plays an important role for the development of national economy and export earning in Bangladesh (Islam *et al*., 2002). Despite its innumerable importance, attempt has not been made previously for scientific study of species composition and abundance of phytoplankton and their seasonal dynamics in relation to environmental factors of the Shibsha River in Paikgacha, Khulna.

The qualitative and quantitative study of phytoplankton and the influence of hydrographical parameters on them attracted the attention of many researchers, because the phytoplanktons occupy the starting point of the food chain of the aquatic environment. The rate of gross primary productivity is important for assessing the fisheries yield i.e., how much can be taken as the best means for quantitative of potential fisheries of an area (Mridula and Rajesh, 2002). Seasonal variation of phytoplankton biomass, species composition and productivity differ markedly among the estuarine habitat types (Cloern *et al*., 1985). During the past extensive work has been done pertaining to qualitative and quantitative assessment of phytoplankton and other oceanographic feature from the Indian sub-continent coastal waters (Selvam *et al*., 1992; Jewel *et al*., 2002).

To the best knowledge of the authors, there is little or no previous information on plankton studies from this coastal region, although several works have been done on planktonic ecology from the inland waters of this region (Begum *et al*., 2003; Hossain *et al*., 2006; Begum *at al*., 2007; Hossain *et al*., 2007). Therefore, the current study provided a base investigation on the seasonal variations of phytoplanktonic communities and production in the Shibsha River, southwest coast, Bangladesh and its relationship to nutrients and physical-chemical parameters.

MATERIALS AND METHODS

The study was carried out over a period of 12 months from July 2004 to June 2005, at latitude 22° 25′ N and 89° 20′ E. Sampling was done from one selected station at the Shibbari ferry stand point

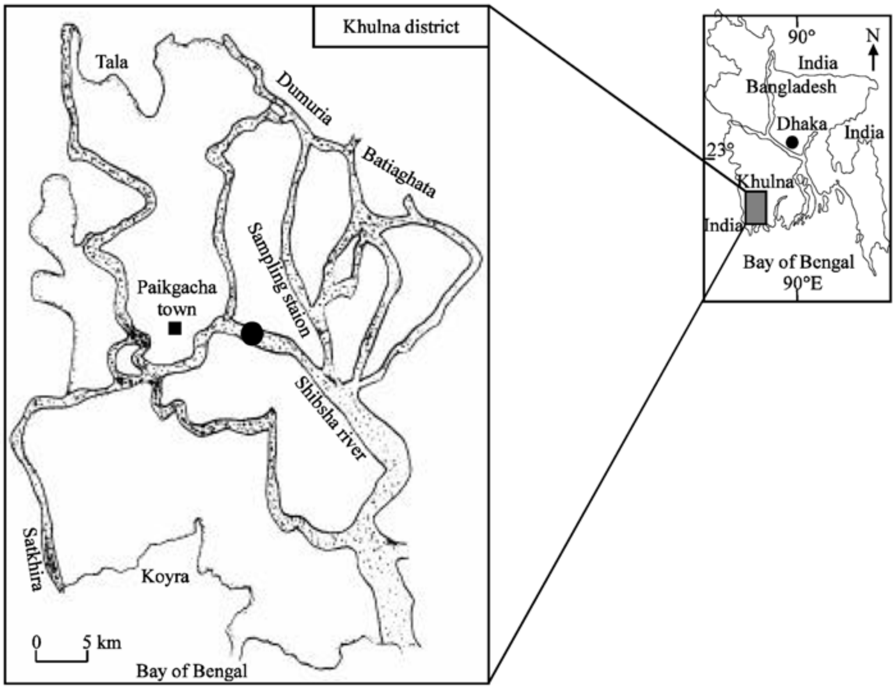

Fig. 1: Map of Paikgacha with sampling station (●) of the Shibsha River, southwest coast of Bangladesh

(near Paikgacha town) of the main stream of the Shibsha River in the southwest coastal portion, Paikgacha, Khulna, Bangladesh (Fig. 1). Three sub-samples in each day were collected on monthly intervals.

Water quality parameters and sampling for plankton analyses was done once a month between 09.00-1.00 h from specific points of the river at a depth of 20 cm below the surface. A mercury thermometer was used to measure both water and air temperature (°C), while salinity (psu) was measured with a Hand Refractometer. Nitrate-nitrogen (NO_3-N) and phosphate-phosphorus (PO_4-P) concentrations were measured in the laboratory by HACH Kit (DR 2010).

For qualitative plankton study, a plankton net was towed for 1 min at a speed of approximately 1 m sec^{-1}. From the net the collected samples were drained in a polyethylene bottle and preserved with 5% buffered formalin in Brackishwater. For quantitative study a known volume (100 L) of sub-surface water was passed through a plankton net (mesh 25 μm) and the concentrate collected from the bucket and preserved in 5% buffered formalin in brackishwater. The quantitative estimation of phytoplankton was done by Sedgewick-Rafter counting chamber (S-R cell) method using an Olympus binocular microscope. The cell counts were used to compute the cell density using the Stirling (1985) formula where the plankton density is estimated by:

$$N = (A \times 1000 \times C)/(V \times F \times L)$$

Where:

N = No. of plankton cells or units per liter of original water.

A = Total No. of plankton counted.

C = Volume of final concentrate of the samples in mL.
V = Volume of a field in cubic mm.
F = No. of fields counted.
L = Volume of original water in liters.

For species identification, a sample was gently shaken to resuspend all materials. It was allowed to settle for a minute and then four drops were removed from the middle of the same sample and placed on a glass slide. A cover slip was placed on the slide and the entire slide was scanned for the species present. Then, the plankton were then identified up to the genus level and enumerated by the following APHA (1992) and Bellinger (1992). The mean number of plankton was recorded and expressed numerically per liter of water of the river. Species diversity (D) was estimated by the formula of Margalef (1967):

$$D = (S-1)/\mathrm{Log}_e n'$$

Where:
S = No. of phytoplankton species
n' = Total No. individuals in the collection

The statistical analysis of different physico-chemical and plankton parameters were carried out using one-way ANOVA and any difference at 5% level of significance using the statistical package of Statgraphics Version 7, while the Microsoft exell® 2003 was used to plot graphs for decimination of the results.

RESULTS

Physico-Chemical Factors

Seasonal changes in temperature and salinity of the Shibsha River is shown in Fig. 2 and 3, respectively. The annual cycle of water temperature at the sampling station during the observation period showed a clear maximum in summer and a minimum in winter. Temperature showed the expected seasonal pattern with lowest value (19.5°C) in December 2004 and highest value in May 2005 (31.5°C). The water temperatures changed within a range of 19.5-31.5°C, with the annual mean value 27.8°C. The statistical analysis (ANOVA) revealed significant differences ($p<0.05$) in temperature among the months during the study period. Salinity of the coastal waters also varied with the season. The maximum salinity occurred at the beginning of May 2005 (15 psu) and the minimum value dropped down near to zero (0 psu) in September 2004. There were significant ($p>0.05$) variations in salinity among the months in the study area. The salinity varied between 0 and 15 psu and the annual mean value was 7 psu.

Seasonal fluctuations of nitrate-nitrogen in the Shibsha River off the coastal waters of Bangladesh were notable during the study period. The maximum and minimum concentration of nitrate-nitrogen (NO_3-N) was recorded in May 2005 and September 2004 at 1.9 and 0.7 mg L^{-1}, respectively (Fig. 4). Fluctuation of phosphate phosphorus (PO_4-P) concentration was ranging from 0.3 to 0.9 mg L^{-1} with the maximum in June 2005 and minimum in September 2004 (Fig. 5). The statistical analysis (ANOVA) revealed significant differences ($p<0.05$) in both NO_3-N and PO_4-P among the months sampled during the current study period.

Seasonal Variation of Phytoplankton

The phytoplankton community of the Shibsha River of Bangladesh consisted mainly of Bacillariophyceae, Cyanophyceae, Chlorophyceae and Dinophyceae groups. A total of 31

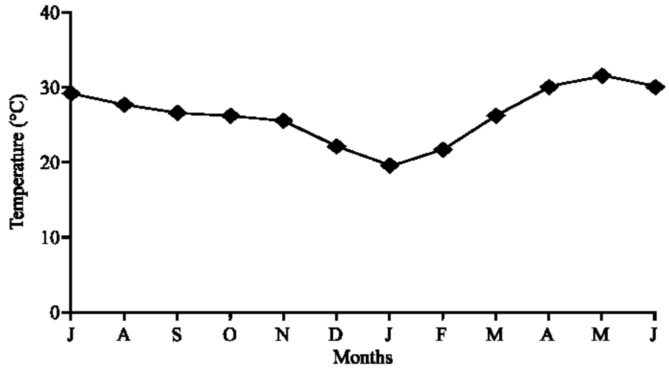

Fig. 2: Monthly variations of water temperature of the Shibsha River southwest coast of Bangladesh during July 2004 to June 2005

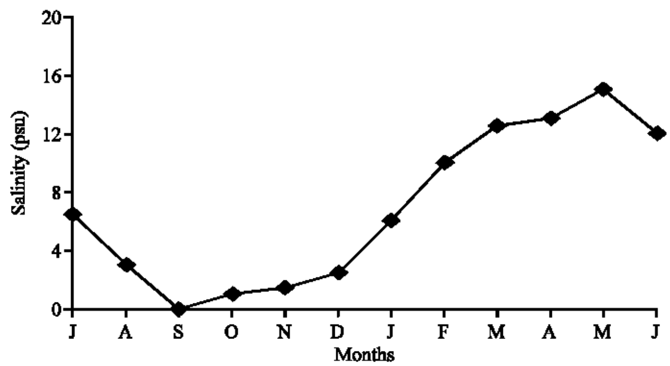

Fig. 3: Monthly variations of water salinity of the Shibsha River southwest coast of Bangladesh during July 2004 to June 2005

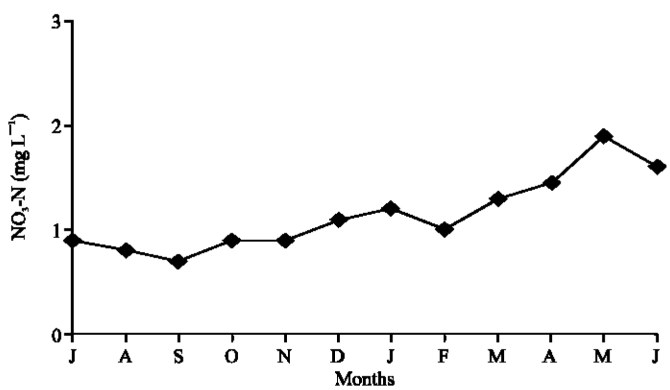

Fig. 4: Monthly variations of NO_3-N of the Shibsha River, southwest coast of Bangladesh during July 2004 to June 2005

phytoplankton species were identified, with seventeen belong to Bacillariophyceae, seven to Cyanophyceae, five to Chlorophyceae and two to Dinophyceae as shown in Table 1. Bacillariophyceae appeared to be the dominant group in terms of total species and cell numbers during

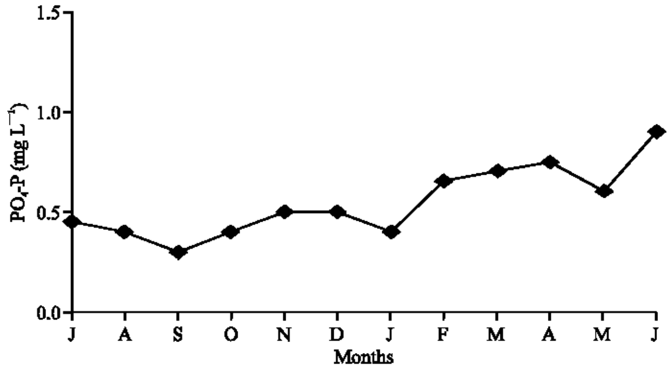

Fig. 5: Monthly variations of PO_4-P of the Shibsha River southwest coast of Bangladesh during July 2004 to June 2005

Table 1: List of phytoplankton recorded from Shibsha River, southwest coast of Bangladesh during July 2004 to June 2005

Chrysophyta	**Phrrhophyta**
Bacillariophyceae	**Dinophyceae**
Thalassiosiraceae	Ceratiaceae
Thalassiosira sp.	*Ceratium* sp.
Cyclotella meneghiniana	Gymnodiniaceae
Coscinodisceae	*Gymnodinium* sp.
Coscinodiscus centralis	**Cyanophyta**
Naviculaceae	**Cyanophyceae**
Pleurosigma directum	Chroococcaceae
P. elongatum	*Microcystis aeruginosa*
Gyrosigma sp.	Oscillatoriaceae
Navicula sp.	*Trichodesmium erythreum*
Chaetoceraceae	*Oscillatoria* sp.
Chaetoceros sp.	*Lyngbya* sp.
Bidulphiaceae	*Spirulina* sp.
Bidulphia mobiliensis	Nostocaceae
Bacillariaceae	*Nostoc* sp.
Nitzschia closterium	*Anabaena* sp.
Melosiraceae	**Chlorophyta**
Melosira sp.	**Chlorophyceae**
Rhizosoleniaceae	Ulotrichaceae
Rhizosolenia sp.	*Ulothrix* sp.
Lithodesmiaceae	*Hydrodictyaceae*
Skeletonema costatum	*Pediastrum simplex*
Ditylum sp.	*Desmidiaceae*
Rhaphoneidaceae	*Closterium spaericum*
Cocconeis placentula	*Zygnemataceae*
Fragilariaceae	*Spirogyra leptocladum*
Fragilaria capucina	Oocystaceae
Thalasionemaceae	*Chlorella* sp.
Thalassionema sp.	

the observation period. Generally, the species diversity was higher in June 2005 compared to December 2004 when fewer species were recorded (Fig. 6).

Seasonal variation of phytoplankton production (cell density L^{-1}) during the study period is shown in Fig. 7. Variation in phytoplankton cell counts was high (12.0×10^3 to 175.8×10^3 cells L^{-1}) during the study period. The highest phytoplankton production was recorded in June 2005 (175.8×10^3 cells L^{-1}) and the lowest in September 2004 (12.0×10^3 cells L^{-1}). Analysis of variance (ANOVA) revealed significant differences in the seasonality of phytoplankton productivity ($p<0.05$).

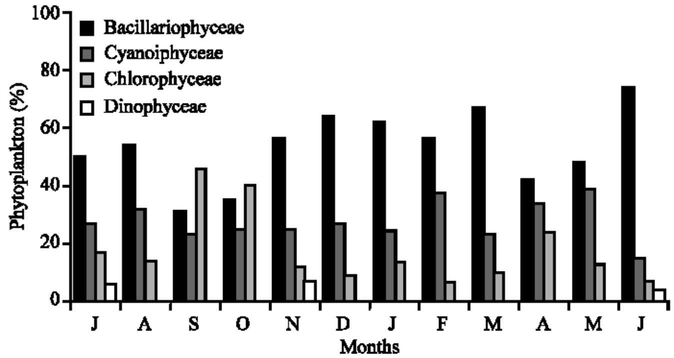

Fig. 6: Monthly percentage variations of major group of phytoplankton in the Shibsha River, southwest coast of Bangladesh during July 2004 to June 2005

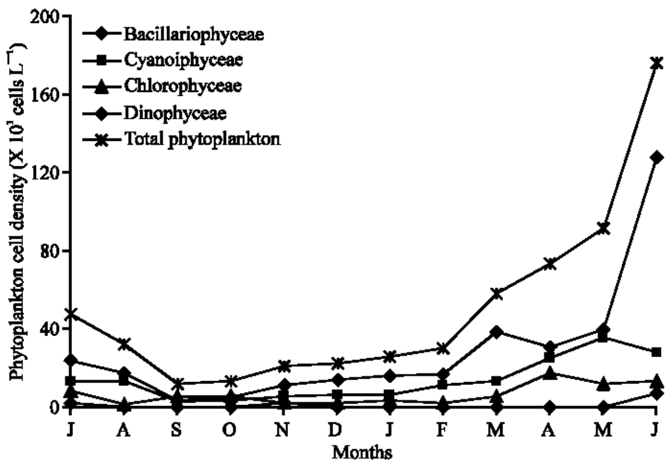

Fig. 7: Monthly variations of phytoplankton cell density (Cells L^{-1}) in the Shibsha River, southwest coast of Bangladesh during July 2004 to June 2005

Number of individual species in all phytoplankton groups started to increase in February and reached its high level in the month of June (Fig. 6). Bacillariophyceae dominated the phytoplankton groups and recorded more species throughout the study period except in September and October, when Chlorophyceae was dominant. The highest and lowest abundance of Bacillariophyceae was recorded in June and September at 12.74×10^3 and 12.0×10^3 cells L^{-1}, respectively, as shown in Fig. 7. The dominant species in the Bacillariophyceae group included *Chaetoceros* sp., *Skeletonema costatum, Ditylum* sp., *Coscinodiscus centralis*, Nitzschia sp., *Bidulphia mobiliensis*, Rhizosolenia sp., *Thalassionema* sp. and *Navicula* sp.

Cyanophyceae ranked second among all phytoplankton groups in terms of both abundance and species number. The Cyanophytes was most abundant in May (35,715 cells L^{-1}) and least abundant in September (2,760 cells L^{-1}) as shown in Fig. 7. The group was dominated by *Nostoc* sp., *Anabaena* sp. and *Oscillatoria* sp. The cell density of chlorophytes was highest in June (17,520 cells L^{-1}) compared to lows of 1280 cells L^{-1} in August (Fig. 7). Among the Chlorophytes, the different species in order of abundance were *Chlorella* sp., *Spirogyra leptocladum*, *Closterium spaericum* and *Micrococcus* sp.

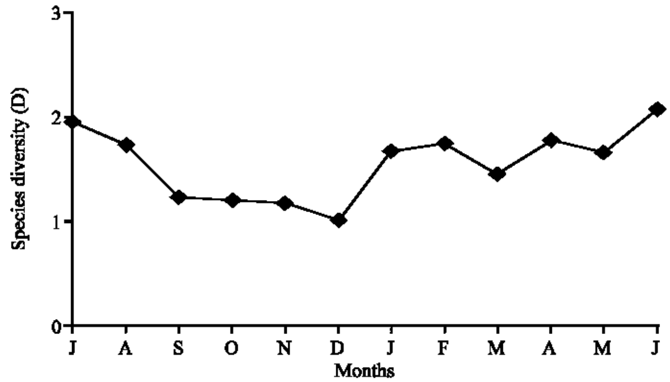

Fig. 8: Monthly variations in phytoplankton species diversity of the Shibsha River, southwest coast of Bangladesh during July 2004 to June 2005

Dinophyceae were most abundant in June (7050 cells L^{-1}) and least in November at 1890 cells L^{-1} as shown in Fig. 7. The dominant species in this group were *Ceratium* sp. and *Gymnodinium* sp. Seasonal succession of phytoplankton population indicated that, diatoms especially the *Chaetoceros* sp. and *Nitzschia* sp. were dominant in the summer while other diatoms including *Skeletonema costatum*, *Coscinodiscus centralis*, *Bidulphia mobiliensis*, *Thalassionema* sp. and *Navicula* sp. showed little variation all year round. Blue-green algae especially *Nostoc* sp. and *Oscillatoria* sp. were most dominant in May. The Monthly variations in phytoplankton species diversity of the Shibsha River, southwest coast of Bangladesh from July 2004 to June 2005 are shown in Fig. 8. Phytoplankton diversity showed clear decline to lowest levels during the winter months.

DISCUSSION

Information regarding the seasonal variations of phytoplankton and environmental factors are quite insufficient in the Indian sub-continent and the data quality and methodology of previous studies are also not clearly defined (Cloern *et al*., 1985; Jewel *et al*., 2002; Hossain *et al*., 2007). For the detection of the seasonal variations of phytoplankton community structure and production in relation to environmental factors of the southwest coastal waters of Bangladesh, the authors collected samples from the Shibsha River near Paikgacha of Khulna districts over a period of one year. During this study, physico-chemical factors and phytoplankton estimations were done in the laboratory according to well defined standard procedures and methods as outlined in APHA (1992).

Seasonal variations in phytoplankton are related to a variety of environmental factors in aquatic environments (Çetin and Şen, 2004). Water temperature and transparency are among the most important physical factors affecting the distribution and seasonal variations of phytoplankton (Mosisch *et al*., 1999). Similarly, Morales-Baquero *et al*. (2006) also indicated that temperature is major determining factor in phytoplankton growth and development. During the current study water temperatures varied between 19.5 and 31.5°C, mainly in line with changes in weather conditions. Statistical tests revealed significant differences ($p<0.05$) in temperatures between the study months. In addition, the variations in water temperatures may also be attributed to water level fluctuations frequently observed in the study area due to use of water for irrigation, hence resulting insufficient water sources to maintain the levels in the dry season. The variations are further aggravated by heavy precipitation during the monsoon. The effects of water temperature on phytoplankton have been directly examined in many aquatic ecosystems and it was found that water temperature strongly regulates the seasonal variations of phytoplankton (Richardson *et al*., 2000). Similar findings were also recorded from the limnological studies in the Lakes in Nepal (Rai, 2000). However, the observed temperatures variations in the current study were within the optimal ranges for (18.3-37.8°C) for production of plankton in tropical ponds (Begum *et al*., 2003; Hossain *et al*., 2007). Boyd (1982) however recommends optimal temperatures for fish culture, in the range of 26.06-31.97°C, if fish growth and consequently yields are to be optimized.

Light is a major resource for phytoplankton and has a complex pattern of spatial and temporal variability (Litchman, 2000; Çetin and Şen, 2004). Generally during summer, water transparency reaches its maximum level. Several researchers recorded a significant correlation between the growth of phytoplankton and transparency in different aquatic ecosystems (Çetin and Şen, 2004; Hossain *et al*., 2007; Begum *et al*., 2007). However, light intensity (transparency) was not encountered during the study.

Salinity refers to total concentration of all ions in water. The salinity of the coastal waters off the study area varied with the season, with the maximum salinity recorded in May 2005 (15 psu) dropping down to near zero (0 psu) in September 2004. The drop in salinity is attributed to increase flooding in the September season. Statistical tests revealed significant difference ($p>0.05$) in salinity over the sampling months during the study period.

Nutrients levels revealed similar seasonal cycles in the study sites. Seasonal differences were statistically significant ($p<0.05$) for both nitrate and phosphate. The lowest (0.7 mg L^{-1}) and highest (1.9 mg L^{-1}) nitrate concentrations were recorded in September and May, respectively. Among the various forms of nitrogenous nutrients, nitrate is the most important, as it is the final form, being absorbed by the plankton for their growth, of nitrogen breakdown (Begum *et al*., 2003). The results of the present study is similar to findings by Jewel *et al*. (2002), who reported 0.8 to 3.0 mg L^{-1} nitrate-nitrogen at the mouth of the Maheshkhali channel of the Bay of Bengal, Cox's Bazar, Bangladesh. On the other hand, phosphorus, though required small quantities for aquatic biota, is the single most important element in waters (Hossain *et al*., 2006). Dissolved phosphorus is probably the most important factor affecting water quality, because its needed for phytoplankton growth (Boyd, 1982; Hossain *et al*., 2006). Fluctuation of PO_4-P concentration ranged from 0.3 to 0.9 mg L^{-1} with maxima and minima recorded in June and September respectively. Phosphate concentration was lower than that reported by Jewel *et al*. (2002) at 0.06 to 3.2 mg L^{-1}.

In the present study, the seasonal variations of total phytoplankton cell density may therefore be attributed to wide range of physico-chemical parameters such as temperature, salinity, nitrate-nitrogen and phosphate-phosphorus. The observed monthly and seasonal variations in plankton species dominance during the study may be attributed to variations in the optimal conditions for the various species. The wide variation in phytoplankton cell counts (12.0×10^3 to 175.8×10^3 cells L^{-1}) during the study period have also been reported in other studies in the coastal waters of Gopalpur (Gouda and Panigrahy, 1996), coastal water of Mangalore, west coast of India (Mridula and Rajesh, 2002). The highest phytoplankton production was found in June (175.8×10^3 cells L^{-1}) and the lowest in September (12.0×10^3 cells L^{-1}). These variations in phytoplankton growth are complicated by interactions between ecological factors and regeneration rate of nutrients (El-Gindy and Dorgham, 1992). In the present study, the highest cell density of phytoplankton was found during the rainy season, similar to that reported by Santhanam and Srinivasan (1996), who recorded highest phytoplankton cell density (11.0×10^5 cells L^{-1}) during the monsoon months in the Tuticorn Bay of India. These high densities are attributed to continuous discharge of sewage water during the rainy periods. Highest phytoplankton count during June can be explained by the higher level of nutrients, particularly phosphate during this period. Cell numbers decreased in September and October but increasing trends observed in February. The highest density was observed when there was an increase in diatom sharing about more than 75% of the total cell counts.

During the study period, 31 species of phytoplankton belonging to Bacillariophyceae, Chlorophyceae, Cyanophyceae and Dinophyceae were recorded. Bacillariophyceae was the dominant group of phytoplankton with large number of species throughout the study period except in September and October when Chlorophyceae was dominant. Phytoplankton species number was highest (26) in June and lowest (11) in December. During the winter months, the species number was relatively low. Maximum number was recorded in summer when the PO_4-P concentration was also found to be highest and NO_3-N was moderate. Margaler's diversity index (D) ranged from 1.01 to 2.07. The highest value (2.07) was in June when the highest number of species was also recorded. The low value of 1.01 was in December, when less number of species was recorded. Phytoplankton population indicates the productive status of a water body, because they are the direct and basic source of food for most of the organisms in aquatic habitat. The results of the seasonal variation in environmental parameters and plankton population suggest that the favourable period for primary production in the Shibsha River is from March to July when nutrients accumulate from freshwater run-off due to monsoon rainfall. Lugomela (1995) found higher primary productivity in different estuarine and coastal waters during rainy season. Phytoplankton abundance and taxonomic diversity depends upon the supply of nutrients in natural waters. In the present study, the highest cell density and species diversity of phytoplankton were found in June, when salinity and nitrate concentration were moderate and phosphate-phosphorus concentration (0.9 mg L^{-1}) highest. Thus, it can be concluded that high phosphate-phosphorus concentration may be an important precursor for higher cell density and taxonomic diversity of phytoplankton in the Shibsha River in June.

These variations in phytoplankton growth are complicated due to interactions between ecological factors and regeneration rate of nutrients (El-Gindy and Dorgham, 1992). In the present study, the highest cell density of phytoplankton was found during the rainy season, agreeing with the findings of Santhanam and Srinivasan (1996), who reported highest phytoplankton cell density (11.0×10^5 cells L^{-1}) during monsoon months in the Tuticorn Bay of India was supposed to be caused by continuous discharge of sewage water during the rainy periods. Highest phytoplankton count during June can be attributed to higher level of nutrients, particularly phosphate during this period. Cell numbers decreased in September and October but showed an upward trend in starting February. The highest density was observed when diatoms increased, accounting for >75% of the total cell counts. The present study concludes that all the environmental factors were within the productive range throughout the year and the highest cell density and species diversity of phytoplankton was found in June, when salinity and nitrate concentration were moderate and phosphate-phosphorus concentration were in the highest level.

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