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RESEARCH ARTICLE

Eco-spatial and Temporal Variation in Waterbirds Composition and their relationship with Habitat Characteristics of Urban Lakes of Bengaluru city, India

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Abstract

Eco-spatial and temporal variation in the occurrence, abundance, density, diversity and community composition of aquatic birds in relation to the characteristics of lakes was studied from February 2008 to January 2010 in Bengaluru city. The species diversity, evenness, and richness of waterbird species were varied among different lakes. Also, the indices of various waterbird populations at different lakes between two years were significantly different (paired Student's t-test at $P<0.05$). The frequency of occurrence of Bubulcus ibis was 100% percent among the recorded 42 waterbird species. Among the studied lakes, the mean population density of waterbirds per hectare was highest in Lalbagh Botanical Garden lake, whereas it was least at Thippagondanahalli lake. Although the occurrence of number of waterbird species recorded between the different seasons varied, it was not significantly ($P>0.05$). The decrease in an anthropogenic disturbances and an increasing water depth of lakes show positive impact on the aquatic avian density in the urban lakes. The present study clearly brought out the need for preparing and implementing the specific conservation plans for urban lake ecosystem.

INTRODUCTION

Birds are the recognized biodiversity indicator species of inhabited areas in an environment (Blair, 1999; Gregory, 2006). Bird surveys are among the most widely employed biodiversity inventories and serve as the basis for an increasing proportion of pure and ecological research (Watson, 2003). Birds are sensitive indicators of pollutions in both terrestrial and aquatic ecosystems (Gaston, 1975; Hardy et al., 1987; Gregory et al., 2008). Waterbirds are an excellent indicator of water quality and help to measure the biodiversity. Wetland birds are the indicators of wetland function (Weller, 1999). Studies on biodiversity could be useful to understand fluctuations in ecosystem functioning which help in prioritization the areas of conservation (Myers et al., 2000; Franco et al., 2009; Ma et al., 2010). The estimation of local densities of avifauna helps to understand the abundances of various species of other organisms (Turner, 2003). One of the major priorities in conservation of animals is monitoring their populations to find methods for their long term survival (Caughley, 1982).

Wetlands are the most productive and biologically diverse but very fragile ecosystems (Gibbs, 1993). Wetlands and waterbirds are inseparable elements and support a rich array of waterbird communities (Grimmett and Inskipp, 2007). Waterbirds are an important component of the most of the wetland ecosystems as they occupy several trophic levels in the food web of wetland nutrient cycles (Kushlan, 1992). Activities of waterbirds are considered as an indicator of the quality of the wetland ecosystem and form the terminal links in many aquatic food chains, and as a result they reflect changes originating in several different ecosystem components (Custer and Osborne, 1977). Wetlands are important bird habitats (Maltby and Turner, 1983), and waterbirds play a crucial role in energy fluxes between terrestrial and aquatic food chains (Moreira, 1997; Gregory et al., 2008).

Lakes in any city serve as balancing reservoirs for sustaining native flora and fauna (Grimmett and Inskipp, 2007; Surana et al., 2007). As lakes in the city region attract a large number of aquatic bird species which include both migratory and resident birds, these are ideal locations for bird watchers and naturalists to undertake avifaunal studies (Grimmett and Inskipp, 2007).

Urbanization is a universal phenomenon and its negative effects on biodiversity, especially in terms of irrecoverable habitat fragmentation and loss, extermination of native and migratory species are slowly being understood (Mckinney, 2002; Faeth et al., 2005). Waterbirds exhibit different behavioural associations with altered and unaltered habitat in an urban riparian system. Effects of urbanized habitat affect the behaviour of waterbirds in an urban setting (Donaldson et al., 2007). Owing to fast urbanization native species tend to become rare and are restricted to sites that have escaped high intensity development (Godefroid, 2001).

The biodiversity indices, i.e. the Shannon-Wiener's and the Fisher's alpha diversity, species evenness and Margalef's species richness indices of waterbirds are calculated for two years from 2008-2010 and compared for the benefit of ornithologists, naturalists, and environmentalists or ecologists to facilitate the periodical monitoring of diversity index because any change in indices would indicate either a new addition of waterbirds or absence in these urban lakes or a major environmental or ecological impact (Peet, 1974; Marja and Pitkanen, 1999; Farago´ and Hangya, 2012).

Bengaluru city is the fifth largest and the second fast developing city in India (Sudhira et al., 2007). It is also known as the Garden City of India because of its many beautiful parks, lakes, gardens and natural vegetations (Issar, 1994; Nair, 2005). Various developmental activities, i.e. construction of buildings, flyovers, and widening of roads, have seriously affected many urban lakes and some lakes are being converted into human dwellings in the Bengaluru region. Like many other Indian metropolitan cities, industrial and automobile pollutions and habitat destruction are common features in Bengaluru city as well (Sudhira et al., 2007). Despite the fast growth, the city has several small to large lakes, which are the verdant areas for various species of waterbirds. The State Wildlife Department of Bengaluru city offers a poor protection to avifauna of the city.

Although aquatic birds in some lakes of Bengaluru have been recorded (Manjunath et al., 2005), their composition, abundance and diversity have not been thoroughly studied in relation to anthropogenic disturbances and characteristics of major lakes. Hence, we evaluated aquatic avian composition in relation to habitat characteristics of urban lakes at different seasons, with a view to generate data which could be used to evolve better management and conservation methods for various waterbird species in Bengaluru lakes.

MATERIALS AND METHODS

Study lakes

Bengaluru is the capital of Karnataka State, which is located in the heart of South Deccan of Peninsular India. The Bengaluru region lies between latitudinal parallels 12º 39' -13º 18' N and longitudinal parallels 77º22'-77º52'E at an elevation range 839-962 m above sea level (http://www.ces.iisc.ernet.in/energy/wetlands/sarea.html). The city covers an area of 2191 km^2 (http://ces.iisc.ernet.in/energy/TR86/intro.html) and has a population of about 9 million (Census of India, 2011). It is well known for its equable and salubrious climate. In Bengaluru, average maximum and minimum temperature is 36 and 14º C respectively, and humidity range is 35-80%. There are three main seasons: winter (December to February), summer (March to May) and the monsoon (June to November, with rainfall averaging 800mm). The dominant vegetation of Bengaluru region is dry deciduous forests and thorny scrub, with patches of moist deciduous forests along the streams (Nayaka et al., 2003).

Bengaluru city is expanding, but several lakes in the city are highly variable and retain their status as aquatic avian habitats. Fifteen study lakes were chosen based on their locations, water level and waterbird populations. The distance of the study lakes from the Central railway station (CRS) are as follows: Anekal (AKL – 38 km), Chandapura (CPL – 26 km), Gottigere (GGL – 17 km), Hebbala (HBL – 08 km), Hesaraghatta (HGL – 28 km), Hoskote (HKL – 25 km), Jakkuru (JKL – 12 km), Kengeri (KGL – 18 km), Lalbagh Botanical Garden lake (LLBG – 05 km), Medahalli (ML – 18 km), Nelamangala (NML – 28 km), Somanahalli (SML – 22 km), Thippagondanahalli (TGHL – 40 km), Ulsooru (UL – 06 km) and Varthuru (VL – 34 km) lakes (Fig. 1).

Waterbird surveys and sampling

The point counting of waterbirds was made within a visible radius for two to three minutes as followed by several workers (Gaston, 1975; Blondel et al., 1981; Beehler et al., 1995; Bibby et al., 2000; Froneman et al., 2001; Kaul and Howman, 1992; Turner, 2003; Urfi et al., 2005; Urfi, 2006). Waterbirds were counted at their point of first detection and care was taken to ensure that individual birds were not counted twice. Counting of waterbirds was made in the morning between 07:30 and 10:30 hr or in the afternoon between 15:00 and 18:00 hr, depending on the light conditions (Namgail et al., 2009). Recordings were not made at the time of heavy rains. Surveys were conducted once a fortnight in the identified lakes during February 2008 - January 2010. As well, regular field observations were also made on the nests, nesting sites, foraging and food sources. Observations were also made on the natural predation of waterbirds.

The data recorded in each survey, from different habitat types was analyzed separately for assessing the relative abundance of waterbirds on the basis of the percent frequency (encounter rates) of sightings as followed by MacKinnon and Philipps (1993) as: very common – sighted 19-24 times, common – sighted 13-18 times, uncommon – 7-12 times, and rare – sighted 1-6 times out of 24 visits during two years. Residential status of waterbirds was recorded and has been assigned strictly with reference to the study area on the basis of presence or absence method by following Ali (2012). Moreover, the diet guild of waterbirds has been assigned to each species by following Ali (2012). A check list of species was prepared by following Grimmett and Inskipp (2007) and Ali (2012). The nomenclature and taxonomy of aquatic birds was assigned according to BirdLife International (2013). The number of aquatic birds of various species was recorded in a data sheet at each sampling lake on each census day. Data generated on aquatic avifauna at each study lake were directly used to estimate the biodiversity indices.

Vegetation survey, lake characteristics and anthropogenic disturbances

Bank vegetations along the urban lakes was examined with 1m^2 quadrants (based on transect belt of 100m from the edges) placed at 50m intervals along parallel transects at four points (Mukherjee et al., 2002). At each study lake, various aquatic vegetation types were identified up to the species level (Ramaswamy and Razi, 1973) and also the number of weed species was determined. Lake characteristics, i.e. lake area, water and weed coverage, water depth, a number of islands, and tree density around the lakes were evaluated as effective tools to assess the abundance of aquatic birds in Bengaluru lakes.

Habitat impact factors, i.e. roads around the lakes, traffic, usage of lakes for various purposes of human needs for example washing of clothes and utensils, fishing by local boats, refreshing, bathing, swimming, boating and; inlet of domestic sewage, encroachment of lakes for construction, and housing were evaluated in relation to the populations of waterbirds in the different lakes of Bengaluru city.

Anthropogenic disturbances were given scores of 1, 2 or 3 based on the factors affecting the activities of waterbird communities where the surveys conducted in the urban lakes. A score of '3' represented a maximum disturbance, 2 as moderate disturbance; disturbance by visitors was considered to have the least negative effect on waterbird communities, and was scored 1.

$$\text{Disturbance level} = \sum_{i=1}^{3} \text{score}_i * \text{total number of incidents of activity } i/\text{ observer effort}$$

where i was the type of activity (Shenoy et al., 2006).

We defined visit frequency as the number of visits by waterbird communities to the stretch of bank, per waterbird community site per unit observer effort. The number of waterbird community-sites in a stretch could be a function of habitat quality rather than anthropogenic disturbance. To control for the habitat effect while comparing visit frequency with disturbance index, the visit frequency was calculated by averaging the number of waterbird visits across all sites in the stretch of the lakes.

Visit frequency = total number of visits by waterbirds/number of waterbird community sites/observer effort.

Data analyses

The population density is used more frequently than abundance owing for scaled relative to area and is more useful for comparisons among lakes (Verner, 1985). The number and density of waterbird species in each lake were estimated (Acharya and Vijayan, 2010). Density was calculated based on Reynolds et al. (1980); $D = n*10000/ \pi r^2 C$, where D = bird density (numbers/ha), n = total number of birds observed in all counts within the specific radius, r = specific radius (m), C = total number of counts conducted and $\pi = 3.14$.

The Shannon-Wiener's diversity index (H') is the commonly used index to characterize species diversity in a community. Diversity index of different species of avian populations were estimated according to Shannon and Wiener's (1949) diversity index using the following formula:

$$H' = - \sum_{i=1}^{S} [(ni/n) \times \ln (ni/n)]$$

Where, ni = Number of individuals belonging to the i^{th} species

n = Total number of individuals in the sample.

The diversity is characterized by the number of individuals represented by each species/category in a sample. This diversity index gives more importance to rare species in a community. H' varies between 0 and $\log_2 S$. H' close to 0 indicates low diversity, where a value close to $\log_2 S$ indicates high diversity. Higher index value represents high species diversity and clearly indicates a healthy environment. The value of Shannon diversity is usually found to fall between 1.5 and 3.5 and rarely it surpasses 4.5. The quantity (ni/n) is the proportion of individuals found in the i^{th} species. A higher value of H' indicates high species diversity in a sample (Magurran, 2004).

Fisher's alpha diversity is a diversity index, defined implicitly by the formula (Fisher et al., 1943):

$$S = a * \ln (1+ n/a)$$

Where, S = is the number of taxa,

n = is the number of individuals and

a = is the Fisher's alpha.

It is estimated by an iterative procedure that may take an appreciable amount of time with large data sets (Kempton and Taylor, 1976). It is a useful index provides the ratio of the total number of individuals to the species number (N/S or N:S) exceeds 1.44 (Hayek and Buzas, 1997). In many situations, alpha is approximately equal to the number of species represented by a single individual. The value of alpha is independent of sample size when the number of individuals in the sample exceeds 1000. Therefore, this index is a very useful tool to understand the extent of relative differences in diversity among the regions, even when sample size is relatively small.

Evenness, a measure of the equitability of the abundance of the observed taxa, is calculated using the method followed by Buzas and Gibson's evenness index (1969), Sheldon (1969) and Harper (1999). This index measures the evenness of species abundance, is complementary to the diversity index concept and it indicates how the individuals of various species are distributed in a community (Harper, 1999). Evenness values attempt to quantify the unequal representation of species against a hypothetical community in which species are equally common. Evenness ranges from zero to one. When evenness is close to zero, it indicates that most of the individuals belong to one or a few species/categories, whereas close to one indicates that each species consists of almost same number of individuals (Magurran, 2004). The evenness of species (E2) was estimated using the following formula:

$$E2 = e^H / S \qquad (0 < E < 1)$$

Where, e = is the natural logarithm base

H' = Shannon-Wiener diversity index

S = Number of species

The number of species in a region or in an observation represents species richness, which is the simplest and most useful measure of species diversity. The simplest form of richness is the Hill's number 0 (N_0) which is the total number of species (S) in a given habitat. Species richness was estimated based on Margalef's richness index (1958) using the following formula:

$$R1 = (S-1) / \ln (n)$$

Where, S = is the number of species in a community

n = is the total number of individuals observed

Thus, Shannon-Wiener's, and the Fisher's alpha diversity, species evenness and Margalef's species richness indices of waterbirds were evaluated using PAST version 1.60 software (Hammer et al., 2001).

Incidence (encounter rate) is the number of times a species was encountered, that is, the number of intervals in which it was recorded divided by the total number of sampling intervals (Dawson, 1981). Spearman's rank correlation was applied to determine the relationship between percent frequency and percent abundance as well as lake area and population density of waterbirds. The statistical difference in diversity indices of waterbird population between the two years was analyzed by Student's paired t-test at each sampling lake (SPSS Inc., 2008). Further, the difference in the number of waterbird species among different seasons were statistically analyzed utilizing one way ANOVA (SPSS Inc., 2008). Bray-Curtis Cluster Analysis (Ward's method) was carried out to create a dendrogram to assess the similarity in the populations of waterbirds and weed coverage among the study lakes using PAST version 1.60 software (Hammer et al., 2001). The characteristics of each lake and anthropogenic disturbances were analyzed with waterbird density using Pearson's linear Correlation Analysis (SPSS Inc., 2008) and Principal Components Analysis (Hammer et al., 2001). The structure of waterbird assemblages and their habitat selection were studied by Principal Components Analysis, which helps to reduce a large number of species or ecological factors into a few meaningful dimensions for easy interpretation (Singh, 2010).

RESULTS

Waterbird communities of different lakes

The occurrence and distribution of different species of aquatic birds recorded at the study lakes of Bengaluru city are given in Table 1 and 2. The forty two species of waterbirds under 32 genera belonging to 15 families were recorded during the study period. Among them 22 species were common in all the study lakes (Table 2). The number of waterbird species was highest (40) at Lalbagh Botanical Garden lake and lowest (26) in Ulsooru lake (Table 2).

The percentage of frequency of occurrence of each waterbird species is given in Table 1. Among recorded waterbird species, the frequency of occurrence of *Bubulcus ibis* was 100%, whereas it was least (1.94%) with *Dendrocygna javanica* (Table 1). Based on the percentage of frequency of occurrence of waterbirds, six species were considered as uncommon, eight species as common, 12 as rare and 16 species as very common. Of the various waterbird species, *Anhinga melanogaster*, *Pelecanus philippensis* and *Mycteria leucocephala* are near threatened species and rest of the 39 species are the least concerned.

A maximum number (10 species) of aquatic bird species were belonging to carnivores/insectivores group (Table 1). Similarly, resident migrants were formed the largest group with 20 species (Table 1). Ardeidae with eight species is the most dominant family, followed by Anatidae (seven), Rallidae and Motacillidae (four each), Alcedinidae (three), Scolopacidae, Jacanidae, Charadriidae, Phalacrocoracidae, Pelecanidae and Ciconiidae (two each), and Recurvirostridae, Laridae, Podicipedidae and Anhingidae (one sp., each).

Waterbird diversity and richness among different lakes

The mean population density of waterbirds (35.23) per hectare was highest at Lalbagh Botanical Garden lake and lowest (0.52) in Thippagondanahalli lake (Table 3). The Shannon-Wiener's diversity (2.83 to 3.15) of waterbirds was highest at Lalbagh Botanical Garden lake and least (2.14 to 2.79) in Medahalli lake (Table 3). The diversity indices of various waterbird populations at different lakes between two years (2008-2010) were significantly different ($P<0.05$) only in seven lakes.

The Fisher's alpha diversity (5.15 to 6.64) of waterbirds was highest at Lalbagh Botanical Garden lake and lowest (3.76 to 5.55) in Medahalli lake (Table 3). Further, the diversity indices of various bird populations at different lakes between two years (2008-2010) were significantly different ($P<0.05$) only in six lakes.

The Margalef's species richness was highest in Lalbagh Botanical Garden lake (3.50 to 4.51) and lowest in Ulsooru lake (2.59 to 3.60) (Table 3). The richness indices of various waterbird populations at different lakes between two years (2008-2010) were significantly different ($P<0.05$) only in eight lakes.

The species evenness index was highest in Somanahalli lake (0.85 to 0.83) and lowest in Medahalli lake (0.40 to 0.55) (Table 3). The evenness indices of various waterbird populations at different lakes between two years (2008-2010) were significantly different ($P<0.05$) only in seven lakes.

There was a significant positive correlation between the abundance and frequency of aquatic bird species in the lakes ($r_s = 0.938$, $P<0.01$, $n = 40$). Similarly, there was a significant positive correlation between the density of aquatic birds and lake area ($r_s = 0.625$, $P<0.05$, $n = 13$).

Seasonal fluctuations of waterbird species

The number of waterbird species observed in summer was 27 (64.29% of total species), which increased up to 34 (80.95%) in monsoon and 38 (90.48%) in winter. However, 22 species (52.38%) were common throughout the year in the study lakes of Bengaluru city. The occurrence of number of waterbird species between seasons was not significantly different (one way Anova, $F_{2, 23} = 3.459$, $P>0.05$) (Fig. 2).

Aquatic weed assemblages in different lakes

Thirty two species of aquatic plants under 27 genera belonging to 18 families were recorded in the study lakes. Of which, two species, *Ipomea aquatica* and *Ricinus communis* were common to all the study lakes (Table 4). The highest number (31) of aquatic weed species was recorded at Gottigere lake, and lowest (11 each) at Thippagondanahalli and Ulsooru lake.

Lake characteristics and anthropogenic disturbances

Thippagondanahalli has the largest lake area (897.43 ha.) and Ulsooru lake was the smallest one (11.00 ha) (Table 5). The maximum water coverage area was observed at Thippagondanahalli lake (92.29% of total lake area), and minimum in Gottigere lake (11.91%). Similarly, the maximum weed coverage was observed at Gottigere (89.08%), and minimum in Thippagondanahalli lake (5.0%). The highest water level was recorded at Thippagondanahalli (8.76) lake, and lowest at Hoskote lake (0.72). The tree density and number of islands was highest at Lalbagh Botanical Garden lake. The highest number of aquatic bird nests (70) was found at Kengeri, and lowest (5) at Ulsooru lake. The highest number of fishing boats (8) was used at Varthuru lake, and lowest (2 each) at Gottigere, Hesaraghatta, Hoskote and Nelamangala lakes.

The examination of lake characteristics within Principal Component Analysis indicates that waterbird density showed significant positive correlation with the lake area, the number of islands, water coverage, water depth, tree density, fishing boats, the number of nests, and the number of weed species at Anekal, Chandapura, Hebbala, Hesaraghatta, Jakkuru, Kengeri, Lalbagh Botanical Garden, Medahalli, Somanahalli, Thippagondanahalli, Ulsooru and Varthuru lakes (Fig. 3). Similarly, waterbird density exhibited significant negative correlation only with weed coverage at Gottigere, Hoskote, and Nelamangala lakes. The cumulative percentage of variance explained by the first four PC axes was 83.597%, with the first axis accounting for 34.195% of the variation, and second axis explaining a further 20.959% with close correlation ($r = -0.0121$, $P \leq 0.01$).

Furthermore, the population density of waterbird communities showed significant negative correlation with the lake area ($P<0.01$) and positive correlation with the number of islands ($P<0.01$) in Bengaluru lakes. In contrast, the population densities of waterbird communities showed negative correlation with the water coverage and water depth of lakes with irrespective of the number of weed species and weed coverage (Table 6).

Dendrogram showing similarity in the mean population density of waterbirds and weed coverage of different lakes with three major clusters showed significant negative affinities. Hoskote, Nelamangala and Gottigere lakes accounted for less to moderate (1.28, 8.50 and 21.51 respectively) population density of waterbirds seen/ha. with the highest weed coverage (81.50-89.08%) were belonging to the first cluster, whereas Thippagondanahalli lake without weed coverage alone form the second cluster with a less population population density of waterbirds (0.52). While the rest of the eleven lakes with moderate (4.20) to maximum (35.23) population density of waterbirds seen/ha. with the moderate to low weed coverage (15.00-47.71%) were formed another cluster (Fig. 4).

Lalbagh Botanical Garden Lake representing fewer disturbances from the anthropogenic factors with moderate water depth, contributing to a maximum density of waterbird fauna (Fig. 5).

The activities of terrestrial birds, i.e. *Corvus splendens* and *Corvus macrorhynchos, Acridotheres tristis* and *Acridotheres fuscus*, and *Milvus migrans* and *Haliastur indicus* around the study lakes were not found interfering with the activities of aquatic birds. But, the kites were the competitors of waterbird communities in fish capturing in the lakes.

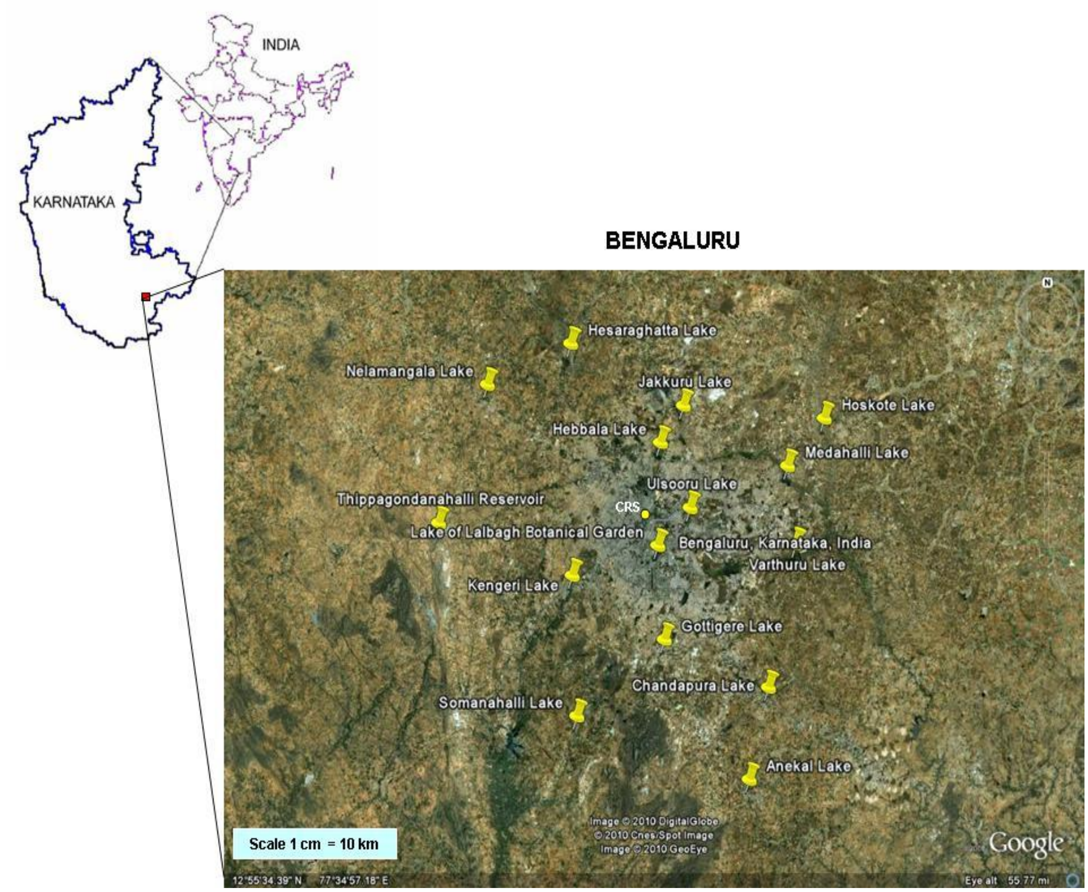

Figure-1: Map of Bengaluru showing locations of the study lakes [Courtesy: www.GoogleEarth.com].

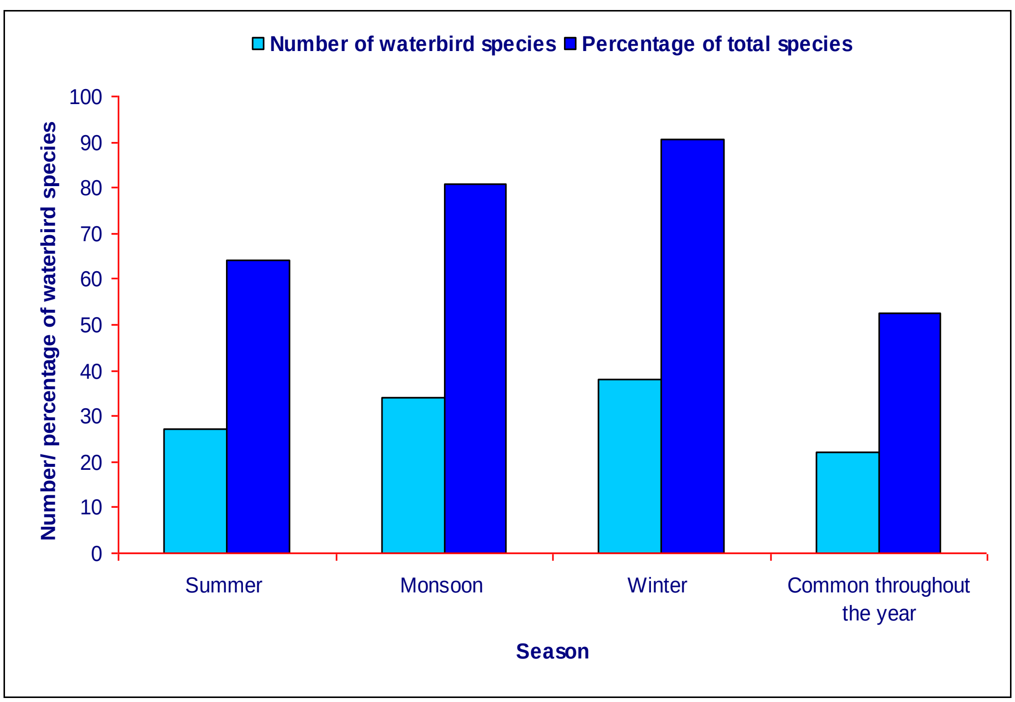

Figure-2: Seasonal variation of aquatic birds in different lakes of Bengaluru city.

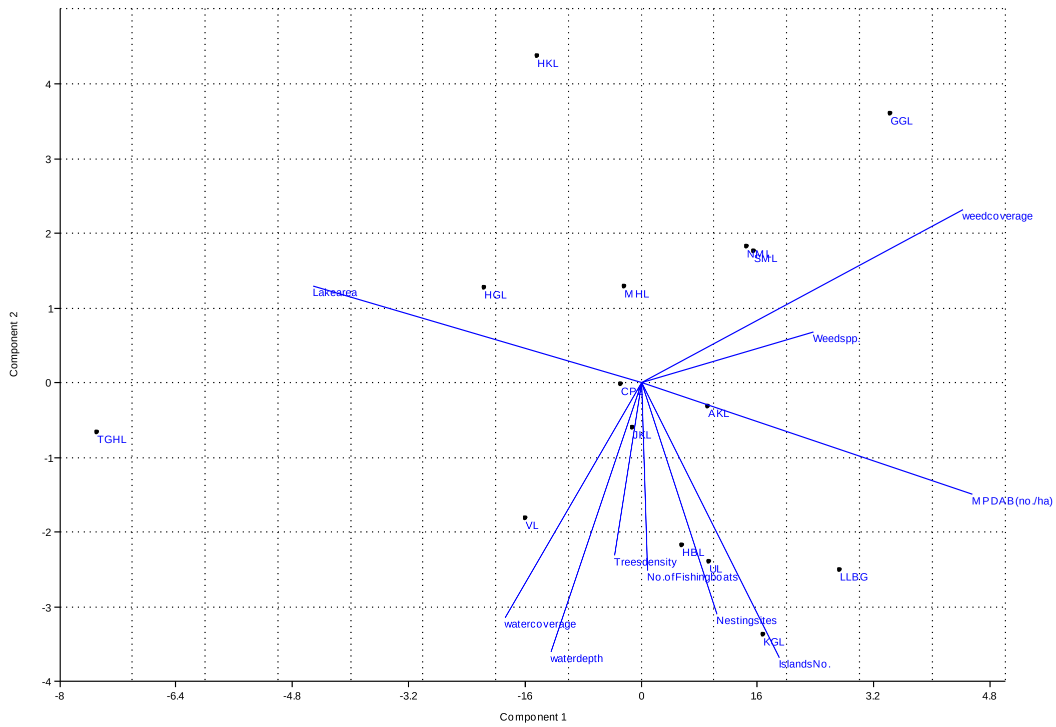

Figure-3: Principal component analysis (PCA) of waterbird density in relation to habitat factors in different lakes of Bengaluru city (for abbreviations of lakes, please see text).

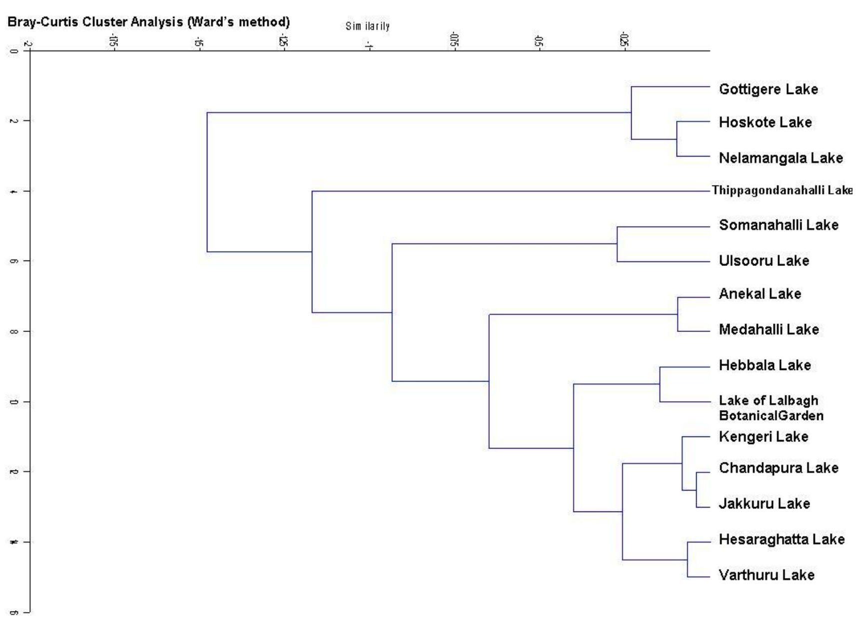

Figure-4: Dendrogram showing similarity based on the mean population density of waterbirds in different lakes of Bengaluru city.

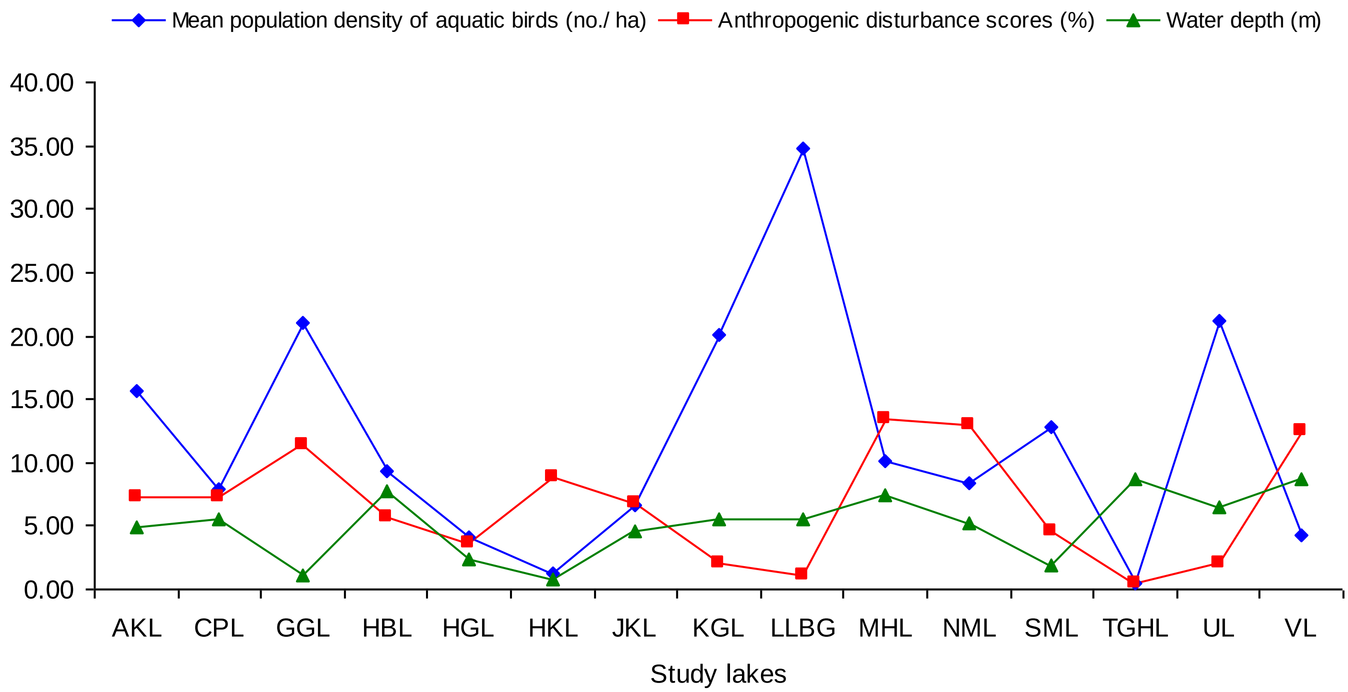

Figure-5: Waterbird density in relation to water depth and anthropogenic disturbances along the urban lakes of Bengaluru city (for abbreviations of lakes, please see text).

Table-1: Encounter rates, occurrence, residential and conservation status, and the diet type of aquatic birds in various lakes of Bengaluru city

Aquatic bird species	Encounter Rate (%)	Occurrence Status	Residential Status*	Diet*	IUCN status♦	Ranking order
Bubulcus ibis	100.00	Vc	Resident Migrant	Carnivore/Insectivore	Lc	1
Anas acuta	99.72	Vc	Migrant	Herbivore	Lc	2
Motacilla madaraspatensis	99.17	Vc	Resident	Insectivore	Lc	3
Egretta garzetta	98.61	Vc	Resident	Carnivorous	Lc	4
Phalacrocorax niger	97.22	Vc	Resident Migrant	Piscivore	Lc	5
Halcyon smyrnensis	96.11	Vc	Resident	Carnivore/Insectivore	Lc	6
Ardeola grayii	94.17	Vc	Resident	Carnivore/Insectivore	Lc	7
Ardea cinerea	91.39	Vc	Resident Migrant	Carnivore	Lc	8
Fulica atra	91.39	Vc	Resident Migrant	Omnivore	Lc	9
Alcedo atthis	91.11	Vc	Resident Migrant	Piscivore/insectivore	Lc	10
Motacilla cinerea	89.17	Vc	Migrant	Insectivore	Lc	11
Actitis hypoleucos	87.22	Vc	Resident Migrant	Carnivore/Insectivore	Lc	12
Ceryle rudis	85.00	Vc	Resident	Piscivore/insectivore	Lc	13
Charadrius dubius	84.10	Vc	Resident Migrant	Carnivore/Insectivore	Lc	14
Motacilla flava	80.00	Vc	Resident Migrant	Insectivore	Lc	15
Motacilla alba	78.06	Vc	Resident Migrant	Insectivore	Lc	16
Casmerodius albus	70.28	C	Resident Migrant	Carnivore	Lc	17
Tachybaptus ruficollis	68.61	C	Resident	Carnivore/Insectivore	Lc	18
Ardea purpurea	66.94	C	Resident Migrant	Carnivore	Lc	19
Anas poecilorhyncha	65.56	C	Resident Migrant	Herbivore	Lc	20
Vanellus indicus	60.84	C	Resident	Carnivore/Insectivore	Lc	21
Mesophoyx intermedia	56.11	C	Resident Migrant	Carnivore	Lc	22
Porphyrio porphyrio	54.17	C	Resident	Omnivore	Lc	23
Phalacrocorax carbo	51.11	C	Resident Migrant	Piscivore	Lc	24
Anas querquedula	42.20	Uc	Migrant	Herbivore	Lc	25
Pelecanus philippensis	37.78	Uc	Resident Migrant	Piscivore	NT	26
Anhinga melanogaster	36.39	Uc	Resident Migrant	Piscivore	NT	27
Anas platyrhynchos	35.30	Uc	Resident Migrant	Herbivore	Lc	28
Tringa nebularia	33.61	Uc	Migrant	Carnivore/Insectivore	Lc	29
Mycteria leucocephala	31.94	Uc	Resident Migrant	Carnivorous	NT	30
Nycticorax nycticorax	25.83	Re	Resident	Carnivore/Insectivore	Lc	31
Himantopus himantopus	16.11	Re	Resident	Carnivore	Lc	32
Hydrophasianus chirurgus	16.11	Re	Resident	Omnivore	Lc	33
Metopidius indicus	14.72	Re	Resident	Omnivore	Lc	34
Amaurornis phoenicurus	14.44	Re	Resident	Omnivore	Lc	35
Anastomus oscitans	13.61	Re	Resident	Carnivore/Insectivore	Lc	36
Gallinula chloropus	12.78	Re	Resident Migrant	Omnivore	Lc	37
Pelecanus onocrotalus	9.44	Re	Resident Migrant	Piscivore	Lc	38
Anas clypeata	6.94	Re	Migrant	Animal matter	Lc	39
Sterna aurantia	2.78	Re	Resident	Piscivore	Lc	40
Sarkidiornis melanotos	2.50	Re	Resident	Omnivore	Lc	41
Dendrocygna javanica	1.94	Re	Resident	Omnivore	Lc	42

0 – 25% as rare (Re), 26 – 50% as uncommon (Uc), 51 – 75% as common (C), 76 – 100% as very common (Vc)
*Ali (2012); ♦ BirdLife International (2013): Lc - Least concern, NT- Near threatened

Table-2: Distribution of aquatic bird species in the various lakes of Bengaluru city

Aquatic bird species	AKL	CPL	GGL	HBL	HGL	HKL	JKL	KGL	LLBG	MHL	NML	SML	TGHL	UL	VL
Actitis hypoleucos	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
*Alcedo atthis**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Amaurornis phoenicurus	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0
Anas acuta	0	0	0	1	1	1	0	1	1	1	0	0	0	0	0
Anas clypeata	0	0	0	1	1	0	0	0	1	1	0	0	0	0	0
Anas platyrhynchos	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
Anas poecilorhyncha	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Anas querquedula	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Anastomus oscitans	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
Anhinga melanogaster	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1
Ardea cinerea	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1
*Ardea purpurea**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Ardeola grayii**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Bubulcus ibis**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Casmerodius albus**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Ceryle rudis**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Charadrius dubius**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dendrocygna javanica	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
*Egretta garzetta**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Fulica atra**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Gallinula chloropus	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0
*Halcyon smyrnensis**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Himantopus himantopus	1	1	0	0	1	1	0	0	1	1	1	0	0	0	1
Hydrophasianus chirurgus	1	0	1	0	0	0	0	0	0	1	1	1	0	0	0
Mesophoyx intermedia	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
Metopidius indicus	1	0	1	0	0	0	0	0	1	1	1	1	0	0	0
*Motacilla alba**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Motacilla cinerea**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Motacilla flava**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Motacilla madaraspatensis**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Mycteria leucocephala**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Nycticorax nycticorax**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Pelecanus onocrotalus	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1
*Pelecanus philippensis**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Phalacrocorax carbo**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Phalacrocorax niger**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Porphyrio porphyrio	1	1	1	1	0	1	1	1	1	1	1	0	0	0	1
Sarkidiornis melanotos	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sterna aurantia	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0
*Tachybaptus ruficollis**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Tringa nebularia	1	1	0	1	1	1	1	1	1	1	1	0	0	0	1
Vanellus indicus	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
Total number of waterbird species	**38**	**34**	**31**	**34**	**34**	**33**	**32**	**34**	**40**	**39**	**36**	**27**	**29**	**25**	**32**

*** Recorded in all the study lakes; ‘1’present, ‘0’ absent; (for abbreviations of lakes, please see text)**

Table-3: Aquatic avifaunal density and diversity in different lakes of Bengaluru city

Lakes	No. of waterbird species	Mean population density (n) /ha.	Diversity indices															
			Shannon-Wiener's diversity				Sheldon's Evenness index				Margalef's species richness				Fisher's alpha diversity			
			2008-09	2009-10	t (22) =	P values	2008-09	2009-10	t (22) =	P values	2008-09	2009-10	t (22) =	P values	2008-09	2009-10	t (22) =	P values
AKL	38	15.76	2.78	2.26	2.763	0.011*	0.74	0.39	5.074	0.000*	3.43	4.07	-3.096	0.005*	4.84	5.54	-2.009	0.057
CPL	34	07.96	2.78	2.91	-1.616	0.120	0.83	0.74	2.911	0.008*	3.28	3.81	-2.146	0.043	4.71	5.39	-1.809	0.084
GGL	32	21.51	2.76	2.79	-0.222	0.826	0.82	0.82	-0.141	0.889	3.38	3.43	-0.142	0.888	5.00	4.98	0.034	0.973
HBL	34	09.41	2.60	3.00	-3.747	0.001*	0.65	0.75	-4.019	0.001*	3.18	3.92	-2.608	0.016	4.32	5.47	-2.662	0.014*
HGL	34	04.20	2.36	2.21	0.734	0.470	0.75	0.54	3.664	0.001*	2.75	2.81	-0.134	0.895	3.99	3.73	0.395	0.697
HKL	33	01.28	2.24	2.44	-0.993	0.332	0.63	0.64	-0.106	0.917	3.14	3.02	0.302	0.766	4.44	4.16	0.487	0.631
JKL	32	06.78	2.67	2.72	-0.296	0.770	0.78	0.69	1.561	0.133	3.20	3.52	-0.852	0.403	4.60	4.92	-0.529	0.602
KGL	34	20.43	2.76	2.89	-1.745	0.095	0.76	0.67	2.809	0.01*	3.44	3.91	-2.261	0.034*	4.94	5.45	-1.577	0.129
LLBG	40	35.23	2.83	3.15	-3.485	0.002*	0.83	0.80	2.205	0.038	3.50	4.51	-3.261	0.004*	5.15	6.64	-2.967	0.007*
MHL	39	10.25	2.14	2.79	-5.781	0.000*	0.40	0.55	-5.495	0.000*	2.93	4.07	-3.922	0.001*	3.76	5.55	-4.205	0.000*
NML	36	08.50	2.81	3.05	-2.602	0.016*	0.84	0.76	3.738	0.001*	3.35	4.19	-3.365	0.003*	4.87	6.01	-2.824	0.010*
SML	28	12.86	2.60	2.81	-1.980	0.060	0.85	0.83	0.788	0.439	2.96	3.41	-1.671	0.109	4.41	5.03	-1.337	0.195
TGHL	29	00.52	2.50	2.78	-2.287	0.032	0.71	0.68	0.777	0.445	2.99	3.63	-2.293	0.032*	4.26	5.10	-1.81	0.084
UL	26	21.22	2.32	2.94	-5.593	0.000*	0.83	0.85	-1.272	0.217	2.59	3.60	-4.011	0.001*	4.01	5.25	-2.765	0.011*
VL	32	04.31	2.71	2.88	-3.404	0.003*	0.70	0.69	0.317	0.754	3.28	3.74	-2.954	0.007*	4.49	5.15	-3.034	0.006*

*Results in a row indicate significant difference @ df = 22, α = 0.05 within indices between the years (paired student's t-test); (for abbreviations of lakes, please see text)

Table-4: Distribution of aquatic weeds in different lakes of Bengaluru city

Family	Aquatic weed species	AKL	CPL	GGL	HBL	HGL	HKL	JKL	KGL	LLBG	MHL	NML	SML	TGHL	UL	VL
Amaranthaceae	*Alternanthera sessilis*	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1
	Alternanthera philoxeroides	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1
	Amaranthus spinosus	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1
	Celosia argentea	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1
Aponogetonaceae	*Aponogeton natans*	1	0	1	0	1	0	0	1	1	1	1	1	0	0	1
Araceae	*Colocasia esculenta*	0	1	1	1	0	1	1	1	1	1	1	1	1	0	1
	Lemna minor	0	1	1	1	0	0	1	1	1	1	1	1	0	0	1
	Spirodela polyrhiza	0	1	1	1	1	0	0	1	1	1	1	1	0	1	1
	Pistia stratiotes	0	0	1	0	0	0	1	1	1	1	1	0	0	1	1
Apocynaceae	*Calotropis gigantea*	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
	Calotropis procera	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0
Convolvulaceae	*Ipomea aquatica* *	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Ipomea carnea	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
	Ipomea coccinea	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0
	Evolvulus alsinoides	0	1	1	1	0	1	1	1	1	1	1	1	0	0	1
Cyperaceae	*Cyperus articulatus*	0	1	1	1	1	0	1	0	1	1	1	1	0	0	1
Euphorbhiaceae	*Ricinus communis* *	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Hydrocharitaceae	*Hydrilla verticillata*	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1
	Ottelia alismoides	1	1	1	1	0	1	0	1	1	0	1	1	0	0	1
	Vallisneria spiralis	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
Lentibulariaceae	*Utricularia vulgaris*	1	1	1	0	0	0	1	0	0	1	1	1	0	0	1
Nelumbonaceae	*Nelumbo nucifera*	1	0	0	0	1	0	0	0	1	0	0	0	0	1	0
Nymphaceae	*Nymphaea nouchali*	1	1	1	1	1	0	1	1	1	0	0	1	0	0	0
Oxalidaceae	*Oxalis latifolia*	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1
	Oxalis corniculata	1	1	1	1	0	1	0	1	1	1	1	1	0	1	1
Polygonaceae	*Polygonum glabrum*	1	1	1	0	1	1	1	1	1	0	1	1	1	0	0
Pontederiaceae	*Eichhornia crassipes*	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1
	Monchoria vaginalis	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1
Saliviniaceae	*Salvinia spp.*	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1
Scrophulariaceae	*Bacopa monnieri*	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0
Selaginellaceae	*Selaginella bryopteris*	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1
Typhaceae	*Typha angustata*	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
	Total number of weed species	**24**	**28**	**31**	**25**	**16**	**20**	**24**	**25**	**28**	**26**	**29**	**29**	**11**	**11**	**26**

* Recorded in all the study lakes; '1'present, '0' absent; (for abbreviations of lakes, please see text)

Table-5: Habitat characteristics of lakes in Bengaluru city

Lakes	Lake area (ha.)	Weed coverage (~ %)	Water coverage (~ %)	Water depth (in m)	No. of fishing boats	No. of Islands	No. of Nests	No. of weed spp.	No. of trees	Mean anthropogenic disturbance scores (%)
Anekal Lake	67.60	47.71	52.29	4.83	6	0	40	24	50	7.25
Chandapura Lake	60.00	23.42	76.58	5.46	6	0	15	28	40	7.25
Gottigere Lake	14.98	89.08	11.91	1.03	2	0	10	31	50	11.40
Hebbala Lake	78.04	34.71	65.29	7.70	4	2	60	25	100	5.70
Hesaraghatta Lake	182.10	15.00	74.25	2.40	2	0	10	16	100	3.63
Hoskote Lake	522.22	81.50	27.50	0.72	2	0	10	20	40	8.81
Jakkuru Lake	80.00	24.42	75.58	4.57	5	1	30	24	30	6.74
Kengeri Lake	30.00	22.29	77.71	5.61	5	4	70	25	100	2.07
Lake of Lalbagh Botanical Garden	12.90	33.79	66.21	5.60	3	5	20	28	200	1.04
Medahalli Lake	134.00	40.38	59.63	7.46	5	0	10	26	10	13.47
Nelamangala Lake	58.00	83.92	16.08	5.18	2	0	20	29	100	12.95
Somanahalli Lake	18.00	41.38	65.60	1.89	4	0	10	29	20	4.66
Thippagondanahalli Lake	897.43	5.00	92.29	8.70	3	0	10	11	100	0.52
Ulsooru Lake	11.00	17.08	82.92	6.55	6	4	05	11	50	2.07
Varthuru Lake	180.40	18.58	81.83	8.76	8	0	50	26	100	12.44

Table-6: Pearson's correlation analysis showing the mean population density of waterbird communities in relation to lake characteristics in Bengaluru city

	Lake area	Weed coverage	Water coverage	Water depth	No. of fishing boats	No. of Islands	Nesting sites	Weed spp.	Tree density
Waterbird Density (no./ ha)	-0.597 (*)	0.102	-0.084	-0.070	0.011	0.750 (**)	0.113	0.299	0.397

(**) Significant at 0.01 level; (*) Significant at 0.05 level

DISCUSSION

Waterbird communities of different lakes

Manjunath et al. (2005) recorded the 42 species of waterbirds and water dependent bird species in the lakes of north Bangalore, which includes all the present species. Some of the common waterbirds such as *Bubulcus ibis*, *Tachybaptus ruficollis*, *Egretta garzetta*, *Ardeola grayji*, and *Porphyrio porphyrio* recorded in the lakes were also recorded as commonly occurring waterbirds in the wetland agro-ecosystems of plains of Karnataka, India (Basavarajappa, 2006). The feeding habit and residential status of individual waterbird species in the Bengaluru region was similar to the waterbird fauna of Mayurbhanj district, Orissa, India (Sahu and Rout, 2005) and Didwana Inland Saline Lake, Nagaur, Rajasthan, India (Bhatnagar et al., 2008). The percentage of frequency of the occurrence of waterbird species in the Bengaluru region is similar to that recorded in Mundanthurai Plateau, Tamil Nadu, in India (Joshua and Johnsingh, 1988). Of all the recorded species, *Anhinga melanogaster*, *Pelecanus philippensis* and *Mycteria leucocephala* are near threatened species, and the rest of the species are least concerned (BirdLife International, 2013).

Waterbird diversity and richness among different lakes

The highest number of species, a high density, species diversity and richness indices at Lalbagh Botanical Garden lake is because of its maintenance by Horticulture and Forest departments. The varying diversity of waterbirds in different lakes could be because of differing habitat conditions for roosting/nesting/feeding and the availability of food sources. In addition, tree islands benefit colonial waterbirds by providing colony sites in open wetlands (Hoffman et al., 1994). The lowest density of waterbirds at Thippagondanahalli lake may be because of human interference and a very less number of aquatic weed species and weed coverage in the vicinity of the lake locality. Similarly, the lowest number of species, and richness of waterbird species at Ulsooru lake which is located within the busy city area may be because of its smallest lake area and greater human disturbances. Also, the lowest diversity of waterbird species at Medahalli lake was due to fish harvesting and local boating activities and dense vehicular traffic around the lake.

The highest evenness index of waterbird species at Somanahalli lake is because of its location adjacent to agricultural lands in the outskirts of the city. The standing crops around this lake provide shelter to a variety of resident and migratory waterbird species (Sivaperuman et al., 2007). In contrast, the lowest evenness index of waterbird species at Medahalli lake is due to the high anthropogenic disturbance and fishing activities.

A significant positive correlation between the abundance and frequency of waterbirds as well as the density of waterbirds and lake area of the Bengaluru region are similar to the ponds of Spain (Paracuellos and Tellería, 2004). The wetland size influences the species richness and abundance of waterbirds (Froneman et al., 2001; Paracuellos and Telleria, 2004; Sánchez-Zapata et al., 2005). Larger wetlands support a greater species diversity of both area-independent and area-dependent species, whereas smaller wetlands generally support lower species diversity and only area-independent species (Paracuellos and Tellería, 2004). Species-area relationships have been documented in the wetland systems of different regions (Brown and Dinsmore, 1986; Webb et al., 2010).

Seasonal fluctuations of waterbird species

The number of waterbird species was highest in winter compared to other seasons because of the arrival of migratory waterbirds. Similarly, the highest abundance of waterbirds were recorded in winter months in the Carambolim lake of Goa (Shanbhag et al., 2001), Pulicat lake of Andhra Pradesh in India (Raghavaiah and Davidar, 2006), Chimadi lake of Sunsarii, Nepal (Surana et al., 2007), and lakes of Florida, USA (Hoyer and Canfield 1990; Hoyer et al., 2001). Because wetland birds may use many wetlands in a season, the amount of wetland habitats can influence species richness (Farmer and Parent, 1997; Fairbairn and Dinsmore, 2001). The more number of waterbirds were recorded when the lakes were full during the monsoon and winter periods, while in summer with drying lakes the abundance of waterbirds decreased. Similarly, varying waterbird population in relation to the water level and season has been reported in lakes of Dudwa National Park, India (Maheswaran and Rahmani, 2001). However, there was no significant difference in the number of waterbird species occurring in different seasons in

Bengaluru lakes as reported by Takekawa et al. (2001) in the baylands and ponds in San Francisco. The seasonal variations of waterbird communities may be associated with migration (Berthold, 1993).

Aquatic weed assemblages in different lakes

The aquatic plants in the lakes provide sustainable habitat for aquatic birds. Ramaswamy and Razi (1973) recorded the 47 species of aquatic weeds in and around the lakes of Bengaluru region, which includes the present 14 species of weeds. Mukherjee et al. (2002) recorded the 19 species of water weeds in the man-made reservoirs of Kheda District, Gujarat, India, in which the presently recorded four species (*Eichhornia crassipes*, *Hydrilla verticillata*, *Ipomoea aquatica* and *Typha angustata*) are included.

Lake characteristics and anthropogenic disturbances

The Principal Component Analysis and the Pearson's Correlation Analysis of the aquatic bird community indicated that the lake area, the number of islands, water and weed coverage, water depth, tree density, the number of fishing boats, the number of nesting sites/nests, and the number of weed species were the dominant factors that influence the waterbird communities in the lakes of Bengaluru region. These are similar to the habitat variables affecting the use of wetlands by waterbirds (Ma et al., 2010). Also, other habitat variables included water depth, water level fluctuation, vegetation, salinity, topography, food type, food accessibility, wetland size, and wetland connectivity showing either positive or negative affinity as observed by Ma et al. (2010). López et al. (2009) and Sebastián-González et al. (2010) reported that pond characteristics influence the waterbird density. Water depth, vegetation composition and structure, and wetland size are the important local characteristics of lake habitats determining waterbird composition and are positively correlated with the abundance of waterbird species as observed by Elphick and Oring (1998), Riffell et al. (2001), Ge et al. (2006) and Guadagnin et al. (2009). The vegetation coverage was positively correlated with the abundance of waterbirds in the lakes of Bengaluru. The vegetation cover and interspersed patterns persuade the avian diversity and abundance (Moreno-Mateos et al., 2009). Water level, water area and fishing activity are known to have negative impact on the number, distribution and diversity of waterbird species (Ge et al. 2006). The reduction in water depth results in a decline of waterbird populations as reported by Takekawa et al. (2001). Khan (2010) reported that changes in the waterbird composition were because of reduction in the surface area of water in a lake by the proliferation of water hyacinth. In our study, water depth was inversely correlated and aquatic vegetation was positively correlated to the abundance of waterbirds in the aquatic ecosystems. Thus, water depth and aquatic vegetations are the two important factors that determine the distribution and abundance of waterbirds in wetlands (Hoyer et al., 2006). Therefore, there are a number of biotic and abiotic factors in different lakes that influence the distribution, abundance and diversity of waterbird species as reported by McParland and Paszkowski (2007).

An increased linear pattern curve indicating that a high percentage of anthropogenic disturbances including fishing activity tend to had negative impact on the waterbird density as observed by Zydelis and Kontautas (2008) and Khan (2010). Therefore, maintaining the continuous cover of water and water level (>60 cm) (Maheswaran and Rahmani, 2001), and aquatic vegetations along the lakes particularly in the urban ecosystem zone is necessary for aquatic avian community composition and their distribution (Wu et al., 2007). Also, the population density of waterbird communities showed significant negative correlation with the lake area and positive correlation with the number of islands in the urban lakes irrespective of weed coverage and the number of weed species. In addition, waterbirds benefit from tree islands as they provide colony sites (Hoffman et al., 1994). Species diversity of waterbirds was generally positively correlated with water levels (Farago´ and Hangya, 2012). Water levels are probably to decrease waterbird richness and abundance and should be an issue to suitable environmental impact assessment (Farago´ and Hangya, 2012).

The study points out that intense biotic and anthropogenic pressure around the urban lakes have made a negative impact on the waterbird community composition of urban ecosystem (Zydelis and Kontautas, 2008). The most rare and uncommon species in the lake ecosystem of urban zone have been replaced by common and generalist species. The conservation of lakes and wetland vegetations in the lake environment act as a passage and boundaries for the life movement of waterbirds, and it also supports the livelihood means of the aquatic avian community composition (Teel et al., 2007; Athearn et al., 2012). A minimum width of aquatic vegetation in the passage and boundaries of the lake ecosystem in urban region is very much essential to maintain the quality of environment and also for the biological conservation of waterbird species (Mukherjee et al., 2002). Abundant food supply, safe roosting site, habitat size and habitat complexities are important factors that influence the waterbird species diversity of a particular site (Mukherjee et al., 2002; Erwin and Beck, 2007; O'Neal et al., 2008).

MANAGEMENT AND CONSERVATION IMPLICATIONS

Our study shows that the availability of water, safe habitat and food sources for both adults and nestlings and essential nesting/roosting sites (Erwin and Beck, 2007; O'Neal et al., 2008) i.e. tree density and the number of islands in the lakes are important factors for the occurrence and density of aquatic bird populations. However, it is difficult to assess the direct effect of other factors for example pollution, and anthropogenic activities on the waterbird populations in the city lakes. Further follow up studies for a longer period will help to determine species-specific conservation measures for aquatic birds (De Boer et al., 2011; Athearn et al., 2012). As a precautionary measure a specific awareness programme should be initiated to educate publics and resource users to protect waterbirds. Like all other animals the aquatic bird community too is facing threats due to lake encroachment/ habitat loss, the scarcity of water and food resources as reported by Kumar and Choudhary (2010) and other pollution causing factors i.e., filling up of lake outer edges with scrap materials, domestic solid wastes, garbage and polythene bags or polyvinyl plastics, hardened cement bags and destroyed house materials (Jayson, 2001; Khan, 2010). The State Wildlife Department should review periodically the status of waterbird population and take appropriate steps to conserve them in situ (Ma et al., 2010). The variety of anthropogenic alterations has made most of the lakes environment vulnerable and their further degradation affects the activities of wetland birds (Ramachandra and Solanki, 2007). In India, presently recorded waterbird species in Bangalore city are categorized under the Schedule IV (Entry No. 14, 15, 21, 22, 31, 32 and 36) species of the Indian Wildlife Protection Act 1972 (Anonymous, 2002). These waterbird species should be protected as they reside in a fragile habitat (Gibbs, 1993; Ramachandra and Solanki, 2007). The threatened species should be monitored regularly as reported by Balakrishnan and Thomas (2004). For conserving the lake ecosystem and its rich biodiversity, a management plan should be prepared emphasizing an avenue for the sustainable utilization of resources of the wetland without jeopardizing its continued ecological values and functions (Ma et al., 2010; D'Souza and Nagendra, 2011; Farago´ and Hangya, 2012). As water depth and tropic structure are the important habitat characteristics that influence the abundance and diversity of aquatic birds in lakes, the proper and regular maintenance of Bengaluru lakes would further increase the aquatic bird populations (Maheswaran and Rahmani, 2001; Mukherjee et al., 2002; Farago´ and Hangya, 2012). By looking at the species diversity of waterbirds in the urban lakes of Bengaluru city, one can predict the quality of the habitats which affect aquatic bird communities. All in all the present study provides a basic information on which appropriate management strategies can be evolved for the conservation of waterbirds in major lakes of Bengaluru city.

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