Comparison of Limnochemical Features between two Large Perennial Lentic Waterbodies in the context of Waterbird Colonization

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ABSTRACT

Around 8 km away from the centre of Kolkata city, West Bengal, lies a 12.77 ha (mean depth 1.5 m) freshwater lake, known as the Santragachi *Jheel* (in this communication stated as Lake-B), in the district of Howrah of West Bengal, India (Lat. 22° 34' 60N Long. 88° 17' 60E; Altitude 8m msl) which has recently attracted the attention of the avian migrant watchers India-wide. About 150 m south-west of Santragachi lake, there is a large (4.0 ha; mean depth 1.5 m) perennial water body (Colony *Jheel* and in this communication stated as Lake-NB) where no waterfowl colonize during the period of congregation of migratory birds (early October to late March). Limnochemical conditions of these two water bodies were compared during October to March for three consecutive years. Impact of avian colonization was evident from the comparison of limnochemical features of these two adjacent water bodies. Mean data shows much less dissolved O_2 (2.00 – 5.00 mg L^{-1}) and total hardness (125.31 – 188.53 mg L^{-1} $CaCO_3$) while very high phosphate (0.83 – 2.67 mg L^{-1}) and nitrate (50.00 – 116.67 mg L^{-1}) in Lake-B in comparison to Lake-NB (ranges were noted as 4.43 – 6.00 mg L^{-1} and 197.58 – 249.20 mg L^{-1} $CaCO_3$ while 1.00 – 1.25 mg L^{-1} and 15.00 – 25.00 mg L^{-1} respectively). Gross and net primary productivity were also much different between these two adjacent water bodies. In Lake-B GPP (2066.42 – 3749.67 mg C m^{-2} d^{-1}) and NPP (1114.99 – 2558.33 mg C m^{-2} d^{-1}) were much lower than the mean GPP (4937.50 – 7875.00 mg C m^{-2} d^{-1}) and NPP (2449.50 – 4250.00 mg C m^{-2} d^{-1}) values that were recorded from Lake-NB. Net-Gross ratio, that reflects the rate of respiratory consumption at the primary producer level, was also much higher in Lake-B (42.01 – 68.25%) than Lake-NB (45.40 – 57.14%). Lindeman Efficiency, on the contrary, of Lake-B (3.71 – 8.71%) was considerably lower than Lake-NB (7.63 – 13.29%) and such a lower efficiency, even when the nutrients were not in short supply, could be attributed to the thick water hyacinth covering of the Lake-B. Addition of bird guano surely enriched nutrient profile of the Lake-B. Further, the nutrient rich water of Lake-B might have a bottom-up control on the food web, however, very high bird congregation in December-January would surely have a top-down cascading effects on the lake food web. Thereby, mollusk, fish and plankton production supported the large

avian congregation during the study period in Lake-B and in sequel a lower total hardness, dissolved oxygen content and primary productivity were recorded.

INTRODUCTION

The effect of urbanization can be immense and it has much deteriorated wetlands in India. Though urbanization increases avian biomass it typically results in the declination of richness (Chase and Walsh 2004). In the last couple of decades a marked decline in number of migratory waterbirds to the West Bengal wetlands has been recorded. Despite all this a small lake (Santragachi *jheel*) near a crowded and noisy railway station, 20 km from the East Calcutta Wetlands regularly invites 4,000 to 5,000 migratory waterbirds. Lesser Whistling ducks (*Dendrocygna javanica*) dominate this lake, as they do in most parts of eastern India, but several other species are also found. However, about 150 m south-west of Santragachi lake, there is a large perennial water body (Colony *Jheel*) devoid of any waterfowls during the period of congregation of migratory birds (early October to late March). Impacts of bird colonization on physico-chemical conditions of lake water and *vice versa* are on record (Manny *et al.* 1994; Hanson 2003; Olson *et al.* 2005; Longcore *et al.* 2006; Geest *et al.* 2007; Unckless and Makarewicz 2007). Available water space was most interestingly observed to be an important factor to encourage bird congregation (Patterson 1976); while colonization of migratory birds in smaller water spaces significantly change the water quality (Andrikovics *et al.* 2003). The objective of the present study was to compare the limnochemical conditions of the two water bodies in context of waterbird colonization. Limnochemical conditions of these two water bodies were compared during October to March for three consecutive years along with waterbird census. During the present course of fieldwork bird populations and limnological features were studied with an eye on the extent to which humans had altered them.

METHODS

Study Area

The 12.77 ha, roughly rectangular, Santragachi lake is 8 km away from the centre of Calcutta city, in the district of Howrah of West Bengal, India (Lat. 22° 34' 60N Long. 88° 17' 60E; Altitude 8m msl; mean depth 1.5 m) and about 150 m south-west of Santragachi lake, is a large (4.0 ha; mean depth 1.5 m) perennial water body (Colony *Jheel*). Studies were conducted between 06 – 07 hr, 12 –13 hr and 17 – 18 hr, once in each month; usually a day in the first week of the month, from October to March of three consecutive years (2005 – 2008).

Avian Population Sampling

The Line transect method was used to record species richness and abundance (Hutto *et al.* 1986; Bibby *et al.* 1992; Buckland *et al.* 1993). The order of sampling was random; however, each of the four sides of the lake was traversed at each sampling time; each side was traversed by walking along a transect and all birds seen were counted within 50 m of the transect, all parts of which were at least 50 m from the edge of the shoreline. Birds were counted as seen more than 50 m in front or behind as long as they were within 50 m perpendicular to the transect. The time and weather conditions were recorded at the start of each sampling. Birds flying over the habitat were recorded separately from those using the habitat.

For a more robust estimate of the populations, random hand-frame and binocular-frame counts (Gopal 1995) of the birds were also made in three selected distance-ranges, viz., 50m, 100m and 150m. Areas of both hand-frame and binocular-frame were standardized by the average of three measurements, working out the ground cover on land at the pre-set distances. Such frame-counts encompass all the avian species, either resting on the bank or islands, or wandering on the water surface. Three individual counts at three time intervals were averaged to get the representative data of a particular month (Gibbons *et al.* 1996). Inskipp *et al.* (1996) was followed for avian species identification and nomenclature.

ESTIMATION OF PHYSICO-CHEMICAL FACTORS

Chemical analysis of water sample was made on spot by using Emerck (Germany) Merckquant and Aquamerck field-testing kits. Temperature was recorded by using a digital thermometer (CIE310) with a 1m long probe and pH by using a pen grip digital pH meter (Hanna). Kyritshu illuminometer (M5200) recorded mean luminance. Irradiance energy received by the water body was approximated by multiplying the luminance value in lux by 149.25 (Reifsynder and Lull, 1965). Primary productivity was measured by employing light-dark bottle technique and conversion of Oxygen values to calorific values were calculated following Eaton *et al.* (1995). Gross production for a span of 12 hours (mean light hours of the day) was compared with total respiration (R) for 24 hours.

STATISTICAL ANALYSES

For statistical computation and presentation, *Statistica* for Windows, Version 5.1A, Statsoft Inc., 1996 and SPSS for Windows, Release 10.0.1 SV, SPSS Inc., 1999 were used. Shannon-Wiener Diversity Index (H'), Pielou's Evenness Index (J'), Margalef's Richness Index (D_{MARG}) and Simpson's Dominance Index (D_{SIMP}) were calculated using Dindex software Version 4.0.

RESULTS

A comparative representation of wetland weeds along with their abundance status are listed in the Table 1 for Lake-B and Lake-NB. Initial open water for Lake-B nearly doubled by manual clearing of the floating water hyacinth in November allowing more space for waterbirds. Mean Physico-chemical conditions and the rates of primary production and energy fixation efficiency status of Lake-B and Lake-NB during the study period i.e., from October to March for three consecutive years, are given in Table 2 and

5 respectively. Seventeen physico-chemical factors of the two water bodies were recorded during the period of the bird colonization and the general patterns of fluctuations of nutrients and primary productivity were characteristically different in consecutive three seasons for the two sites depending on waterbird colonization. Mean data shows much

Table 1 : Important wetland floral composition of Lake-B and Lake-NB during study period (2005-2008)

Type	Common Name	Scientific Name	Status	
			Lake-B	Lake-NB
Submerged	Hydrilla	*Hydrilla verticillata*	+	++
	Coontail	*Ceratophyllum demursum*	+	+
Floating	Water hyacinth	*Eichhornia crassipes*	+++	++
	Water lettuce	*Pistia stratiotes*	++	++
	Water spinach	*Ipomea aquatica*	++	+
Emergent	Cattails	*Typha latifolia*	++	+
	Bulrush	*Scirpus longii*	++	+
	Reed	*Phragmites communis*	+	+

(Abundance status: + = rare presence; ++ = moderate presence; +++ = dominant).

Table 2 : Average of seasonal changes in the physico-chemical conditions of Lake-B for the years 2005 - 2008

Parameters	OCT	NOV	DEC	JAN	FEB	MAR
Solar Radiation (Kcal m^{-2} d^{-1})	451.33	378.33	562.33	589.67	574.33	608.67
Air Temperature (°C)	29.53	27.87	25.93	25.90	30.67	35.53
Water Temperature (°C)	28.50	24.90	22.23	21.83	27.83	30.63
pH	7.53	7.50	7.73	7.87	7.50	7.53
Weed Coverage (%)	56.67	48.33	41.67	43.33	48.33	48.33
Dissolved O_2 (mg L^{-1})	5.00	3.93	4.33	4.13	3.17	2.00
Total Alkalinity (mmol L^{-1} $CaCO_3$)	3.80	4.03	5.37	5.60	5.07	4.87
Total Acidity (mmol L^{-1} $CaCO_3$)	0.40	0.23	0.17	0.40	0.37	0.57
Total Hardness (mg L^{-1} $CaCO_3$)	125.31	149.54	171.39	156.60	188.53	176.84
Chlorides (mg L^{-1})	273.33	260.00	308.00	362.67	396.00	417.33
Phosphate (mg L^{-1})	2.33	1.33	2.00	1.00	0.83	2.67
Nitrate (mg L^{-1})	116.67	50.00	70.83	50.00	62.50	75.00
Silicate (mg L^{-1})	0.23	0.27	0.22	0.16	0.12	0.08
GPP (mg C m^{-2} d^{-1})	2066.42	3526.19	3057.83	3749.67	3397.89	2379.17
NPP (mg C m^{-2} d^{-1})	1114.99	1481.19	1643.11	2558.33	2541.12	1158.33
Net-Gross Ratio (%)	60.82	42.01	54.26	68.25	68.03	46.79
Lindeman Efficiency (%)	4.28	8.71	5.16	5.92	5.53	3.71

Table 3. Correlations between bird density and physico-chemical parameters of Lake-B (*Marked correlations are significant at $p < 0.05$). Parameters are abbreviated as follows: solar radiation (SR), air temperature (AT), water temperature (WT), pH (PH), weed cover (WEED), dissolved oxygen (DO), total alkalinity (ALK), total acidity (ACD), total hardness (HRDN), chloride content (CLRD), phosphate (PO4), nitrate (NO3), silicate (SIO2), gross primary productivity (GPP), net primary productivity (NPP), net-gross ratio (N_G), Lindeman efficiency (LEF) and total bird count (BIRD).

	SR	AT	WT	PH	WEED	DO	ALK	ACD	HRDN	CLRD	PO4	NO3	SIO2	GPP	NPP	N_G	LEF
AT	0.26																
WT	0.03	0.93*															
PH	0.44	-0.64	-0.79*														
WEED	-0.49	0.43	0.71*	-0.68													
DO	-0.52	-0.79*	-0.54	0.31	0.17												
ALK	0.84*	-0.23	-0.49	0.72*	-0.85*	-0.27											
ACD	0.46	0.79*	0.70*	-0.18	0.37	-0.60	-0.23										
HRDN	0.69	0.31	0.07	0.00	-0.58	-0.73*	0.68	0.10									
CLRD	0.87*	0.58	0.35	0.08	-0.27	-0.80*	0.63	0.68	0.76*								
PO4	0.04	0.51	0.50	-0.24	0.34	-0.14	-0.33	0.34	-0.24	-0.05							
NO3	-0.15	0.28	0.52	-0.33	0.75*	0.33	-0.54	0.26	-0.53	-0.25	0.67						
SIO2	-0.85*	-0.68	-0.47	0.01	0.13	0.80*	-0.52	-0.77*	-0.68	-0.99*	-0.08	0.10					
GPP	0.03	-0.58	-0.70*	0.43	-0.67	0.03	0.50	-0.45	0.34	0.05	-0.89*	-0.91*	0.11				
NPP	0.42	-0.40	-0.48	0.47	-0.51	-0.01	0.68	-0.12	0.46	0.40	-0.89*	-0.61	-0.27	0.79*			
N_G	0.45	-0.28	-0.19	0.42	-0.02	0.28	0.44	0.13	0.08	0.31	-0.49	0.09	-0.29	0.21	0.72*		
LEF	-0.64	-0.51	-0.49	-0.04	-0.22	0.23	-0.19	-0.61	-0.13	-0.51	-0.63	-0.64	0.61	0.72*	0.24	-0.30	
BIRD	0.19	-0.68	-0.83*	0.56	-0.88*	0.10	0.68	-0.66	0.46	0.01	-0.67	-0.79*	0.15	0.87*	0.67	0.16	0.52

Table 4 : Average seasonal changes in the migratory waterfowl densities (Nos. ha^{-1}) at Lake-B for the years 2005 to 2008 (NR=Not Recorded)

Common Name	Scientific name	OCT	NOV	DEC	JAN	FEB	MAR
Northern Pintail	*Anas acuta*	0.05	0.37	2.40	6.87	1.20	0.23
Lesser Whistling Duck	*Dendrocygna javanica*	8.80	148.68	199.92	162.67	144.48	41.66
Gadwall	*Anas strepera*	NR	0.52	1.10	2.79	1.02	0.44
Gargany	*Anas querquedula*	NR	NR	0.23	0.31	0.10	0.18
Northern Shoveller	*Anas clypeata*	NR	0.05	0.47	1.31	1.20	0.10
Cotton Pigmy-Goose	*Nettapus coromandelianus*	NR	NR	0.31	4.07	1.41	2.43
White-breasted Waterhen	*Amaurornis phoenicurus*	0.10	0.26	0.29	0.21	0.13	0.18
Common Moorhen	*Gallinula chloropus*	0.05	0.26	0.68	1.64	0.70	0.99
Bronze Winged Jacana	*Metopidius indicus*	0.21	0.81	1.07	1.07	2.04	0.73
Common Coot	*Fulica atra*	NR	0.26	0.50	0.78	0.16	NR
Little Cormorant	*Phalacrocorax niger*	1.25	1.51	1.62	1.78	3.03	5.56
Asian Openbill	*Anastomus osciatans*	NR	NR	0.05	0.08	NR	NR
Pond Heron	*Ardeola grayii*	0.60	0.42	0.26	0.55	1.17	0.97
Common Sandpiper	*Actitis hypoleucos*	NR	NR	0.21	0.21	NR	NR
White Wagtail	*Motacilla alba ocularis*	0.31	0.21	0.31	0.31	0.16	NR
Citrine Wagtail	*Motacilla citreola citreola*	NR	NR	NR	0.16	NR	NR
Grey Wagtail	*Motacilla cinerea*	0.03	NR	NR	NR	NR	NR
Total Birds		11.41	153.35	209.42	184.81	156.80	53.48
Shannon-Wiener Diversity Index		0.886	0.196	0.291	0.625	0.442	0.883
Pielou's Evenness Index		0.426	0.167	0.107	0.225	0.172	0.368
Margalef's Richness Index		1.405	1.319	1.774	1.931	1.579	1.533
Simpson's Dominance Index		0.602	0.941	0.910	0.776	0.850	0.622

Table 5 : Average seasonal changes in the physico-chemical conditions of Lake-NB for the year 2005 - 2008

Parameters	OCT	NOV	DEC	JAN	FEB	MAR
Solar Radiation (Kcal m^{-2} d^{-1})	451.33	378.33	562.33	589.67	574.33	608.67
Air Temperature (^{o}C)	28.93	27.47	25.87	25.83	29.67	35.27
Water Temperature (^{o}C)	27.40	24.10	21.40	22.00	27.33	29.97
pH	7.70	7.83	7.87	7.97	7.60	7.63
Weed Coverage (%)	10	10	10	10	10	10
Dissolved O_2 (mg L^{-1})	4.43	5.40	5.57	6.00	5.00	5.20
Total Alkalinity (mmol L^{-1} $CaCO_3$)	3.57	3.87	4.33	4.77	5.03	5.17
Total Acidity (mmol L^{-1} $CaCO_3$)	0.30	0.23	0.30	0.40	0.50	0.57
Total Hardness (mg L^{-1} $CaCO_3$)	197.58	216.57	227.25	249.20	226.65	223.69
Chlorides (mg L^{-1})	173.33	176.67	186.67	216.67	226.67	236.67
Phosphate (mg L^{-1})	1.00	1.00	1.00	1.00	1.25	1.25
Nitrate (mg L^{-1})	15.00	25.00	25.00	25.00	25.00	25.00
Silicate (mg L^{-1})	0.25	0.25	0.25	0.25	0.25	0.23
GPP (mg C m^{-2} d^{-1})	5062.50	5375.00	4937.50	5000.00	6625.00	7875.00
NPP (mg C m^{-2} d^{-1})	2637.50	2449.50	2812.50	2750.00	3750.00	4250.00
Net-Gross Ratio (%)	52.10	45.40	57.14	54.82	56.72	53.86
Lindeman Efficiency (%)	7.63	13.29	8.32	7.94	10.80	11.11

less dissolved O_2 (2.00 mg L^{-1} in March - 5.00 mg L^{-1} in October) and total hardness (125.31 mg L^{-1} $CaCO_3$ in October - 188.53 mg L^{-1} $CaCO_3$ in February) while very high phosphate (0.83 mg L^{-1} in February - 2.67 mg L^{-1} in 2.67) and nitrate (50.00 mg L^{-1} November - January and 116.67 mg L^{-1} in October) in Lake-B in comparison to Lake-NB (ranges were noted as 4.43 mg L^{-1} in October – 6.00 mg L^{-1} in January and 197.58 mg L^{-1} $CaCO_3$ in October – 249.20 mg L^{-1} $CaCO_3$ in January while 1.00 mg L^{-1} in October to January – 1.25 mg L^{-1} in February and March and 15.00 mg L^{-1} in October – 25.00 mg L^{-1} in November to March respectively). Gross and net primary productivity were also much different between these two adjacent water bodies. In Lake-B GPP (2066.42 mg C m^{-2} d^{-1} in October – 3749.67 mg C m^{-2} d^{-1} in January) and NPP (1114.99 mg C m^{-2} d^{-1} in October – 2558.33 mg C m^{-2} d^{-1} in January) were much lower than the mean GPP (4937.50 mg C m^{-2} d^{-1} in December – 7875.00 mg C m^{-2} d^{-1} in March) and NPP (2449.50 mg C m^{-2} d^{-1} in November – 4250.00 mg C m^{-2} d^{-1} in March) values that were recorded from Lake-NB. Net-Gross ratio, that reflects the rate of respiratory consumption at the primary producer level, was also much higher in Lake-B (42.01% in November – 68.25% in January) than Lake-NB (45.40% in November – 57.14% in December). Lindeman Efficiency, on the contrary, of Lake-B (3.71% in March – 8.71% in November) was considerably lower than Lake-NB (7.63% in October – 13.29% in November). Colder months were observed to have higher total alkalinity, total hardness, and primary productivity both for Lake-B and Lake-NB. However, lower nitrate and silicate values were recorded in Lake-B during the period having colder water temperature. Interestingly Lake-NB showed a repetitive pattern in nitrate and silicate concentration, however, the mean values recorded for nitrate in Lake-NB were always much lower than that of Lake-B. Correlations between physical, chemical, vegetal factors (total 17 factors) and avian densities for Lake-B and Lake-NB are presented in Table 3 and table 6 respectively. Significant positive correlations ($p<0.05$) between bird density and gross ($r=0.87$) and net ($r=0.67$) primary productivity in Lake-B were noted. Gross and net primary productivity were significantly negatively correlated with water temperature, weed coverage, total phosphate and total nitrate in lake-B. However, it was interesting to note that gross and net primary productivity in Lake-NB were significantly positively correlated with water temperature and total phosphate though it was significantly negatively correlated with silicate. Pearson's correlation value between bird density and alkalinity was also significantly positive ($r=0.68$) for Lake-B. Significant negative correlations ($p\leq0.10$) in Lake-B were recorded between bird density and temperature, weed coverage, acidity, nitrates and phosphate. Similarities between the months under investigation of Lake-B and Lake-NB are described depending on limnochemical conditions with a help of dendrogram using cluster analysis in Figure 1 and 2. Hierarchical cluster analysis of the months of availability of migratory birds in Lake-B depending on avian density is depicted in Figure 3. The Principal Component Analysis (PCA) with Varimax rotation and Kaiser Normalization were made for data reduction to focus the most important components to influence the limnochemical features of the study sites. Table 7 and 8 depicts the factor loadings (FL) in different components and 3 components for Lake-B and 2 components for Lake-NB were extracted.

Table 6. Correlations between different physico-chemical parameters of control water (*Marked correlations are significant at $p < 0.05$). Parameters are abbreviated as follows: solar radiation (SR), air temperature (AT), water temperature (WT), pH (PH), dissolved oxygen (DO), total alkalinity (ALK), total acidity (ACD), total hardness (HRDN), chloride content (CLRD), phosphate (PO4), nitrate (NO3), silicate (SIO2), gross primary productivity (GPP), net primary productivity (NPP), net-gross ratio (N_G), Lindeman efficiency (LEF).

	SR													
AT	0.29	AT												
WT	0.10	0.92*	WT											
PH	-0.10	-0.79*	-0.91*	PH										
DO	0.34	-0.43	-0.70*	0.76*	DO									
ALK	0.86*	0.46	0.25	-0.26	0.38	ALK								
ACD	0.80*	0.74*	0.62	-0.57	-0.02	0.90*	ACD							
HRDN	0.64	-0.26	-0.49	0.52	0.89*	0.68	0.34	HRDN						
CLRD	0.83*	0.58	0.42	-0.36	0.24	0.97*	0.96*	0.58	CLRD					
PO4	0.54	0.80*	0.75*	-0.80*	-0.24	0.77*	0.90*	0.08	0.82*	PO4				
NO3	0.41	-0.01	-0.29	0.22	0.77*	0.67	0.31	0.76	0.53	0.32	NO3			
SIO2	-0.43	-0.90*	-0.66	0.46	0.06	-0.54	-0.70*	-0.01	-0.61	-0.63	-0.20	SIO2		
GPP	0.45	0.93*	0.81*	-0.75*	-0.20	0.71*	0.86*	0.01	0.77*	0.93*	0.31	-0.85*	GPP	
NPP	0.68	0.85*	0.72*	-0.72*	-0.15	0.82*	0.95*	0.14	0.87*	0.96*	0.32	-0.78*	0.95*	NPP	
N_G	0.86*	0.02	-0.05	-0.11	0.11	0.58	0.54	0.42	0.51	0.35	0.14	-0.06	0.14	0.45	N_G
LEF	-0.36	0.36	0.30	-0.31	0.02	0.14	0.07	-0.10	0.13	0.38	0.48	-0.28	0.48	0.24	-0.61

Rescaled Distance Cluster Combine

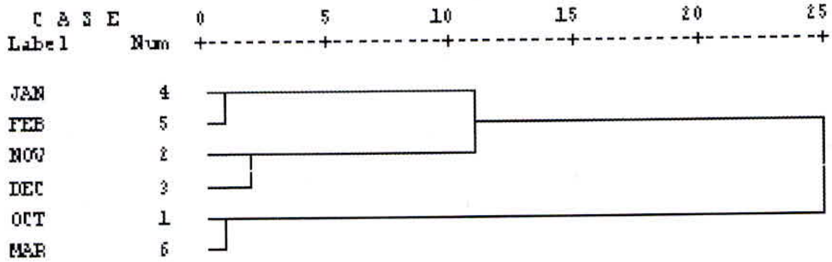

Fig. 1 : Hierarchical cluster analysis of the months under study of Lake-B depending on the limnochemical conditions (05-08).

1=October; 2=November; 3=December; 4=January; 5=February; 6=March

Rescaled Distance Cluster Combine

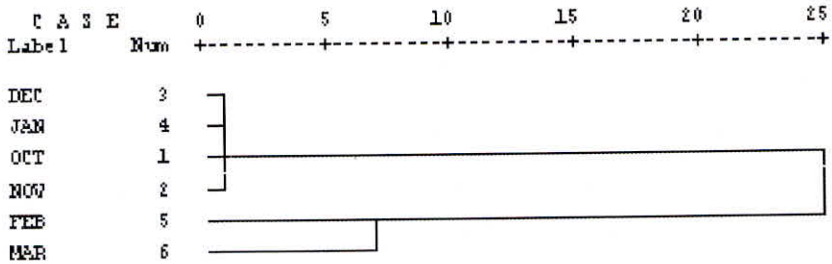

Fig. 2 : Hierarchical cluster analysis of the months under study of Lake-NB depending on the limnochemical conditions (05-08).

1=October; 2=November; 3=December; 4=January; 5=February; 6=March

Rescaled Distance Cluster Combine

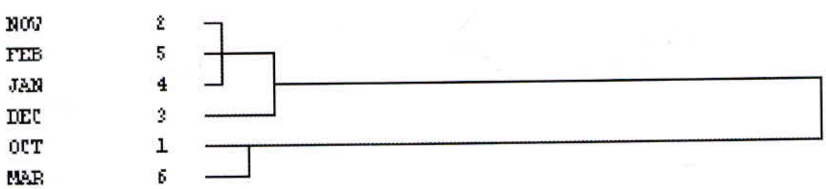

Fig. 3 : Hierarchical cluster analysis of the months of availability of migratory birds in the study site depending on the avian density (05-08).

1=October; 2=November; 3=December; 4=January; 5=February; 6=March

Table 7 : Principal Component Analysis (3 components extracted) with varimax rotation for Lake-B

Limnochemical Factors	Components		
	1	2	3
Solar Radiation	0.493	0.731	0.443
Air Temperature	-0.505	0.836	-0.188
Water Temperature	-0.717	0.643	-0.240
pH	0.690	-0.214	0.639
Weed Coverage	-0.886	-1.157E-02	-0.184
Dissolved O_2	-9.155E-02	-0.886	0.296
Total Alkalinity	0.870	0.337	0.346
Total Acidity	-0.299	0.796	0.113
Total Hardness	0.568	0.653	-0.221
Chlorides	0.352	0.926	2.876E-02
Phosphate	-0.698	0.256	0.522
Nitrate	-0.812	-8.691E-03	0.434
Silicate	-0.200	-0.964	-6.856E-02
GPP	0.861	-0.269	-0.404
NPP	0.845	4.350E-02	-0.194

Table 8 : Principal Component Analysis (2 components extracted) with varimax rotation for Lake-NB

Limnochemical Factors	Components	
	1	2
Solar Radiation	0.635	0.553
Air Temperature	0.884	-0.337
Water Temperature	0.770	-0.582
pH	-0.738	0.616
Weed Coverage	-0.432	0.668
Dissolved O_2	-0.191	0.951
Total Alkalinity	0.796	0.590
Total Acidity	0.947	0.218
Total Hardness	0.104	0.988
Chlorides	0.858	0.472
Phosphate	0.960	-3.219E-02
Nitrate	0.275	0.784
Silicate	-0.802	2.921E-02
GPP	0.967	-6.891E-02
NPP	0.995	4.242E-02

Migrants started to congregate in good number and variety in November, reaching a peak density in December and January while started leaving the lake in February were evident from two separate neighbouring clusters December – January and November – February. However, these clusters were placed quite distantly from the third cluster composed of October – March, the time of arrival and departure of the migratory avian species.

Seventeen species of birds were observed to be active in and around Lake-B during the present study. Table 4 depicts the average seasonal changes in the migratory waterfowl densities (Number Ha^{-1}) of Lake-B for three consecutive years (2005- 2008). Lesser Whistling duck followed by Northern Pintail (*Anas acuta*), Cotton Pigmy goose (*Nettapus coromandelianus*) and Gadwall (*Anas strepera*) dominated the ducks. In the average data for three seasons, a maximum Shannon diversity index was noted in October (0.886) where as the minimum was associated with November (0.196); evenness index showed a maximum evenness in October (0.426) and a minimum evenness in December (0.107). Richness index for the average data was maximum in January (1.931) and the minimum in November (1.319); dominance index showed a maximum value in November (0.941) and the minimum value was found to be associated with October (0.602).

DISCUSSION

In tropical waters lower water temperature supports higher photosynthesis (Wetzel 2001) and it is also evident in the present study from both Lake-B and Lake-NB. Higher uptake of CO_2 for photosynthesis by autotrophs encourages higher reverse reaction from CO_3^{2-} to HCO_3^- and ultimately leads to supply of CO_2 in photosynthetic process. Higher alkaline condition of the lake water during the colder months can be attributed to such reverse reactions which along with favourable temperatures enhances the rates of photosynthesis. Surface coverage by floating weeds classically influences the phytoplankton gross productivity as it is also evident in the present study where Lake-NB always invariably showed higher gross productivity than Lake-B possibly because the later was mostly shaded by thick water hyacinth cover throughout the investigation period. A positive correlation between total hardness and total alkalinity observed in both the water bodies might have resulted from the fact that CO_3^{2-} and HCO_3^- alkalinity are the major contributors to total hardness (Arvola *et al.* 1990). Interestingly, for Lake-B total hardness increased with total bird density possibly because of addition of excess divalent cations through bird droppings (Olson *et al.* 2005) while no such observations in Lake-NB can be attributed to the complete absence of waterfowls. Manny *et al.* (1994), Olson *et al.* (2005), Geest *et al.* (2007) and Unckless and Makarewicz (2007) worked out the amount of nutrient additions by waterbirds to lakes and reservoirs and observed that such nutrient additions positively influenced the primary productivity of the waters. Addition of bird guano increases the total nutrient content specially phosphate and nitrate (Olson *et al.* 2005) which in the present investigation was rapidly utilised by higher GPP as well as in secondary production of the Lake-B occupants. Higher rates of both primary and secondary production influenced the rapid uptake of basic nutrients like phosphate and nitrate that was reflected in negative correlation with both GPP as well as higher avian density for Lake-B while Lake-NB in the absence of waterbirds did not show such increase in GPP and accordingly the correlations between GPP and phosphate and nitrate were positive. The PCA on physico-chemical factors also showed an interesting result (Table 7 and 8). For Lake-B, highest factor loadings for 1st, 2nd and 3rd components were considered and these were for total alkalinity (FL = 0.870) in the 1st component, chlorides (FL = 0.926) in the 2nd component and pH (FL = 0.639) in the 3rd. For Lake-NB, highest factor loadings for 1st and 2nd components were noted for NPP (FL = 0.995) and total hardness (FL = 0.988). Lindeman Efficiency of Lake-B was found to be considerably lower than Lake-NB and such a lower efficiency, even when the nutrients were not in short supply, could be attributed to the thick water hyacinth covering of the Lake-B. Addition of bird guano surely enriched nutrient profile of the Lake-B. Further, the nutrient rich water of Lake-B might have a bottom-up control on the food web, however, very high bird congregation in December-January would surely have a top-down cascading effects on the lake food web. Thereby, mollusk, fish and plankton production supported the large avian congregation during the study period in Lake-B and in sequel a lower total hardness, dissolved oxygen content and primary productivity were recorded.

Hierarchical cluster analyses depending on the limnochemical conditions of Lake-B (Fig.1) and Lake-NB (Fig.2) were interesting to compare. In Lake-B, three distinct clusters were observed. November – December and January – February clusters were much nearer while October and March, that formed the third cluster, was furthest from the other two clusters. October being the month of onset of bird colonization while March, when the waterfowls departed, showed much comparable limnochemical features. November and December, the months of early avian colonization, had a comparable impact on limnochemical features and there by formed a cluster. Likewise, January and February, the months of peak avian colonization, had similar impact on limnochemical factors and thereby occurred in a cluster. Contrastingly different clustering pattern was noticed for Lake-NB as this water body did not harbour waterfowl. October – January, relatively colder part of the year, formed a single cluster which was furthest from February, when the ambient temperature suddenly increased and influenced all other limnochemical factors. Both February and March formed two different clusters and were much closer. Interestingly these clusters showed closest similarity with October suggesting much comparable limnochemical environment. Figure 3, that depicted dendrogram on the basis of avian density, showed three distinct clusters. October and March were much nearer as it has been observed in Fig. 1. These two were furthest from the clusters of other four months. November January and February formed one cluster and December, another one and they were much closer suggesting their similarity so far as the density of waterfowl was concerned.

CONCLUSIONS

Waterbirds have long been postulated to influence limnochemical conditions of lakes throughout the world. In the present study, where two large water bodies were compared for limnochemical conditions depending on the presence or absence of water birds, a clear demonstration of the influence of waterbirds on lake limnochemistry was found. A diverse group of birds occupied Lake-B to bring a dramatic change in the limnochemical composition specially by uploading phosphate and nitrate. However, no such fluctuation in the limnochemical composition was observed in Lake-NB in the absence of waterfowls. Migratory waterbirds, thus, every year colonizing at Santragachi lake influence or influenced by the limnochemistry in a manner which altogether make it a home for them.

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