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Changes in Densities of Waterbird Species in Santragachi Lake, India: Potential Effects on Limnochemical Variables

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Utpal Singha Roy, Abhishek Roy Goswami, Anulipi Aich, and SK Mukhopadhyay (2011) Changes in densities of waterbird species in Santragachi Lake, India: potential effects on limnochemical variables. *Zoological Studies* **50**(1): 76-84. We carried out limnological investigations in relation to anticipated effects of migratory waterbird use in an urban lake 20 km from the East Calcutta Wetlands, a Ramsar site. Twenty-two species of birds used the lake during the migration and wintering periods (Oct.-Mar.) in 3 successive years (2004-2007). The lowest Shannon diversity index value of 0.360 was found in Nov., while the highest of 0.963 was found in Oct. for the pooled data collected during the 3-yr study period. We examined correlations among 17 physical, chemical, and vegetal factors with avian densities. The addition of bird guano increased the nutrients and was rapidly utilized by higher gross primary productivity (GPP) as well as by secondary production of the lake body. Higher rates of both primary and secondary production resulted in the rapid uptake of basic nutrients like phosphate, nitrate, and silicate. We found negative correlations of major nutrients (phosphate, nitrate, and silicate) with both GPP and higher avian densities. Increased areas of open water, which were free of floating vegetation, also likely influenced bird aggregation and the limnochemistry by allowing more space for avian interactions and increased solar input for photosynthesis, respectively.
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Key words: Santragachi wetland, Limnochemistry, Waterbirds, East Calcutta Wetlands, Ramsar site.

Rapid urbanization has damaged wetlands throughout India. A large (1200-ha) wetland area in the eastern fringe of Calcutta, India, was recently classified as a Ramsar Site (no. 1208) and has attracted much local and global attention. A number of wetlands of various sizes, close to this area also support migratory bird populations during winter but remain poorly known and often face conversion due to ever-escalating anthropogenic activities. In the last couple of decades, despite a marked decline in the number of migratory waterbirds on the West Bengal wetlands, a small lake (Santragachi *jheel*) near a crowded and noisy railway station, 20 km from the East Calcutta Wetlands regularly supports 4000-5000 migratory waterbirds between Oct. and Mar. Lesser Whistling Ducks (*Dendrocygna javanica*) dominate this lake, as they do in most parts of eastern India, but several other species are also found. Interesting studies on the effects of bird aggregation on the physicochemical conditions of lake water and vice versa have been published (Manny et al. 1994, Hanson 2003, Longcore et al. 2006, Unckless and Makarewicz 2007). The area of open water is an important factor determining bird congregation (Patterson 1976), while aggregations of migratory birds in smaller bodies of water significantly change the water quality by the addition of extra loads of nutrients (Andrikovics et al. 2003). Our objectives were first to determine if use by avifauna was affected by coverage of floating vegetation, second to determine if chemical variables,

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including primary productivity of the lake, were affected by migratory bird aggregation, and third to monitor such changes over time. We also focused on the extent to which humans have altered the use by bird populations and affected changes in limnochemical features of the lake.

MATERIALS AND METHODS

Study area

The 12.8-ha, roughly rectangular, Santragachi Lake is 8 km from the center of Calcutta City, in Howrah District, West Bengal, India (22°34'60"N, 88°17'60"E; at an elevation of 8 m).

Avian population sampling

We used the line transect method to record the 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 4 sides of the lake was traversed during each sampling time. We surveyed each side by walking along a transect and counted all birds seen within 50 m of the transect. All sections of the transect were at least 50 m from the edge of the shoreline. We included birds observed more than 50 m in front or behind as long as they were within 50 m perpendicular to the transect. We recorded the time and weather conditions at the start of each sampling. We recorded birds flying over the habitat separately from those using the habitat.

For a more-robust estimate of the populations, we also conducted random hand-frame and binocular-frame counts (Gopal 1995) of birds in 3 selected distance ranges of 50, 100, and 150 m. We standardized areas of both the hand-frame and binocular-frame by averaging 3 measurements and worked out the ground cover on land at pre-set distances. Such frame-counts encompassed all avian species, either resting on the bank or islands, or wandering on the water surface. We averaged 3 individual counts at 3 time intervals to obtain representative data of a particular month (Gibbons et al. 1996). We used Inskipp et al. (1996) for avian species identification and nomenclature.

When counting birds, we categorically made a rough estimate of vegetative coverage of the water surface to get an idea of the relation of area of sunlight penetration and gross primary productivity (GPP). This site is under the National Wetland Conservation Programme of the Ministry of Environment and Forests, Government of India, and every year at the time of bird aggregation, the local authority clears the water hyacinths to make a space for waterbirds.

We conducted observations at 06:00-07:00, 12:00-13:00, and 17:00-18:00, once a month; usually during the 1st wk of the month, from Oct. to Mar. in 2004-2007. Waterbirds use this protected area from Oct. to Mar.

Estimation of physicochemical factors

We analyzed the water chemistry of samples on site using Merck (Germany), Merckquant, and Aquamerck field-testing kits. Temperature was recorded using a digital thermometer (CIE310) with a 1-m-long probe, and pH was measured with a pen grip digital pH meter (Hanna, India). An illuminometer (M5200; Kyoritsu Thailand) was used to record the 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 the light-dark bottle technique (Wetzel 2001), and conversion of oxygen values to calorific values was calculated following Eaton et al. (1995). We compared gross production for a span of 12 h (mean light hours of the day) with total respiration (R) for 24 h.

Statistical analyses

We used Statistica for Windows, vers. 5.1A (Statsoft 1996) to calculate the mean, standard deviation (SD), and correlation matrices. We considered correlations of $p < 0.05$ to be significant. We also calculated correlations of $p < 0.10$, for statistical evaluation between physicochemical factors and migratory waterbirds. We used SPSS for Windows, release 10.0.1 SV (SPSS, Chicago, IL, USA) for the hierarchical cluster analysis. We used the cluster analysis to prepare a dendrogram to describe the relationship of months with limnochemical conditions and of months with the availability of migratory birds. We calculated the Shannon-Wiener diversity index (H'), Pielou's evenness index (J'), Margalef's richness index (D_{MARG}), and Simpson's dominance index (D_{SIMP}) using Dindex software vers. 4.0 (company info).

RESULTS

Wetland plant species along with their abundance status are listed in table 1. The area of open water nearly doubled after manual clearing of the floating water hyacinth (*Eichhornia crassipes*) in Nov. which provided more open water for waterbirds. Physicochemical conditions and the rates of primary production and energy fixation efficiency status of the lake during Oct. to Mar. 2004-2007 are presented in table 2. Seventeen physicochemical factors of the lake water were recorded during the period of bird utilization. The general patterns of nutrient fluctuations (Fig. 1) and primary productivity (Fig. 2) were similar in each of the 3 yr. Months with colder weather had higher total alkalinity, total hardness, and primary productivity. Lower water temperatures also supported higher dissolved oxygen (Fig. 3); however, periods with lower water temperatures had lower amounts of nitrates and silicates.

We found positive ($p < 0.05$) correlations between bird density and gross ($r = 0.69$, $p = 0.001$) and net ($r = 0.63$, $p = 0.005$) primary productivity. Bird density and alkalinity were also positively correlated ($r = 0.66$, $p = 0.003$). We found negative correlations ($p < 0.10$) of bird density with temperature, the amount of plant coverage, nitrate, and phosphate. Fluctuations over time in bird densities along with productivity (GPP) and nutrients (phosphate and nitrate) are depicted in figure 4.

Analysis of limnochemical variables indicated that months with the highest abundances of

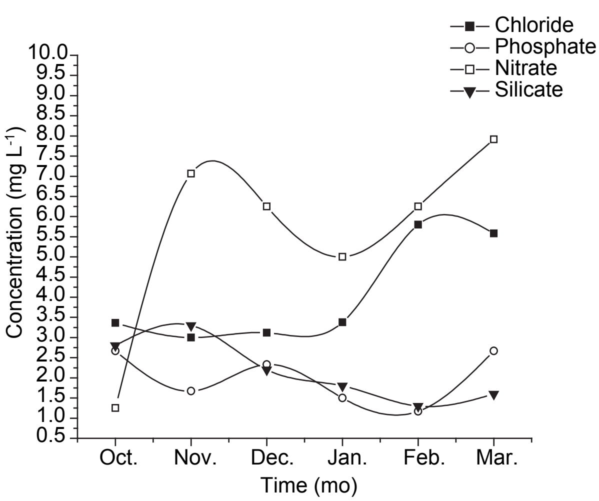

Fig. 1. Seasonal pattern of nutrient fluctuation (mean values of mg/L) of Santragachi Lake, Howrah District, West Bengal, India for the period 2004-2007.

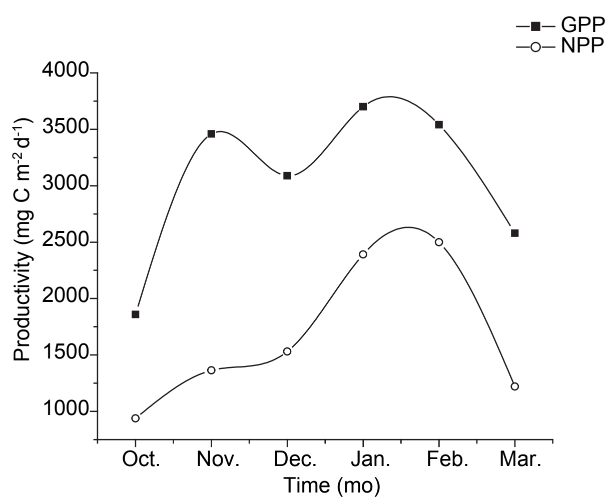

Fig. 2. Pattern of primary productivity (mean gross and net primary productivity in mg C/m^2/d) of Santragachi Lake, Howrah District, West Bengal, India for the period 2004-2007.

Table 1. Important wetland floral composition of Santragachi Lake, Howrah District, West Bengal, India during 2004-2007. The percent vegetative cover of the total surface area is given in parentheses. Abundance status: +, rare presence (< 10%); ++, moderate presence (≥ 10% ≤ 25%); +++, dominant (> 25%)

Type	Common name	Scientific name	Abundance
Submerged	Hydrilla	*Hydrilla verticillata*	+
	Coontail	*Ceratophyllum demersum*	+
Floating	Water hyacinth	*Eichhornia crassipes*	+++
	Water lettuce	*Pistia stratiotes*	++
	Water spinach	*Ipomea aquatica*	++
Emergent	Cattail	*Typha latifolia*	++
	Bulrush	*Scirpus longii*	++
	Reed	*Phragmites communis*	+

migratory waterbirds (Nov.-Mar.) formed 3 close comparable clusters, whereas Oct., which had the lowest number of birds and had different water chemistry, formed a separate cluster. During Nov.-Dec., the initial avian congregation period, and in Mar., the month when most of the avian community had left, the water quality was similar and formed 2 neighboring clusters. Jan.-Feb. with comparable avian abundances and physicochemical environments formed a separate cluster (Fig. 5). The dendrogram differed; however, when the analysis was based solely on the density of migratory birds (Fig. 6). Three distinct clusters of months, Dec.-Jan., Nov. and Feb., and Oct. and Mar. were evident.

Migrants began to congregate in numbers (total bird numbers fluctuated between 3000 and 4000) and with a greater variety of species in Nov. Bird densities reached a peak in Dec. and Jan. and began to decline as birds left the lake in Feb. as depicted in the 2 separate neighboring clusters of months, Dec.-Jan. and Nov.-Feb. These clusters; however, were positioned quite distantly from the 3rd cluster composed of Oct.-Mar., the time of arrival and departure of migratory birds.

We observed 22 species of birds active in and around the water body (Table 3). Lesser Whistling Ducks followed by Northern Pintail (*Anas acuta*),

Table 2. Seasonal changes (mean ± S.D.) in the physicochemical conditions with minimum and maximum values given in parentheses of Santragachi Lake, Howrah District, West Bengal, India, for the years 2004-2007

Parameters	Oct.	Nov.	Dec.
Solar radiation (kal/m^2/d^1)	475.3 ± 60.0 (410.0-528.0)	377.0 ± 14.7 (368.0-394.0)	503.0 ± 170.0 (320.0-656.0)
Air temperature (°C)	30.7 ± 1.7 (29.0-32.4)	28.4 ± 0.5 (28.0-29.0)	26.3 ± 0.4 (26.0-26.8)
Water temperature (°C)	28.8 ± 1.6 (27.0-29.9)	24.4 ± 0.4 (24.0-24.8)	23.0 ± 1.1 (22.0-24.2)
pH	7.5 ± 0.3 (7.3-7.8)	7.4 ± 0.2 (7.2-7.6)	7.7 ± 0.3 (7.4-7.9)
Vegetative coverage (%)	58.3 ± 16.1 (40.0-70.0)	41.7 ± 7.6 (35.0-50.0)	36.7 ± 2.9 (35.0-40.0)
Dissolved O_2 (mg/L)	4.7 ± 1.7 (3.2-6.6)	4.6 ± 2.2 (3.3-7.2)	4.0 ± 0.9 (3.0-4.6)
Total alkalinity (mmol/L $CaCO_3$)	4.1 ± 0.6 (3.8-4.8)	4.7 ± 0.4 (4.3-5.1)	5.7 ± 0.9 (5.0-6.7)
Total acidity (mmol/L $CaCO_3$)	1.3 ± 1.4 (0.3-2.9)	0.2 ± 0.1 (0.1-0.3)	0.1 ± 0.1 (0.1-0.2)
Total hardness (mg/L $CaCO_3$)	125.8 ± 13.4 (110.4-134.9)	178.0 ± 64.9 (135.3-252.7)	214.8 ± 107.8 (138.8-338.2)
Chloride (mg/L)	336.7 ± 150.4 (240.0-510.0)	300.5 ± 53.8 (260.0-361.6)	312.8 ± 11.1 (300.0-320.0)
Phosphate (mg/L)	2.7 ± 0.6 (2.0-3.0)	1.7 ± 1.2 (1.0-3.0)	2.3 ± 1.2 (1.0-3.0)
Nitrate (mg/L)	125.0 ± 43.3 (75.0-150.0)	95.7 ± 43.7 (50.0-137.0)	62.5 ± 33.1 (37.5-100.0)
Silicate (mg/L)	0.3 ± 0.1 (0.2-0.4)	0.3 ± 0.1 (0.2-0.5)	0.2 ± 0.0 (0.2-0.3)
Gross primary productivity (mg C/m^2/d)	1858.0 ± 980.6 (1219.0-2987.0)	3459.3 ± 138.7 (3300.0-3553.0)	3087.3 ± 621.4 (2437.0-3675.0)
Net primary productivity (mg C/m^2/d)	938.3 ± 471.8 (563.0-1468.0)	1364.3 ± 587.6 (900.0-2025.0)	1531.3 ± 483.8 (1196.0-2086.0)
Net-gross ratio (%)	56.5 ± 15.3 (46.2-74.1)	39.2 ± 16.0 (27.3-57.4)	50.9 ± 17.1 (32.5-66.2)
Lindeman efficiency (%)	6.8 ± 2.3 (5.2-9.4)	8.6 ± 0.3 (8.4-8.9)	6.5 ± 3.7 (4.3-10.7)

Cotton Pigmy Goose (*Nettapus coromandelianus*), and Gadwall (*Anas strepera*) were the most common duck species. We also recorded Mallard (*Anas platyrhynchos*), Fulvous Whistling Duck (*Dendrocygna bicolor*), Common Pochard (*Aythya ferina*), Garganey (*Anas querquedula*), and Northern Shoveller (*Anas clypeata*) in small numbers during the study period. White-breasted Waterhen (*Amaurornis phoenicurus*), Common Moorhen (*Gallinula chloropus*), and Bronze-winged Jacana (*Metopidius indicus*) were present throughout the year in low numbers, but their numbers increased in late winter. Common Coot (*Fulica atra*) was only present between Nov. and Jan. Two pairs of Grey (*Ardea cinerea*) and Purple Herons (*A. purpurea*) when present were active between Nov. and Jan. Little Cormorant (*Phalacrocorax niger*) and Pond Heron (*Ardeola grayii*) were present throughout the year, and their highest densities were recorded between Dec. and Mar. A maximum of 6 pairs of Common Sandpipers (*Actitis hypoleucos*) arrived in Dec. in all 3 yr. Also White Wagtails (*Motacilla alba ocularis*) were recorded throughout the study period; however, Citrine Wagtail (*M. citreola citreola*) and Grey Wagtail (*M. cinerea*) were observed only on rare occasions.

When we pooled the data for the 3 yr to calculate the diversity indices (Table 3), we found that the highest Shannon diversity index was in Oct. (0.963), whereas the lowest was in Nov. (0.360); the evenness indices showed a maximum

Table 2. (continued)

Parameters	Jan.	Feb.	Mar.
Solar radiation (kal/m^2/d^1)	583.0 ± 28.6 (560.0-615.0)	557.7 ± 47.6 (512.0-607.0)	640.7 ± 115.0 (513.0-736.0)
Air temperature (°C)	26.3 ± 1.2 (25.0-27.0)	31.0 ± 3.6 (28.0-35.0)	36.2 ± 1.2 (35.1-37.5)
Water temperature (°C)	22.0 ± 1.0 (21.0-23.0)	26.7 ± 3.2 (23.0-29.0)	30.7 ± 0.6 (30.2-31.4)
pH	7.9 ± 0.1 (7.8-8.0)	7.5 ± 0.1 (7.4-7.6)	7.7 ± 0.4 (7.5-8.2)
Vegetative coverage (%)	40.0 ± 5.0 (35.0-45.0)	45.0 ± 13.2 (35.0-60.0)	45.0 ± 13.2 (35.0-60.0)
Dissolved O_2 (mg/L)	4.0 ± 1.1 (2.8-4.9)	3.2 ± 0.2 (3.0-3.4)	1.7 ± 0.4 (1.2-2.0)
Total alkalinity (mmol/L $CaCO_3$)	5.8 ± 0.5 (5.4-6.3)	5.4 ± 1.0 (4.5-6.5)	5.0 ± 0.3 (4.7-5.3)
Total acidity (mmol/L $CaCO_3$)	0.2 ± 0.1 (0.1-0.3)	0.3 ± 0.2 (0.1-0.5)	0.4 ± 0.3 (0.1-0.7)
Total hardness (mg/L $CaCO_3$)	217.7 ± 105.9 (156.6-340.0)	229.6 ± 103.3 (135.3-340.0)	199.4 ± 81.6 (128.2-288.4)
Chloride (mg/L)	338.3 ± 55.8 (275.0-380.0)	580.0 ± 346.4 (380.0-980.0)	558.3 ± 161.7 (460.0-745.0)
Phosphate (mg/L)	1.5 ± 1.3 (0.5-3.0)	1.2 ± 0.8 (0.5-2.0)	2.7 ± 0.6 (2.0-3.0)
Nitrate (mg/L)	50.0 ± 0.0 (50.0-50.0)	62.5 ± 12.5 (50.0-75.0)	79.2 ± 19.1 (62.5-100.0)
Silicate (mg/L)	0.2 ± 0.1 (0.1-0.3)	0.1 ± 0.1 (0.1-0.2)	0.2 ± 0.1 (0.1-0.3)
Gross primary productivity (mg C/m^2/d)	3700.0 ± 180.3 (3500.0-3850.0)	3540.0 ± 226.5 (3300.0-3750.0)	2579.3 ± 79.1 (2488.0-2625.0)
Net primary productivity (mg C/m^2/d)	2391.7 ± 251.7 (2125.0-2625.0)	2500.0 ± 139.2 (2375.0-2650.0)	1220.8 ± 281.3 (937.5-1500.0)
Net-gross ratio (%)	64.5 ± 4.9 (60.7-70.0)	64.1 ± 9.8 (54.7-74.2)	44.2 ± 16.0 (26.3-57.1)
Lindeman efficiency (%)	5.9 ± 0.2 (5.8-6.1)	6.6 ± 3.7 (3.5-10.7)	3.8 ± 0.8 (3.3-4.8)

evenness in Mar. (0.402) and a minimum evenness in Nov. (0.137). The richness index for the pooled data was highest in Oct. (2.107) and lowest in Mar. (1.377); dominance indices showed a maximum value in Nov. (0.884) and a minimum value in Oct. (0.612).

DISCUSSION

Lower water temperatures encourage higher photosynthesis in tropical waters (Wetzel 2001), which was evident in our study. A higher demand of CO_2 for photosynthetic uptake encouraged a higher reverse reaction from CO_3^{2-} to HCO_3^- and ultimately supplied CO_2 for the photosynthetic process. Such reverse reactions created a more highly alkaline condition of the lake water during the colder months which have favorable temperatures for enhanced rates of photosynthesis.

Surface coverage of floating vegetation classically retards phytoplankton gross productivity because shading inhibits photosynthesis. In our study, we found a steady, negative correlation between vegetative cover and waterbird density, and this finding is similar to findings of Ge et al. (2009).

Because the CO_3^{2-} and HCO_3^- alkalinity are the major contributors to total hardness, a positive correlation exists between total hardness and total alkalinity (Arvola et al. 1990). Interestingly in our study we found that total hardness increased with the total bird density, possibly because of the addition of excess divalent cations from bird droppings. The addition of bird guano also increased the total nutrient content of the water, which was rapidly utilized and reflected in higher GPP and in higher secondary production of the lake body. Higher rates of both primary and secondary productivity influenced the rapid uptake of basic nutrients like phosphate, nitrate, and silicate as reflected in the negative correlation with

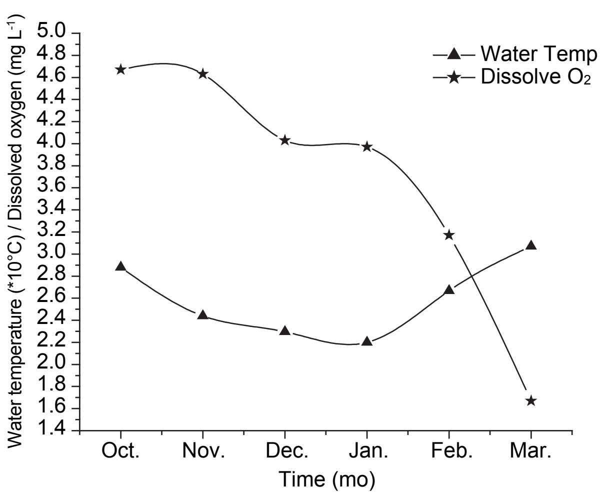

Fig. 3. Relationship between mean dissolved oxygen and mean water temperature of Santragachi Lake, Howrah District, West Bengal, India for the period 2004-2007.

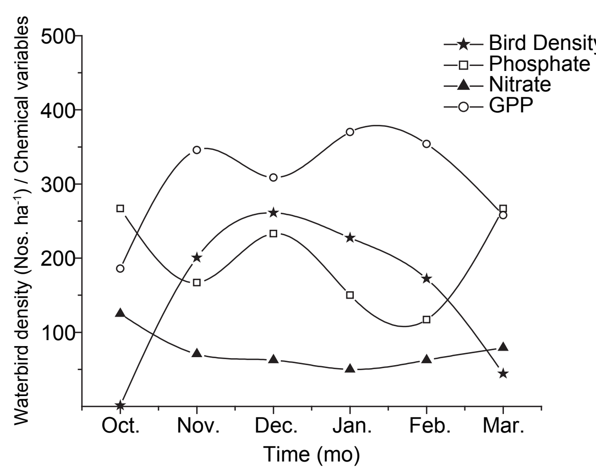

Fig. 4. Relationships of waterbird density (mean number of birds/ha) with nutrients (phosphate and nitrate) and gross primary productivity of Santragachi Lake, Howrah District, West Bengal, India for the period 2004-2007.

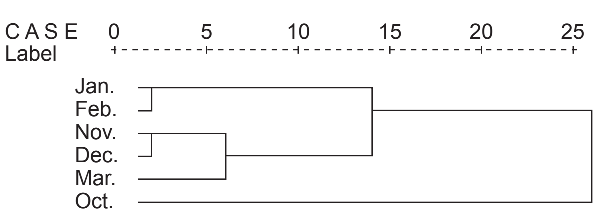

Fig. 5. Hierarchical cluster analysis of the limnochemical conditions (physicochemical parameters) by month at Santragachi Lake, Howrah District, West Bengal, India for the period 2004-2007. The dendrogram was constructed using average linkages (between groups).

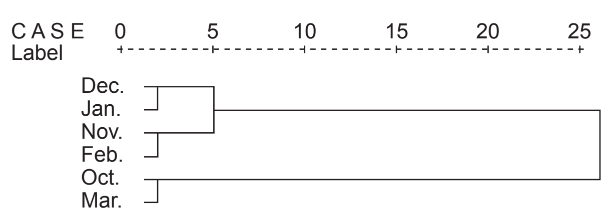

Fig. 6. Hierarchical cluster analysis of migratory birds (both density and diversity) by month of availability on Santragachi Lake, Howrah District, West Bengal, India for the period 2004-2007. The dendrogram was constructed using average linkages (between groups).

both GPP and higher avian density in the present study (Fig. 4). Similar observations were made by Manny et al. (1994) and Unckless and Makarewicz (2007) who determined the amount of nutrient additions by waterbirds to lakes and reservoirs. They observed that such nutrient additions positively influenced the primary productivity of the waters.

Wetzel (2001) reported the influence of pH perturbation on PO_4^{3-} uptake. Algal species exhibit a higher uptake of P within a distinct range of pH. pH alters the rates of PO_4^{3-} absorption by directly affecting the activity of enzymes and the permeability of cell membranes, and by changing the degree of PO_4^{3-} ionization. Longcore et al. (2006) reported that a water pH in the alkaline range supported higher macroinvertebrates and thereby attracted more ducks to the water bodies under investigation. The average water pH was in a slightly alkaline range (7.2-8.2) at our study site during the period of waterbird use, but we did not sample for invertebrates.

Limnochemically, Nov. and Dec. were almost identical and were similar to Mar., Jan., and Feb.;

Table 3. Seasonal changes in the migratory waterfowl densities (mean number of birds/ha) ± standard deviation (SD) along with diversity indices of Santragachi Lake, Howrah District, West Bengal, India during 2004-007. The minimum and maximum values of the diversity indices recorded for individual months during the total study period are given in parentheses. The ALPHA CODE is used to designate the common name of birds following Bird Banding Laboratory system used in the US. NR, not recorded

Common Name	Scientific name	Oct.	Nov.	Dec.
NOPI	*Anas acuta*	0.05 ± 0.09	0.19 ± 0.11	11.40 ± 14.82
MALL	*Anas platyrhynchos*	NR	NR	NR
LEWD	*Dendrocygna javanica*	11.28 ± 10.13	134.28 ± 77.70	217.56 ± 27.55
FUWD	*Dendrocygna bicolor*	NR	NR	NR
GADW	*Anas strepera*	0.10 ± 0.17	0.71 ± 0.42	4.84 ± 6.21
GARG	*Anas querquedula*	0.10 ± 0.17	NR	0.16 ± 0.27
NOSH	*Anas clypeata*	NR	NR	0.32 ± 0.17
COPG	*Nettapus coromandelianus*	0.10 ± 0.17	0.70 ± 1.21	7.66 ± 12.86
COPO	*Aythya ferina*	0.07 ± 0.12	NR	0.07 ± 0.12
WBWA	*Amaurornis phoenicurus*	0.35 ± 0.47	0.68 ± 0.65	0.57 ± 0.46
COMO	*Gallinula chloropus*	NR	0.21 ± 0.08	0.80 ± 0.44
BRWJ	*Metopidius indicus*	0.26 ± 0.08	1.22 ± 0.53	1.43 ± 0.49
COCO	*Fulica atra*	NR	0.21 ± 0.24	0.37 ± 0.35
LICO	*Phalacrocorax niger*	1.15 ± 0.40	1.41 ± 0.47	4.13 ± 4.31
ASOP	*Anastomus osciatans*	NR	0.07 ± 0.12	NR
POHE	*Ardeola grayii*	0.34 ± 0.32	0.76 ± 0.65	2.29 ± 3.56
GRHE	*Ardea cinerea*	NR	0.07 ± 0.12	0.07 ± 0.12
PUHE	*Ardea purpurea*	NR	NR	0.07 ± 0.12
COSA	*Actitis hypoleucos*	NR	NR	0.32 ± 0.17
WHWA	*Motacilla alba ocularis*	0.31 ± 0.54	0.32 ± 0.28	0.43 ± 0.10
CIWA	*Motacilla citreola citreola*	NR	NR	NR
GRWA	*Motacilla cinerea*	0.03 ± 0.05	NR	NR
Total Birds		14.14 ± 11.25	140.82 ± 74.57	252.58 ± 34.02
Shannon-Wiener diversity index		0.963 (0.69-1.24)	0.360 (0.16-0.85)	0.654 (0.24-1.14)
Pielou’s evenness index		0.388 (0.33-0.77)	0.137 (0.07-0.34)	0.242 (0.09-0.42)
Margalef’s richness index		2.107 (1.10-1.36)	1.783 (1.02-1.67)	1.733 (1.36-1.71)
Simpson’s dominance index		0.612 (0.33-0.73)	0.884 (0.68-0.95)	0.749 (0.51-0.93)

however, were also similar indicating effects of migrant waterbird densities on limnochemical features of the study site (Fig. 5).

Monthly and annual variations in species dominance, diversity, evenness, and richness of the waterbird community seemed confounded. The Shannon-Wiener species diversity index (*H'*), based mainly on proportional species abundances, usually reached maximum values during the early and late phases of the annual waterbird congregation. Pielou's index of evenness (*J'*) was also highest in months when the highest *H'* value was noted. Simpson's dominance index (D_{SIMP}), which is also based on proportional abundances like *H'*, revealed contrasting values to those for *H'*. Maximum D_{SIMP} values occurred in the month with the minimum diversity as reflected by the *H'* value.

Although both Shannon measures and Simpson's index consider the proportional abundances of species, *H'* is more sensitive to rare species, whereas D_{SIMP} puts greater emphasis on common species. Therefore, these indices point out the occurrence of many rare species in the early and late periods of waterbird aggregation reflecting lower dominances, while the reverse situation is evident in the period of peak aggregation. Margalef's richness index (D_{MARG}), which considers both abundances and species numbers, also indicated that maximum values were associated with the period of peak aggregation, whereas minimum values were evident in the early and late aggregation phases.

Table 3. (continued)

Common Name	Scientific name	Jan.	Feb.	Mar.
NOPI	*Anas acuta*	15.03 ± 10.46	6.89 ± 9.63	0.20 ± 0.18
MALL	*Anas platyrhynchos*	0.03 ± 0.06	NR	NR
LEWD	*Dendrocygna javanica*	194.49 ± 9.96	163.56 ± 4.52	42.31 ± 27.17
FUWD	*Dendrocygna bicolor*	0.03 ± 0.06	NR	NR
GADW	*Anas strepera*	5.70 ± 3.73	2.73 ± 3.19	0.13 ± 0.23
GARG	*Anas querquedula*	0.27 ± 0.06	0.10 ± 0.17	NR
NOSH	*Anas clypeata*	0.94 ± 0.96	1.06 ± 0.93	NR
COPG	*Nettapus coromandelianus*	9.42 ± 7.64	0.84 ± 0.96	1.38 ± 1.88
COPO	*Aythya ferina*	NR	NR	NR
WBWA	*Amaurornis phoenicurus*	0.56 ± 0.56	1.74 ± 2.74	1.23 ± 1.79
COMO	*Gallinula chloropus*	1.64 ± 0.63	1.13 ± 0.68	1.48 ± 1.15
BRWJ	*Metopidius indicus*	1.44 ± 0.48	2.66 ± 0.72	0.99 ± 0.39
COCO	*Fulica atra*	0.64 ± 0.39	0.53 ± 0.92	NR
LICO	*Phalacrocorax niger*	1.36 ± 0.54	2.70 ± 0.93	3.49 ± 1.91
ASOP	*Anastomus osciatans*	0.03 ± 0.06	NR	NR
POHE	*Ardeola grayii*	0.52 ± 0.16	1.85 ± 0.57	2.21 ± 1. 73
GRHE	*Ardea cinerea*	0.10 ± 0.17	0.07 ± 0.12	NR
PUHE	*Ardea purpurea*	0.07 ± 0.12	NR	NR
COSA	*Actitis hypoleucos*	0.57 ± 0.72	0.43 ± 0.75	0.23 ± 0.40
WHWA	*Motacilla alba ocularis*	0.31 ± 0.01	0.27 ± 0.20	0.07 ± 0.12
CIWA	*Motacilla citreola citreola*	0.11 ± 0.09	0.07 ± 0.12	NR
GRWA	*Motacilla cinerea*	NR	NR	NR
Total Birds		233.27 ± 10.51	186.63 ± 19.26	54.06 ± 29.46
Shannon-Wiener diversity index		0.723 (0.59-0.98)	0.616 (0.39-.90)	0.926 (0.74-1.01)
Pielou's evenness index		0.274 (0.22-0.33)	0.248 (0.16-0.33)	0.402 (0.32-0.52)
Margalef's richness index		1.626 (1.76-2.24)	1.415 (1.29-1.78)	1.377 (0.95-1.28)
Simpson's dominance index		0.708 (0.57-0.78)	0.777 (0.64-0.87)	0.624 (0.54-0.71)

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