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Phytoplankton community and limnology of Chatla floodplain wetland of Barak valley, Assam, North-East India

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ABSTRACT

Key-words: *limnology, habitats, phyotplankton, community, Chatla floodplain wetland*

Phytoplankton diversity was investigated over a period of two years (2006 to 2008) in Chatla floodplain wetland in Barak valley, Assam, North-East India. Site 1 and site 2 are two inlets and site 3 is a lentic system associated with vegetation cover of *Calamus tenuis* and *Baringtonia acutangula*. The floodplain has a unique hydrology because of the presence of different types of habitats (inlets, fisheries, beels and outlets) which maintains a network among the floodplains, rivers and streams. Phytoplankton community composition, density and diversity were studied in relation to environmental variables. All the variables were estimated by following standard methods. Phytoplankton was collected by plankton net and quantitative estimation was made by using Sedgwick Rafter counting cell. Phytoplankton community comprised 53 taxa represented by Chlorophyceae (31), Cyanophyceae (11), Bacillariophyceae (7), Euglenophyceae (1) and Dinophyceae (3). Phytoplankton taxa was dominated by *Volvox* sp., *Nostoc* sp., *Eunotia* sp., *Navicula* sp., *Euglena* spp. and density was found highest in site 3 and lowest in site 1. Shannon diversity index (H′) for phytoplankton community varied between 2.4 to 2.65 indicating fairly high species diversity. The varying magnitude of correlationship among environmental variables and phytoplankton species density as shown by Canonical correspondence analysis (CCA) indicated that some of the environmental variables (water temperature, transparency, rainfall, nitrate and ammonia) are the driving factors for governing the phytoplankton species assemblages in Chatla floodplain wetland. Fluctuation of phytoplankton density and community composition in different habitats indicated various niche apportionment as well as anthropogenic influences.

RÉSUMÉ

La communauté phytoplanctonique et la limnologie de la zone humide de la plaine d'inondation Chatla dans la vallée de Barak, Assam, nord-est de l'Inde

Mots-clés : *habitats, limnologie, phytoplancton, communauté,*

La diversité du phytoplancton a été étudiée sur une période de deux ans (2006 à 2008) dans la zone humide de la plaine d'inondation Chatla dans la vallée de Barak, dans l'Assam, au nord-est de l'Inde. Le site 1 et le site 2 sont deux arrivées d'eau et le site 3 est un système lentique associé à la couverture végétale de *Calamus tenuis* et *Baringtonia acutangula*. La plaine alluviale a une hydrologie unique en raison de la présence de différents types d'habitats, qui maintiennent un réseau entre les plaines inondables, les rivières et les fleuves. La composition

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plaine d'inondation Chatla

de la communauté phytoplanctonique, la densité et la diversité ont été étudiées en fonction des variables d'environnement. Toutes les variables ont été estimées en suivant des méthodes standard. Le phytoplancton a été recueilli par un filet à plancton et l'estimation quantitative a été réalisée en utilisant une cellule de comptage Sedgwick Rafter. La communauté phytoplanctonique comprend 53 taxons représentés par des Chlorophyceae (31), Cyanophycées (11), Bacillariophyceae (7), Euglenophyceae (1) et Dinophyceae (3). Les taxons phytoplanctoniques sont dominés par *Volvox* sp., *Nostoc* sp., *Eunotia* sp., *Navicula* sp., *Euglena* sp. et la densité est la plus forte dans le site 3 et la plus faible dans le site 1. L'indice de diversité de Shannon (H′) pour la communauté phytoplanctonique varie entre 2,4 à 2,65 indiquant une diversité spécifique assez grande. L'ampleur variable de la corrélation entre les variables environnementales et la densité des espèces de phytoplancton, comme indiqué par l'analyse canonique de correspondance (CCA), indique que certaines des variables environnementales (température de l'eau, la transparence, la pluie, le nitrate et l'ammoniac) sont les facteurs déterminant les assemblages d'espèces de phytoplancton dans la plaine d'inondation Chatla. La variation de la densité du phytoplancton et de la composition de la communauté dans les différents habitats indique diverses répartitions de niche ainsi que les influences anthropiques.

INTRODUCTION

Floodplain wetlands are known as biological supermarkets because of the extensive food chain and immensely rich biodiversity they support (Mitsch and Gosselink, 1993). Phytoplankton, an integral component of freshwater wetlands, lies at the base of the aquatic food web (Mustapha, 2009) and is used as an indicator of the environmental conditions of water bodies. Phytoplankton constitute the basis of the nutrient cycle in an aquatic ecosystem and play an important role in maintaining the equilibrium between living organisms and abiotic factors. The phytoplankton community on which the whole aquatic population depends is largely influenced by the interaction of a number of physicochemical factors (Hulyal and Kaliwal, 2009). The community composition in floodplain lakes is clearly related to hydrology, relevant nutritional resources and habitat characteristics, mainly *via* input of N and P from the eutrophic main channels during floods. The plankton species richness is related to the complexity of habitats formed by the presence of aquatic vegetation (Van den Brink *et al.,* 1994). Phytoplankton productivity and composition are influenced by the spatial and temporal dynamics of environmental factors (Sommer, 1989) dominated by the solar energy cycle (Patterson and Wilson, 1995).

Several studies have been carried out on the diversity of the phytoplankton community in relation to limnological characteristics of different aquatic ecosystems worldwide (Nabout *et al*., 2005; Onyema, 2007; Branes *et al*. 2007; Chattopadhyay and Banerjee, 2007; Senthilkumar and Sivakumar, 2008; Nwankwo *et al*., 2008; Olele and Ekelemu, 2008; Chellappa *et al*., 2008; Borges and Train, 2009; Silva *et al*., 2010). However, information on the role of different habitats in determining the phytoplankton diversity of a particular aquatic ecosystem is scarce. Chatla floodplain wetland is formed by the meandering River Ghagra, a south bank tributary of River Barak of southern Assam, North-East India, and has a unique hydrology because of the presence of different types of habitats (inlets, floodplain fisheries, beels and outlets) which maintains a network among the floodplains, rivers and streams. The phytoplankton dynamics of different habitats of Chatla wetland has not yet been thoroughly investigated. A limited number of studies have been carried out on the phytoplankton community composition of Chatla floodplain (Gupta *et al*., 1994; Duttagupta *et al*., 2004; Bhuiyan and Gupta, 2007; Laskar and Gupta, 2009, 2010, 2011). Therefore, the main focus of this study is to depict the relevance of limnological characteristics and the role of different habitats in assessing the phytoplankton diversity, community composition and abundance in three different habitats of Chatla wetland.

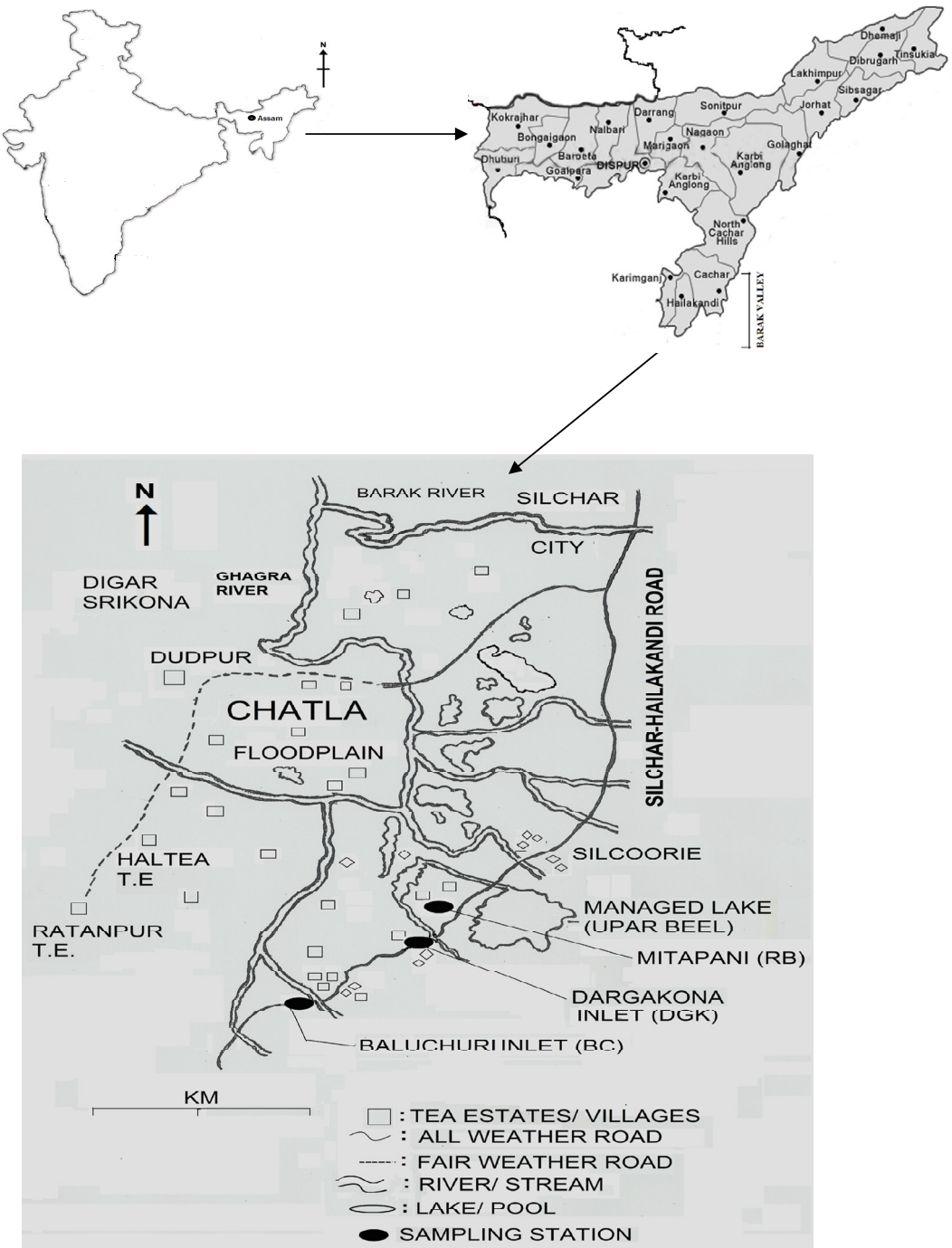


Figure 1
Map showing different sampling sites of Chatla floodplain wetland, Cachar, Assam, North-East India.

MATERIALS AND METHODS

Water samples in three replicates were collected seasonally (in PET bottles) from 3 (three) selected sampling sites of Chatla floodplain from September 2006 to August 2008 where site 1, Baluchuri (BC), and site 2, Dargakona (DGK), are lotic systems and site 3, an area with *Calamus tenuis-Baringtonia acutangula* associations (RB), is a lentic system (Figure 1). Surface water temperature and transparency were measured *in situ* by using a mercury thermometer and a Secchi disc, respectively. Turbidity was measured by a Turbidimeter (Systronics). Samples for dissolved oxygen (DO) were fixed in the field and estimated by Winkler's

method (Winkler, 1888). Total alkalinity (TA), pH, electrical conductivity (EC), total dissolved solids (TDS), free carbon dioxide (FCO_2), chloride content (Cl_2^-) and biochemical oxygen demand (BOD) were measured by standard methods (APHA, 2005). Total hardness (TH) was determined by the EDTA titration method (Romesh and Anbu, 1996). Nutrients such as nitrate-nitrogen (NO_3^-), phosphate-phosphorus (PO_4^{3-}) and ammonium-nitrogen (NH_4^+) were determined by the spectrophotometric method (Golterman *et al.,* 1978; Michael, 1984; APHA, 2005).

For phytoplankton collection, 20 (twenty) litres of water sample in three replicates from each site was filtered through a standard plankton net (mesh size 40 μm) and preserved in 4% formaldehyde solution (Van Den Brink *et al*., 1992; Lund and Davies, 2000). Qualitative and quantitative estimation of phytoplankton was carried out with the help of a "Sedgwick Rafter" counting cell and identified using the standard literature (Edmondson, 1959; Anand, 1998). The phytoplankton community structure was analysed using the Shannon-Wiener Index of Diversity (H'), Margalef's species richness index (d), the Evenness index (J') and the Berger-Parker index of dominance (D_{BP}) (Magurran, 2004). One-way analysis of variance (ANOVA) was performed using SPSS v. 12.0. CCA (Canonical correspondence analysis) was performed using CANOCO v. 4.5.

RESULTS AND DISCUSSION

The limnological characteristics of different habitats of Chatla floodplain wetland are shown in Table I. Water temperature did not show much variation, ranging between 24.2 °C–24.8 °C (2006–2007) and 25.9 °C–27.45 °C (2007–2008). Low transparency was found in 2006–2007 (range: 3.7–5.72 cm), indicating high density of phytoplankton, and higher values in 2007–2008 (10.43–18.05 cm) indicated lower density of phytoplankton. The range of turbidity was found to be higher in 2006–2007 (19.9–23.4 NTU) than that of 2007–2008 (4.3–5.98 NTU), indicating higher abundance of phytoplankton in the previous year of study. DO concentration ranged between 3.52 mg·L^{-1} and 4.98 mg·L^{-1} (2006–2007) and 4.2 mg·L^{-1} and 5.36 mg·L^{-1} (2007–2008), with the highest mean DO concentration in site 2 (DGK) in both the cycles. This suggested that oxygen saturation increased due to thorough mixing of water due to the favourable impact of the monsoon rains (Thomaz *et al*., 2007) because this inlet is connected with Chatla floodplain wetland during monsoon. TA was found to be below the optimum level ($<$50.0 mg·L^{-1}) (30.52–40.7 mg·L^{-1} in 2006–2007 and 29.3–34.4 mg·L^{-1} in 2007–2008) and pH of different sites was found to be in the range of 6.3–6.63 (slightly acidic to nearly neutral) in 2006–2007 and acidic to nearly neutral (5.7–6.43) in 2007–2008, which could be due to digging of sediment for construction of RCC bridges over the inlets. High EC values in all the sites indicated a high concentration of salts present in the water bodies. However, the range of TH and Cl_2^- concentrations were well within the permissible limit, which abruptly declined in 2007–2008, suggesting wash-out during the large flood event of 2007. Similarly, NO_3^- concentration ranged from 3.81 mg·L^{-1} to 4.46 mg·L^{-1} and 2.54 mg·L^{-1} to 2.72 mg·L^{-1} in 2006–2007 and in 2007–2008, respectively, much lower than the permissible limit (45.0 mg·L^{-1}). However, the range of PO_4^{3-} (3.14–4.18 mg·L^{-1} and 5.45–7.15 mg·L^{-1}) and NH_4^+ (0.22–0.66 mg·L^{-1} and 0.19–0.79 mg·L^{-1}) concentrations in different habitats of Chatla wetland was found to be higher and was several times higher than the optimum value in site 1 (BC), indicating the eutrophic nature of the water body. This is further confirmed by the range of high BOD (7.67–11.68 mg·L^{-1} and 9.51–12.68 mg·L^{-1}) in both the cycles, suggesting high organic load due to accumulation of dead organic matter from nearby areas and increase in microbial activity.

A total of 53 phytoplankton taxa were identified belonging to Chlorophyceae (31), Cyanophyceae (11), Bacillariophyceae (7), Euglenophyceae (1) and Dinophyceae (3). Out of these, 38 and 45 taxa of phytoplankton were recorded during 2006–2007 and 2007–2008, respectively, of which site 3 (RB) contributed the highest relative abundance (44.3% and 65.6%), followed by site 2 (DGK –33.9% and 19.73%). Site 1 (BC –21.84% and 14.72%) was the lowest contributor of phytoplankton density in both the years of study (Table II and III).

Table I

Annual mean values of physico-chemical properties of water of different sites of Chatla floodplain during 2006-07 and 2007–2008.

Parameters	2006–2007 (Mean ± SE)			2007–2008 (Mean ± SE)		
	BC	DGK	RB	BC	DGK	RB
W. Temperature (°C)	24.2 ± 3.05	24.8 ± 3.14	24.4 ± 3.13	25.9 ± 3.44	27.14 ± 3.25	27.45 ± 3.32
Transparency (cm)	3.7 ± 1.18	5.72 ± 3.11	5.05 ± 4.42	10.43 ± 3.92	16.94 ± 6.52	18.05 ± 6.43
Turbidity (NTU)	20.55 ± 8.61	19.9 ± 12.54	23.4 ± 6.94	5.98 ± 1.82	5.45 ± 2.8	4.3 ± 0.52
DO ($mg{\cdot}L^{-1}$)	3.89 ± 0.97	4.98 ± 0.71	3.53 ± 0.56	4.72 ± 1.44	5.36 ± 1.69	4.2 ± 1.17
T. Alkalinity ($mg{\cdot}L^{-1}$)	40.32 ± 7.97	40.7 ± 4.74	30.52 ± 5.19	29.8 ± 4.68	29.31 ± 3.98	34.37 ± 6.61
pH	6.43 ± 0.18	6.63 ± 0.16	6.3 ± 0.27	5.9 ± 0.17	6.43 ± 0.16	5.7 ± 0.31
Conductivity ($\mu S{\cdot}cm^{-1}$)	3335.84 ± 786.85	2875.84 ± 597.53	5082.34 ± 1037.71	1144.42 ± 919.29	760.41 ± 620.3	723.62 ± 604.69
TDS ($mg{\cdot}L^{-1}$)	25.5 ± 5.25	35.9 ± 7.29	27.92 ± 5.74	31.52 ± 4.42	33.09 ± 8.66	24.8 ± 6.03
Free CO_2 ($mg{\cdot}L^{-1}$)	12.2 ± 1.43	9.95 ± 2.02	10.96 ± 2.21	9.7 ± 2.48	11.4 ± 2.46	10.9 ± 2.98
Chloride ($mg{\cdot}L^{-1}$)	36.2 ± 26.84	25.12 ± 15.16	27.7 ± 20.83	13.06 ± 0.67	13.16 ± 1.16	16.46 ± 2.98
BOD ($mg{\cdot}L^{-1}$)	10.2 ± 1.74	11.68 ± 3.16	7.67 ± 0.34	11.75 ± 4.16	9.51 ± 3.24	12.68 ± 5.03
T. Hardness ($mg{\cdot}L^{-1}$)	54.85 ± 16.43	38.64 ± 6.55	59.7 ± 21.57	14.2 ± 1.04	13.61 ± 1.21	10.67 ± 0.73
NO_3 (mg.L -1)	3.81 ± 0.26	4.12 ± 0.57	4.46 ± 0.72	2.54 ± 0.81	2.72 ± 0.85	2.65 ± 0.82
PO_4 ($mg{\cdot}L^{-1}$)	3.71 ± 1.01	3.14 ± 0.45	4.18 ± 0.57	6.63 ± 2.98	7.15 ± 4.14	5.45 ± 2.45
NH_3 ($mg{\cdot}L^{-1}$)	0.66 ± 0.10	0.22 ± 0.06	0.26 ± 0.08	0.71 ± 0.25	0.27 ± 0.07	0.19 ± 0.04
Rainfall (mm)	218.87			225.5		

Table II

Mean density (no·L^{-1} × 10^2) of phytoplankton taxa recorded in Chatla floodplain during September 2006 to August 2007 (Mean ± SE).

Sl. No.	Genus/ Species	Species code	BC	DGK	RB
1	*Actinastrum* sp.	*Acti*	0.17 ± 0.17	0.3 ± 0.3	0.94 ± 0.65
2	*Chlorella* sp.	*Chlo*	0.54 ± 0.32	3.38 ± 1.92	0.69 ± 0.36
3	*Chlamydomonas* sp.	*Chla*	1.16 ± 0.42	1.33 ± 0.24	0.5 ± 0.35
4	*Cladophora* sp.	*Clad*	1.19 ± 0.4	0.6 ± 0.35	1.5 ± 1.02
5	*Closterium* sp.	*Clos*	–	–	0.94 ± 0.71
6	*Cosmarium* sp.	*Cosm*	1.07 ± 0.09	1.03 ± 0.73	1.5 ± 0.46
7	*Cylindrocapsa* sp.	*Cyli*	0.47 ± 0.47	0.86 ± 0.29	0.38 ± 0.38
8	*Desmidium* sp.	*Desm*	0.93 ± 0.31	0.65 ± 0.38	0.34 ± 0.34
9	*Golenkinia* sp.	*Gole*	0.96 ± 0.35	–	4.44 ± 1.3
10	*Microspora* sp.	*Micr*	0.67 ± 0.38	2.21 ± 0.32	1.19 ± 0.57
11	*Maugeotia* sp.	*Maug*	0.34 ± 0.34	0.57 ± 0.33	3.29 ± 1.23
12	*Spirogyra* sp.	*Spiro*	1.62 ± 0.2	2.13 ± 0.43	1.85 ± 0.75
13	*S. indica*	*Sind*	0.55 ± 0.34	1.49 ± 0.33	1.25 ± 0.63
14	*Sphaerozosma* sp.	*Spha*	0.47 ± 0.47	1.04 ± 0.63	0.75 ± 0.47
15	*Scenedesmus quadricauda*	*Scen*	–	0.73 ± 0.47	0.9 ± 0.34
16	*Triploceros* sp.	*Trip*	0.16 ± 0.16	0.51 ± 0.32	0.63 ± 0.63
17	*Ulothrix* sp.	*Ulot*	1.26 ± 0.55	0.94 ± 0.31	0.5 ± 0.5
18	*Volvox* sp.	*Volv*	1.79 ± 0.61	1.87 ± 0.43	4.4 ± 3.66
19	*Zygnema* sp.	*Zygn*	0.58 ± 0.36	1.18 ± 0.25	0.94 ± 0.41
	Chlorophyceae		**13.93 ± 1.1**	**20.82 ± 4.4**	**26.93 ± 11.1**
20	*Anabaena* sp.	*Anab*	1.02 ± 0.67	2.25 ± 0.84	0.71 ± 0.29
21	*Aulosira fertilissima*	*Aulo*	0.35 ± 0.35	1.19 ± 0.08	1.13 ± 0.72
22	*Chlorococcus* sp.	*Chlc*	0.59 ± 0.35	1.3 ± 0.45	1.13 ± 1.13
23	*Lyngbya* sp.	*Lyng*	0.47 ± 0.29	0.5 ± 0.29	0.5 ± 0.35
24	*Microcoleus acutissimus*	*Micl*	0.33 ± 0.33	–	1.06 ± 0.21
25	*Nostoc* sp.	*Nost*	1.48 ± 0.57	2.72 ± 1.19	2.15 ± 0.63
26	*Oscillatoria* sp.	*Oscl*	1.34 ± 0.21	0.86 ± 0.3	0.71 ± 0.35
27	*Rivularia* sp.	*Rivu*	–	0.65 ± 0.39	1.1 ± 0.52
28	*Scytonema* sp.	*Scyt*	1.48 ± 0.19	0.54 ± 0.54	1.56 ± 1.0
29	*Spirulina* sp.	*Spir*	0.21 ± 0.21	1.03 ± 0.39	0.5 ± 0.35
	Cyanophyceae		**7.27 ± 1.35**	**11.04 ± 1.67**	**10.55 ± 2.4**
30	*Cymbella* sp.	*Cymb*	0.57 ± 0.33	1.22 ± 0.29	1.08 ± 0.48
31	*Fragillaria* sp.	*Frag*	0.71 ± 0.42	0.35 ± 0.35	1.08 ± 0.68
32	*Gyrosigma* sp.	*Gyro*	–	1.02 ± 0.59	0.92 ± 0.34
33	*Navicula* sp.	*Navi*	1.72 ± 0.21	2.81 ± 0.52	4.0 ± 1.35
34	*Nitzschia* sp.	*Nitz*	1.0 ± 0.4	1.58 ± 0.17	2.71 ± 1.09
35	*Synedra* sp.	*Synd*	1.27 ± 0.5	0.84 ± 0.3	1.42 ± 0.28
	Bacillariophyceae		**5.27 ± 1.21**	**7.82 ± 1.21**	**11.21 ± 3.34**
36	*Euglena* sp.	*Eugl*	0.31 ± 0.31	1.07 ± 0.18	4.34 ± 0.91
	Euglenophyceae		**0.31 ± 0.31**	**1.07 ± 0.18**	**4.34 ± 0.91**
37	*Amphidinium* sp.	*Amph*	–	0.77 ± 0.46	0.56 ± 0.36
38	*Glenodinium* sp.	*Gleno*	–	–	0.71 ± 0.47
	Dinophyceae		**–**	**0.77 ± 0.46**	1.27 ± 0.83
	Total		**26.78 ± 2.13**	**41.52 ± 5.02**	**54.3 ± 15.18**
	Percentage composition (%)		**21.84**	**33.87**	**44.3**
	Total No. taxa		32	34	38

The relative abundance of different groups of phytoplankton revealed that Chlorophyceae was the most diversified and abundant group of phytoplankton, contributing around 50% of total species (52.02%, 52.14% and 49.6%) in all the sites during 2006–2007 and more than 60% in sites 1 and 2 (60.3% and 61.13%) during 2007–2008. In site 3 (RB) it was 37.9%, followed by the Cyanophyceae and Bacillariophyceae (Figure 2). Sharma (2009) also reported Chlorophyta as the sole dominant quantitative component of phytoplankton in Loktak Lake, Manipur, India. Some authors also reported that Chlorophyceae have short life cycles and

Table III

Mean density (no·L^{-1} × 10^2) of phytoplankton taxa recorded in Chatla floodplain during September 2007 to August 2008 (Mean ± SE).

Sl. No.	Genus/ Species	Species code	BC	DGK	RB
1	*Actinastrum falcatus*	*Actn*	–	–	0.19 ± 0.19
2	*Actidesmium* Reinsh	*Actd*	–	0.29 ± 0.17	0.54 ± 0.33
3	*Apicystis* sp.	*Apis*	0.31 ± 0.31	0.4 ± 0.23	0.63 ± 0.47
4	*Chara* (Valliant) sp.	*Char*	–	–	0.13 ± 0.13
5	*Chlorella* sp.	*Chlo*	0.54 ± 0.36	0.83 ± 0.31	2.67 ± 1.21
6	*Chlamydomonas* sp.	*Chla*	0.25 ± 0.25	0.34 ± 0.2	1.31 ± 0.57
7	*Chlorococcum* sp.	*Chlr*	–	–	0.81 ± 0.34
8	*Cladophora* sp.	*Clad*	0.63 ± 0.63		–
9	*Closterium* sp.	*Clos*	–	–	3.08 ± 1.84
10	*Cosmarium* sp.	*Cosm*	0.31 ± 0.31		–
11	*Cylindrocystis* sp.	*Cyli*	–	0.17 ± 0.17	0.13 ± 0.13
12	*Desmidium* sp.	*Desm*	0.31 ± 0.31	0.81 ± 0.31	0.13 ± 0.13
13	*Microspora* sp.	*Micr*	1.63 ± 0.42	0.69 ± 0.43	0.25 ± 0.25
14	*Maugeotia* sp.	*Maug*	0.5 ± 0.5	0.13 ± 0.13	–
15	*Pandorina* sp.	*Pand*	–	–	0.31 ± 0.31
16	*Pleodorina* sp.	*Pleo*	–	–	0.13 ± 0.13
17	*Pediastrum* sp.	*Pedi*	–	–	0.46 ± 0.46
18	*Spirogyra* sp.	*Spiro*	0.52 ± 0.31	2.79 ± 1.72	2.42 ± 0.17
19	*S. indica*	*Sind*	0.25 ± 0.25		–
20	*Sphaerozosma* sp.	*Spha*	–	–	0.31 ± 0.31
21	*Scenedesmus* sp.	*Scen*	–	–	0.13 ± 0.13
22	*Schizogonium* Kutzing	*Schi*	–	–	0.42 ± 0.25
23	*Schroederia* sp.	*Schr*	–	–	0.88 ± 0.88
24	*Ulothrix zonata*	*Ulot*	0.65 ± 0.37	0.67 ± 0.67	0.63 ± 0.24
25	*Volvox* sp.	*Volv*	1.79 ± 1.79	3.34 ± 3.34	6.21 ± 1.09
26	*Zygnema* sp.	*Zygn*	0.19 ± 0.19	0.25 ± 0.25	0.29 ± 0.29
	Chlorophyceae		**7.88 ± 1.68**	**10.71 ± 3.01**	**22.06 ± 2.54**
27	*Anabaena* sp.	*Anab*	0.63 ± 0.38	2.0 ± 0.84	2.08 ± 0.73
28	*Aulosira fertilissima*	*Aulo*	–	0.25 ± 0.25	–
29	*Lyngbya* sp.	*Lyng*	0.13 ± 0.13		–
30	*Microcoleus* sp.	*Micl*	–	–	0.13 ± 0.13
31	*Microcystis* sp.	*Micy*	0.5 ± 0.5		–
32	*Nostoc* sp.	*Nost*	0.42 ± 0.42	3.0 ± 1.74	2.29 ± 0.79
33	*Oscillatoria* sp.	*Osci*	0.5 ± 0.5	0.31 ± 0.31	0.58 ± 0.36
34	*Scytonema* sp.	*Scyt*	–	–	0.38 ± 0.24
35	*Spirulina* sp.	*Spirul*	–	–	0.58 ± 0.34
	Cyanophyceae		**2.18 ± 0.46**	**5.56 ± 2**	**6.04 ± 2.16**
36	*Cymbella* sp.	*Cymb*	0.19 ± 0.19	–	0.21 ± 0.21
37	*Eunotia* sp.	*Euno*	–	–	16.13 ± 16.13
38	*Fragillaria* sp.	*Frag*	–	–	1.17 ± 0.39
39	*Navicula* sp.	*Navi*	0.63 ± 0.38		0.5 ± 0.18
40	*Nitzschia* sp.	*Nitz*	–	–	2.04 ± 0.36
41	*Synedra* sp.	*Synd*	–	–	2.67 ± 2.5
	Bacillariophyceae		**0.82 ± 0.53**	**–**	**22.72 ± 18.93**
42	*Euglena* sp.	*Eugl*	2.0 ± 1.31	1.25 ± 0.73	6.08 ± 2.37
	Euglenophyceae		**2.0 ± 1.31**	**1.25 ± 0.73**	**6.08 ± 2.37**
43	*Amphidinium* sp.	*Amph*	–	–	0.19 ± 0.19
44	*Ceratium* sp.	*Cera*	0.19 ± 0.19		0.81 ± 0.29
45	*Glenodinium* sp.	*Glen*	–	–	0.31 ± 0.18
	Dinophyceae		**0.19 ± 0.19**	**-**	**1.31 ± 0.94**
	Total		**13.07 ± 2.29**	**17.52 ± 5.26**	**58.21 ± 18.5**
	Percentage composition (%)		**14.72**	**19.73**	**65.6**
	Total No. of taxa		22	17	38

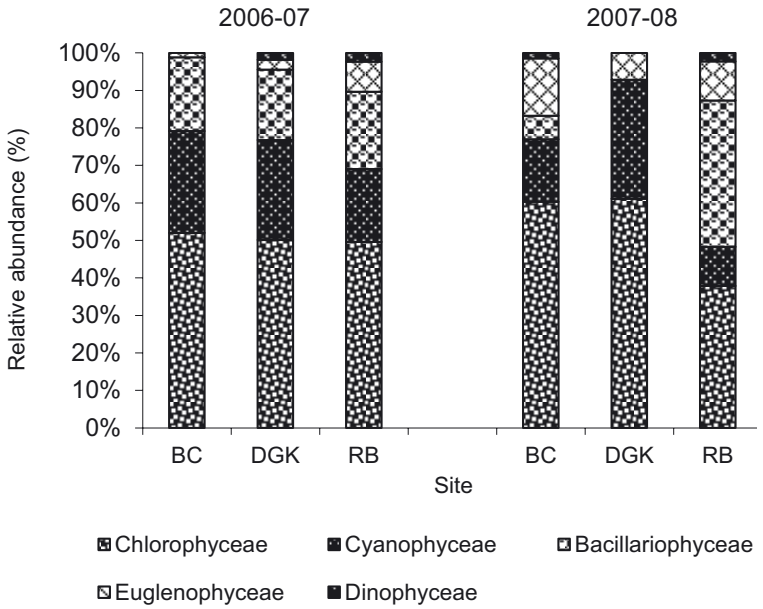


Figure 2
Relative abundance of different groups of phytoplankton community in different sites of Chatla floodplain during 2006–2007 and 2007–2008.

are opportunistic, reaching fast growth rates when nutrient availability is adjusted (Happey-Wood, 1988; Vermaat, 2005). However, in site 3 (RB) Bacillariophyceae (39.03%) dominated over Chlorophyceae (37.9%) and Cyanophyceae (10.4%) during 2007–2008, which could be due to the presence of vegetation cover of *Calamus tennis-Baringtonia acutangula* along with belts of macrophytes (*Nymphaea* sp., *Utricularia* sp. and *Polygonum hydropiper*) in station 3 (RB). It provided a specialised niche for various phytoplankton taxa, particularly *Eunotia*, the most dominant taxon. *Chlorococcum* sp., *Closterium* sp., *Pediastrum* sp., *etc*. (Tables II and III) did not occur in sites 1 and 2 during 2007–2008. Euglenophyceae dominated over Bacillariophyceae in site 1. Bacillariophyceae and Dinophyceae were totally absent in site 2 (2007–2008), while Euglenophyceae and Dinophyceae were the least abundant groups ($<$5% of total taxa) in sites 1 and 2 during 2006–2007.

Analysis of the phytoplankton community in different habitats of Chatla wetland revealed some similarities with phytoplankton studies in Calabar River, Imo River Estuary, Nigeria (Uttah *et al*., 2008; Akoma, 2008), where the predominance of Chlorophyceae in lotic systems with flowing water and Cyanophyceae bloom in eutrophic and polluted water was described. Laskar and Gupta (2009, 2010 and 2011) reported similar trends of phytoplankton community composition in terms of density and abundance.

The mean density of total phytoplankton in Chatla floodplain ranged from 26.78 to 54.3 no·L^{-1} $\times$ 10^2 and 13.7 to 58.21 no·L^{-1} $\times$ 10^2 during 2006–2007 and 2007–2008, respectively (Table II and III). Hulyal and Kaliwal (2009) reported that the density of total phytoplankton ranged from 110 org·L^{-1} to 555 org·L^{-1} in 2003 and 95 org·L^{-1} to 564 org·L^{-1} during 2004 in the Almatti reservoir of Bijapur District, Karnataka State, India, which was much lower than the density obtained in the present study. They suggested that the variation in phytoplankton density was influenced by temperature and pH, as they found the maximum population in the summer season. In the present study, the maximum density of phytoplankton was influenced by temperature, along with heavy rainfall and alteration of nutrient dynamics during monsoon, because most of the phytoplankton taxa were recruited by surface runoff from nearby fisheries and other freshwater ecosystems. This agreed with the findings of Oliveira and Calheiros (2000) in a study on the south Pantanal floodplain, Brazil, where the highest phytoplankton density was recorded in the rising water period.

Table IV

One way analysis of variance (ANOVA) for phytoplankton density and species diversity among different sites of Chatla floodplain during 2006–2007 and 2007–2008.

Parameters	2006–2007	2007–2008
Phytoplankton density	$F = 6.51^{*}$, $p < 0.004$	$F = 15.98^{**}$, $p < 0.000$
Species diversity	$F = 10.72^{**}$, $p < 0.000$	$F = 74.03^{**}$, $p < 0.000$

* Significant at 5% level, ** significant at 1% level.

One-way analysis of variance (ANOVA) showed the significant site-wise variation of phytoplankton density and species diversity ($p < 0.01$) during both the years of study (Table IV). Although in site 3 species richness was found to be higher than that of the other sites with an equal no. of taxa (38) in both the years, species richness drastically declined from the previous year in sites 2 and 1 (17 and 22 taxa) during 2007–2008 (Table III). This could be linked to the disturbances caused by the construction of RCC bridges over the inlets. Further, in lentic systems, phytoplankton species diversity was always found to be higher than that of lotic systems (Rodrigues and Bicudo, 2001; Laskar, 2012).

In contrast to the highest number of taxa in site 3 in both the years, we recorded the highest values of $H^{/}$ and d (2.65 and 2.22) in site 2, followed by site 3 (2.52 and 2.0) during 2006–2007, while during 2007–2008 the highest values of $H^{/}$ and d (2.17 and 1.3) for the phytoplankton community were recorded in site 3 (RB) (Figure 3a and 3b) despite its low depth (~5–6 feet). This might be due to the fact that site 3 is located in the midst of vegetation cover of *Calamus tennis-Baringtonia acutangula.* According to Van den Brink *et al.* (1994), phytoplankton species richness is related to the complexity of habitats formed by the presence of aquatic vegetation. During 2007–2008, the relatively low values of diversity indices (<1.5) and species richness (22 and 17) in sites 1 and 2 clearly indicated that disturbance caused by the construction of RCC bridges eliminated the sensitive phytoplankton such as Bacillariophyceae and Dinophyceae in site 2. Occurrence of *Microcystis* blooms (probably recruited during seasonal inundation) in site 1 indicated their tolerance and differential strategies for survival in polluted environmental conditions, particularly at very high concentration of NH_4^{+} (0.66 mg·L^{-1} and 0.71 mg·L^{-1}). Junk *et al*. (1989) suggested that the great diversity of habitats in floodplain systems probably allows the co-occurrence of many species with differing strategies and levels of adaptation as a result of cyclical changes caused by the flood pulse.

Figures 4a and 4b show the CCA scores with phytoplankton species density and environment variable data for 2006–2007 and 2007–2008 in Chatla floodplain. CCA is a direct gradient analysis technique, and represents a special case of multivariate regression where species composition is directly and immediately related to measured environmental variables (Palmer, 1993). Further, CCA performs quite well with skewed species distributions, with quantitative noise in species abundance data, with samples taken from unusual sampling designs, and with highly intercorrelated environmental variables (Palmer, 1993). CCA extracts synthetic gradients from the biotic and environmental matrices, which are quantitatively represented by arrows in graphical biplots (ter Braak and Verdonschot, 1995). The length of the arrow is relative to the importance of the explanatory variable in the ordination, and arrow direction indicates positive and negative correlations (Jasprica *et al*., 2012).

In the present study, for the first cycle (2006–2007), the eigenvalues were 0.188 and 0.170 for axis 1 and axis 2, respectively, and the variance explained by the first two axes was 24.4%. Similarly, for the second cycle (2007–2008), the eigenvalues for axis 1 and axis 2 were 0.405 and 0.324, respectively, and the variance explained by the first two axes was 23.6%. The cumulative percentage variance of species-environment relationships was 19.6 for axis 1 and 37.3 for axis 2 in the first cycle, while in the second cycle it was 19.2 and 34.5. The variance explained by the CCA in the first cycle was found to be 65.5%, and for the second cycle it was 68.4%. The species-environment correlations of the first two axes (0.943 for both in 2006–2007) and (0.946 and 0.899 in 2007–2008) indicated a strong relationship among all species and environmental variables, suggesting the importance of these variables

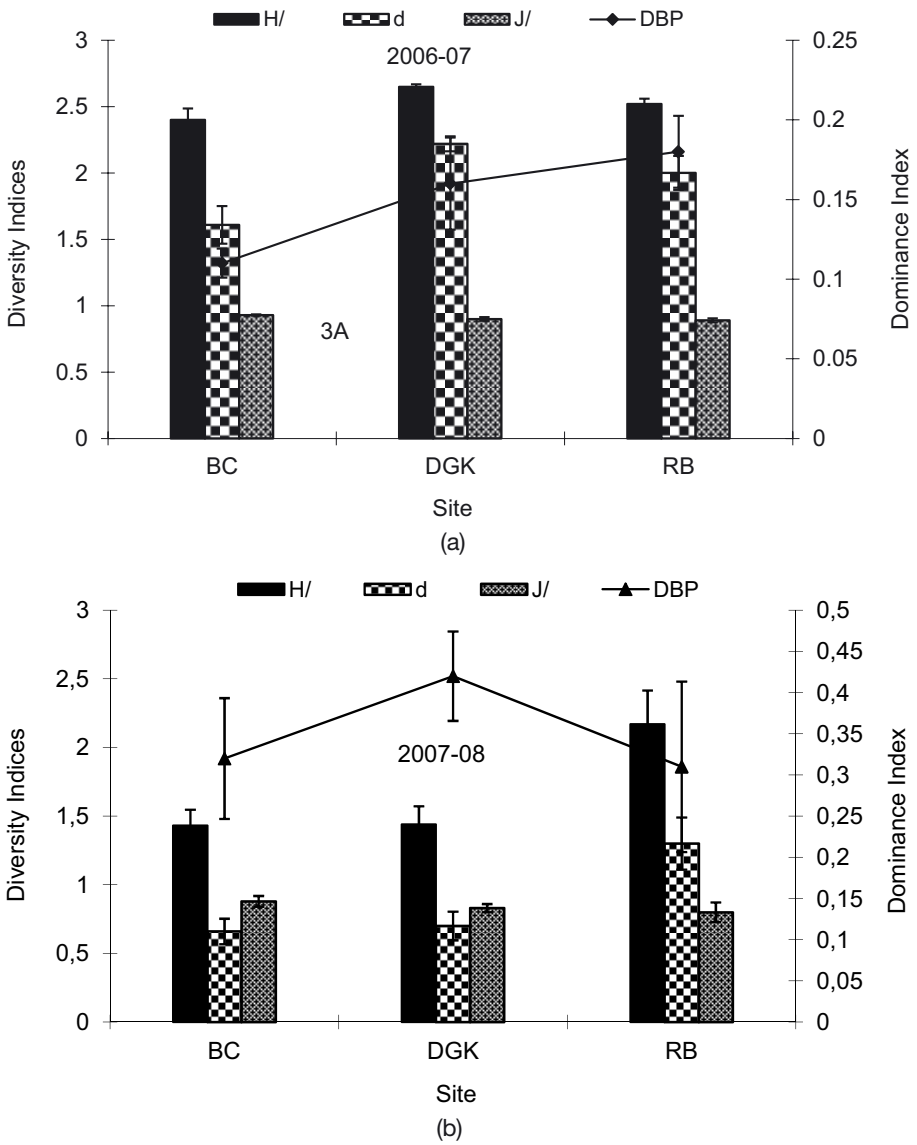
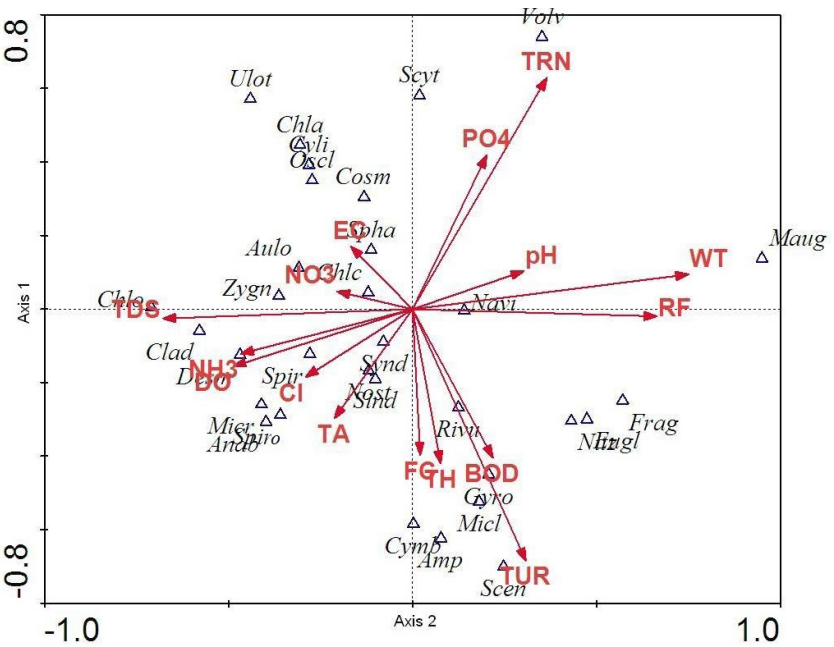


Figure 3

Seasonal variation of phytoplankton density (no·L^{-1} × 10^2) in different sites of Chatla floodplain during 2006–2007 and 2007–2008. (a) Diversity indices for phytoplankton community in different sites of Chatla floodplain during 2006–2007. (b) Diversity indices for phytoplankton community in different sites of Chatla floodplain during 2007–2008. H' = Shannon-Wiener Diversity Index, d = Margalef's index of species richness, J' = Evenness Index and D_{BP} = Berger-Parker Index of dominance.

in explaining plankton distribution. To evaluate the significance of the CCA axes and of the variables which defined these axes Monte Carlo tests were performed with 499 unrestricted permutations and were proved significant for both the cycles ($p < 0.002$: Table V).

The CCA ordination diagram (Figures 4a and 4b) revealed that during 2006–2007 both the axes were found to be highly positively correlated with TRN and WT and negatively related to TDS. Axis 1 showed a negative relationship with RF, while axis 2 was found to have a strong positive relationship with RF and TUR. *Volvox* was strongly influenced by TRN, *Maugeotia* by WT and *Navicula* by RF. During the second cycle (2007–2008) the importance of TRN was less pronounced, with a concomitant increase in the influence of NO_3. WT showed a negative relationship with both the axes. *Ulothrix, Zygnema, Navicula, Spirogyra* and *Oscillatoria* were found to be highly positively correlated with NH_3 and negatively correlated with WT. NO_3, TH and pH showed a positive relationship with axis 2 but a negative relationship



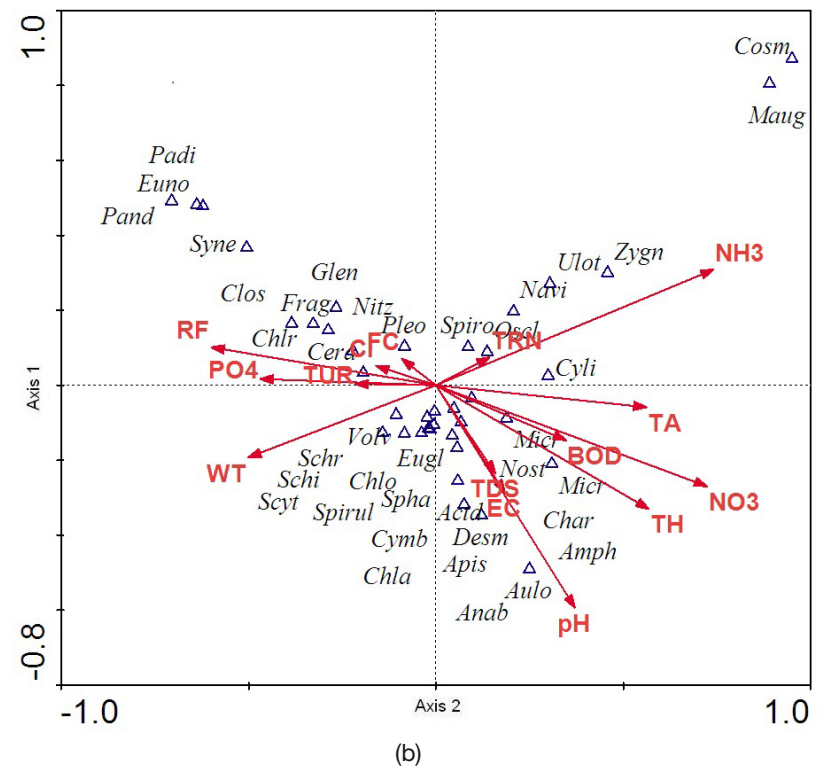


Figure 4

(a) Canorical correspondence analysis (CCA) of the phytoplankton samples collected from Chatla floodplain lake during 2006–2007 and associated environmental variables (bioplots of the species and environmental variables). (b) Canorical correspondence analysis (CCA) among the phytoplankton samples colletcted from Chatla floodplain lake during 2007–2008 and associated environmental variables (bioplots of the species and environmental variables). Abbreviations: species names were listed in Table III, WT = water temperature, TRN = transparency, TUR = turbidity, DO = dissolved oxygen, TA = total alkalinity, EC = electrical conductivity, TDS = total dissolved solids, FC = free carbon-di-xoide, CI = chloride, BOD = biological oxygen demand, TH = total hardness, NO3 = nitrate, PO4 = phosphate, NH3 = ammonia and RF = rainfall.

Table V
Summary statistics of CCA between phytoplankton species and environmental variables for first two axes in Chatla floodplain for the year 2006–2007 and 2007–2008.

	2006–2007		2007–2008	
	Axis 1	Axis 2	Axis 1	Axis 2
Eigenvalues	0.188	0.170	0.405	0.324
Species-environment correlations	0.943	0.943	0.946	0.899
Cumulative percentage variance of species data	12.8	24.4	13.1	23.6
Cumulative percentage variance of species-environment relation	19.6	37.3	19.2	34.5
Sum of all unconstrained eigenvalues	1.468		3.087	
Sum of all canonical eigenvalues	0.961		2.111	
Variance explained by the CCA	65.5%		68.4%	
Variance explained by the first two axes	24.4%		23.6%	
Monte Carlo test Test of significance of all canonical axes: *p* – values	0.002		0.002	

with axis 1. RF showed a negative relationship with axis 2 and a positive relationship with axis 1. Thus, according to CCA, during 2006–2007 phytoplankton species distribution was influenced by the environmental variables TRN, WT, TDS, RF and TUR, while in 2007–2008 it was influenced by NH_3, WT, NO_3, TH, RF and pH. The influence of RF and WT in both the years confirmed that in floodplain lakes they are very important and instrumental in the plankton community distribution.

CONCLUSION

Fluctuation of phytoplankton density and community composition in different habitats indicated various niche apportionment models as well as anthropogenic influences mainly driven by rainfall.

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