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RESEARCH ARTICLE

Impact of Urban Threats and Disturbance on the Survival of Waterbird Communities in Wetlands of Bengaluru City, India

S. Rajashekara[1] · M. G. Venkatesha[1]

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Abstract Threats to waterbird communities on urban wetlands in the Bengaluru city, South India are poorly known. We calculated disturbance scores for 15 lakes along a gradient from low (LDL) to high (HDL) disturbance levels based on vegetation structure and composition. HDL had the highest threat scores and the lowest number of waterbird species whereas LDL supported the highest number of species. Human activities included commercial fishing and aquaculture, and shoreline development leading to habitat fragmentation and degradation. We discuss strategies for the conservation of urban wetlands and the preservation of waterbird diversity.

Keywords Aquatic macrophyte cover · Disturbance scores · Species diversity · Threat Index · Vegetation composition · Water coverage

Introduction

Wetlands are economically valuable owing to their high biodiversity and productivity (Gibbs 1993), with globally threatened avian species depending on them (Green 1996). Frequently, waterbirds appear at or near the top of most wetland food chains that are highly susceptible to habitat disturbances, and therefore they are good indicators of the general condition of wetland habitats (Kushlan 1992). They also play a crucial role in the mass and energy fluxes between terrestrial and aquatic food chains (Moreira 1997). Waterbirds are important components of most of the wetland ecosystems where they occur, as they can occupy multiple trophic levels in food webs and play roles in wetland nutrient cycles (Rajashekara and Venkatesha 2010). Waterbirds are the most prominent groups of vertebrate animals which attract urban people to wetlands and lakes. Also they are good ecological indicators and useful models for studying a variety of environmental problems (Urfi et al. 2005).

The potential loss of wetlands (lake ecosystem) services will have severe consequences for waterbird communities throughout the developing world. Waterbirds play a vital role in the lake ecosystems of urban areas, and control aquatic organisms (species being controlled, for e.g., pest insects and disease vectors) and have been considered indicator species to gauge the health of urban lake-ecosystems (Colwell 2010; Rajashekara and Venkatesha 2014). Freshwater lakes play vital regional roles around cities, especially with reference to agriculture, fishing, livestock maintenance and drinking water facilities in surrounding areas (Puri 2015).

The structure and dynamics of communities including the distribution and abundance of the waterbird species in urban lake ecosystems, is likely influenced by both abiotic and biotic factors (McParland and Paszkowski 2007). Anthropogenic development around urban lakes is affecting waterbird communities but is currently poorly studied. Such research is particularly urgent for endangered species because it can offer information for formulating strategies for their conservation (Green 1996; BirdLife International 2014).

Predicting eco-spatial and temporal patterns for aquatic avian populations and understanding their causes remain

✉ S. Rajashekara
rajachandra3908@yahoo.co.in

M. G. Venkatesha
venkatmelally@gmail.com

[1] Department of Studies in Zoology, Bangalore University, Jnana Bharathi Campus, Off Mysuru Road, Bengaluru 560 056, India

central goals in the study wetland and waterbird synecology of lakes of the urban Bengaluru region of India (Rajashekara and Venkatesha 2014). This research addresses the general question: 'How does spatial and temporal environmental heterogeneity influence avian diversity at different scales?' (Sutherland et al. 2013).

Human activities, which predominate in urban areas, have been shown to decrease the foraging (Rees et al. 2005) and breeding success of waterbirds (Beale and Monaghan 2004), change their distributions (Thiollay 2007), and lower species richness (Palacio-Núñez et al. 2007) and thus alter the composition of waterbird communities (De Boer 2002; Palomino and Carrascal 2007; Rajashekara and Venkatesha 2010, 2014). Although natural and man-made threats to lakes and wetlands of oriental India have been addressed since the 1990s in over 25 studies (e.g., Bharucha and Gogte 1990; Reddy et al. 1993; Nagarajan and Thiyagesan 1998; Jayson 2001; Mukherjee et al. 2002; Chari et al. 2003; Sivaperuman and Jayson 2003; Gupta 2004; Islam 2006; Kumar 2006; Raghavaiah and Davidar 2006; Bhatnagar et al. 2007; Malkanna et al. 2007; Mazumdar et al. 2007; Patankar et al. 2007; Raghavaiah and Davidar 2007; Surana et al. 2007; Hussain and Pandav 2008; Verma 2008; Bhat et al. 2009; Khan 2010; Kumar and Choudhary 2010; Datta 2011; Bhattacharjee and Bargali 2012; Hussain et al. 2012; Gulzar and Kant 2015; Kanaujia et al. 2015; Kupekar et al. 2015; Mistry and Mukherjee 2015), quantification of the magnitude of threats and their effects on the composition, abundance and diversity of aquatic birds have not been thoroughly studied in major lakes in urban regions. Thus, we initiated the present study.

The study objective was answered through exploring the response of waterbird communities to human-induced activities and impact of threats on the activities and patterns of aquatic avian composition of different lakes to review threats faced by the waterbird communities of urban lakes in the Bengaluru region, Karnataka, South India and to quantify long-term changes in waterbird abundance. We (1) conducted an extensive literature review to determine habitat associations of waterbirds in an Indian context such as the composition and structure (coverage) of aquatic vegetation, perching plants/trees, and characteristics of lakes used by representative species, (2) quantified these characteristics in 15 lakes across a disturbance gradient using primary datasets collected for lake development and management planning programs, (3) calculated disturbance scores for habitat suitability indices for representative waterbirds in urban lakes, validated them, and compared habitat suitability indices for study lakes, and (4) tested whether ranking of threats changed over time for low to high disturbance lakes.

Additionally, other main objectives were to: (1) identify and quantify threats faced by waterbird populations and communities on these urban lakes, (Wetlands International 2006); (2) to identify the species present and enumerate waterbird population size on these urban lakes; (3) to consider the conservation implications of our findings.

Materials and Methods

Study Area

Bengaluru is located on the South Deccan plateau of Peninsular region of India (Fig. 1), consisting of 2191 km^2 of urbanized area with a population of 9 million (Census of India 2011). The city occupies valleys where the rivers Arkavathi, Kumadavathi and Vrishabhavathi flow from the Nandi Hills (Devanahalli) to Kengeri (Mysuru Road) (Fig. 1). This metropolitan area contains several lakes in landscapes covered by open, dry deciduous forest scrub to closed canopy evergreen forests along streams. Winter (December to February), summer (March to May) and monsoon (June to November) are the three main seasons. The average maximum and minimum temperatures are −36° and 14 °C, respectively. Annual rainfall for the Bengaluru region is 800 mm with humidity range from 35 to 80%.

Comparison of Indices for Assessing Threat Ranking in Urban Wetlands

Preliminary surveys were made to document threats, including anthropogenic activities, and assign disturbance scores to each wetland/lake in the urban region of Bengaluru, Karnataka, South India following methods of Shenoy et al. (2006), and Rajashekara and Venkatesha (2014). Surveys were conducted once a fortnight February 2008–January 2010. 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. Disturbance level for each study site was calculated using the following relation:

$$\text{Disturbance level}_{i=1}^{3} = \sum \text{Score}_i * \frac{\text{Total number of events of activity } i}{\text{Observer effort}}$$

where i was the type of activity (Shenoy et al. 2006; Rajashekara and Venkatesha 2014).

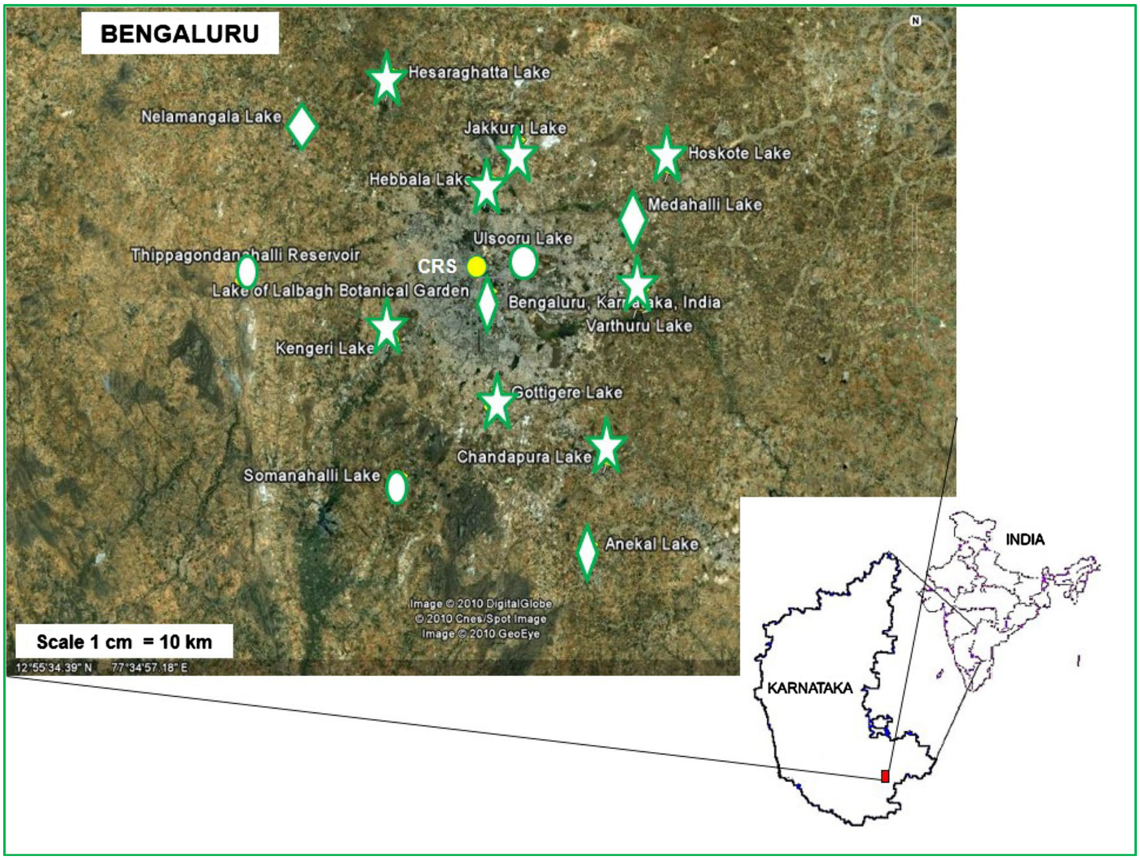

Fig. 1 Map showing the study region with reference to threats faced by the waterbird communities across the disturbance gradients of different lakes in the Bengaluru region, Karnataka, South India. *White circles* represents High disturbance lakes (HDL), *Star* represents Medium disturbance lakes (MDL), *Rhombus* represents Low disturbance lakes (LDL) and *Yellow circle* represents the centre of Bengaluru region—City Railway Station (CRS)

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. Number of waterbird community-lakes 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 lakes.

$$\text{Visit frequency} = \frac{\text{Total number of visits by waterbirds}}{\text{Number of waterbird community lakes/observer effort}}$$

Disturbance scores were given to each lake by qualitatively assessing various disturbances (lake encroachment, construction of roads, eutrophication (macrophyte coverage), livestock grazing, waste disposal, an inflow of domestic sewage, lake soil mud lifting, brick making, commercial fishing and aquaculture) and ranking total disturbance scores/levels as rare (1), occasional (2) or frequent (3) levels of disturbances in the form of total disturbance scores, relative disturbance scores (%)to other survey lakes and total disturbance levels (%). Study lakes were then classified into different anthropological disturbance categories: high disturbance lakes (HDL), moderate disturbance lakes (MDL), and low disturbance lakes (LDL) based on the minimum and maximum values of observed disturbance scores.

Field Sampling for Waterbird Communities

Low to highly disturbed lakes were surveyed for waterbirds in order to assess dynamics in lakes in the Bengaluru region (Fig. 1). Observers used direct counts and point count methods by walking along banks of lakes within a visible radius of 50–100 m for 5 min (see Bibby et al. 2000; Froneman et al. 2001; Turner 2003; Urfi et al. 2005). Aquatic birds were counted at their point of first detection and care was taken to ensure that individual birds were not counted twice. Counts were made in the morning between 07:30 and 10:30 h or in the afternoon between 15:00 and 18:00 h depending light conditions (Namgail et al. 2009). Standardized sampling methods were used for survey methods in fixed time-spans (30–40 min transect count) (Watson 2003). Call notes of bird species were also used for locating them (Ali 2012). Nomenclature and taxonomy of waterbirds was based on BirdLife International (2014). Fixed observations were also made on the nests, nesting sites, foraging and food sources, and natural predation for waterbirds.

Species diversity of the aquatic avifauna is one of the most important environmental indicators to estimate the quality of surrounding dwellings. We calculated species richness (S), the total number of bird species recorded in a particular lake. The number of endangered bird species (including critically endangered, threatened and vulnerable according to IUCN Red List of Threatened Species 2009) were recorded. Ratio of endangered versus bird species that were not at risk was calculated. We calculated the number of families, genera and species, as well as ratios of number of genera to number of species, family and species, and family and genera. Data on aquatic bird species were analyzed for relative frequency, abundance, and species distribution ratio (frequency/abundance), and Species Importance Value Index (SIVI) (Relative frequency + relative abundance + relative species distribution ratio) was calculated (Curtis and McIntosh 1951). Data on aquatic birds were used to calculate Family Importance Value Index (FIVI) (Relative family abundance + relative family richness) to understand community organization using method of Curtis and McIntosh (1951).

Aquatic bird density was calculated by dividing the population of waterbirds (n) relative to lake area during the same period. Fisher's alpha diversity were calculated for waterbird communities at each lake and using the formula:

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

where S = is the number of taxa, n = is the number of individuals and a = is Fisher's alpha (Fisher et al. 1943; Magurran 2004) using PAST version 1.60 software (Hammer et al. 2001).

Vegetation Sampling

Vegetation along the bank of urban lakes was surveyed with 1 m^2 quadrants placed at 50 m intervals along parallel transects at four points along each particular lake (Mukherjee et al. 2002). Observation tower were used as outlook points for aerial viewing of the lakes. Each lake was divided into four imaginary quadrants with the help of landmarks. In each quadrant, water and aquatic macrophyte coverage on the lake was visually estimated as a percentage of the total lake area, and thus mean percent of open water and macrophyte coverage of whole lake was assessed (Froneman et al. 2001; Thakur and Bhattacharjee 2008; Datta 2011; Rajashekar 2011). Water depth was measured at each lake with a measuring stone (Datta 2011; Rajashekar 2011). Vegetation cover for all sections was combined and then averaged to estimate cover for the whole lake (Datta 2011). Emergent vegetation was identified with the help of identification manuals (Ramaswamy and Razi 1973) at each study lake and also, the type of submerged aquatic macrophyte species (number) was determined (Datta 2011).

Canopy cover, an measure of disturbance (Fiala et al. 2006), was quantified by digital canopy photography (Engelbrecht and Herz 2001). Canopy coverage, expressed as percent area around a lake, was calculated by averaging 10 values from 10 images and expressed as range and mean ± standard error. Vegetation cover (%) was measured after Lynch et al. (1985) with strata (St1:0–0.4, St2:0.4–0.8, St3:0.8–1.2, St4:1.2–1.6, St5:1.6–2.0, St6: > 2.0 m). These were combined into two variables, lower vegetation (%) at 0–1.2 m high (VgL:St 1–3) and taller vegetation (%) at >1.2 m high (VgH:St 4–6) for simplicity (Kurosawa 2007). Number of perching trees (>10 cm diameter in size at breast height (DBH) at 1.37 m above the ground level) where exactly waterbird surveys were piloted.

Furthermore, the lake area, water and macrophyte coverage, water depth, a number of islands, and tree density around the lakes are the important characteristics that were evaluated as effective tools to assess the populations of aquatic bird communities in different urban lakes of the Bengaluru region. Direct human interference was measured in terms of average number of persons present in a 1-h duration in a particular lake of the Bengaluru region (Datta 2011). Other habitat factors such as existence of roads around lakes, traffic, usage of lakes for various human activities (i.e. washing clothes and utensils, fishing by local boats, housing, bathing, swimming, boating), input of domestic sewage, and encroachment of lakes for construction purposes were used to evaluate effects of anthropological disturbances on populations of aquatic birds (Datta 2011).

Apart from collecting information from published materials, interviews were conducted with managers responsible for the lake zone and protection of wetland resources. Interviews dealt with the history of lakes, source and availability of water, bio-geographic features, management of threats, conservation issues, etc., (Abhisheka et al. 2013). A questionnaire in the local language was also circulated among randomly selected individuals from villages near the wetlands about their perceptions regarding wetland issues and management.

Statistical Analyses

The influence of various lake environmental variables such as waterbird density, lake area (ha.), nesting sites (n), tree density (n), number of macrophyte species (n), water and macrophyte coverage (%), water depth (m), number of fishing boats (n) and number of islands (n), and mean population density (no./ha) of waterbirds were subjected to Pearson Correlation Coefficient (*r*) analysis to understand the relationships among them (SPSS Inc 2008). All data were log 10 transformed ($x' = \log 10(x)$) to approximate a normal distribution, then subjected to Pearson Correlation Coefficient (r) analysis with waterbird population density used for the simple relationship analyses between the variables (SPSS Inc 2008). Ward's method of Bray–Curtis Cluster Analysis was carried out to create a dendrogram to assess the similarity within various threats faced by the density of aquatic bird communities among study lakes of the Bengaluru region using PAST version 1.60 software (Hammer et al. 2001). We next performed a constrained ordination, using Principal Component Analysis (PCA) (Hammer et al. 2001) without involving varimax rotation of the Kaiser normalization to assess the abiotic and biotic threats (or variables) including anthropogenic disturbances contributed to the patterns of waterbird communities observed in the urban lakes of the Bengaluru region. The assessment of above mentioned urban threats and waterbird survey data were log 10 transformed before further analysis. We constructed a Venn diagram using the software Oliveros (2007–2015) to assess groups of threats faced by the aquatic bird communities in the Bengaluru region.

Results

Comparison of Indices for the Assessment of Threat Ranking in Urban Wetlands

Comparison of the disturbance scores for urban threats for 15 lakes in the Bengaluru region, South India reveals that highly disturbed lakes (HDL) (four lakes—Gottigere (GGL), Medahalli (MHL), Nelamangala (NML) and Varthuru (VL) out of 15 lakes) harbor more threat scores (22–26 with 73.33–86.67%) than the other disturbance lakes (01–17 with 3.33–56.67%) (Table 1). Human activities including commercial fishing and aquaculture, and lake shoreline development (habitat loss/fragmentation and degradation) were recorded as common threats in all the urban lakes of the Bengaluru region ("Appendix 1" and Table 1).

The dendrogram generated by cluster analysis showed similarity in the disturbance scores for urban habitat features and threats faced by waterbird communities across the 15 lakes resulted in three major clusters. The first cluster corresponded to low disturbance and consisted of lake area, tree density and open water coverage were associated with a low disturbance score. The number of macrophyte species, macrophyte coverage and the number of nesting sites for aquatic birds were associated with a moderate score whereas human interferences such as extensive commercial fishing and aquaculture, number of fishing boats, and number of islands present in the lakes, water depth and other recreational activities such as walking, etc., accounted for the third cluster with a high disturbance score (Fig. 2). The three major clusters have significant negative affinities with each other and also with the density of waterbird communities in 15 urban lakes of the Bengaluru region, South India. Furthermore, principal threats to aquatic birds, i.e. lake shoreline development, construction of roads, eutrophication, habitat loss, scarcity of food and water, and dumping of domestic wastes (except SML, TGHL and UL), and improper livestock grazing, were common in most of the urban lakes (11) of the study region (see Table 1). Other threats i.e. presence of islands and perching trees have positive effect on the waterbird population in the urban lakes of the Bengaluru region.

Overall, the maximum number of threats (again using these threats) was found larger in HDL (35.7%) obtained from the Venn diagram. There was no unique percentage of threats shared by the LDL–HDL and LDL–MDL combinations (Fig. 3). Threats that are faced by the waterbird species across the urban lakes showed that HDL and MDL share about 14.3% of the threats. The proportion of threats found larger/bigger in HDL and MDL but not in LDL is much smaller, and probably composed of open habitat of lake of a lesser conservation precedence (Fig. 3).

An examination of threats faced by the waterbird communities in urban lakes with Principal component analysis indicates that waterbird density showed significant positive correlation with the number of islands, water and macrophyte coverage, tree density, fishing boats, the number of nests, and the number of macrophyte species (Fig. 4). Similarly, waterbird density exhibited significant negative correlation only with the lake area and water depth. The cumulative percentage of variance explained in the Principal component analysis by the first four PC axes was 98.957% (aggregate), with the first axis accounting for 91.667% of the variation, and second axis explaining a further 4.6015% with close correlation ($r = -0.0121$, $P \leq 0.01$) (Fig. 4).

Population Fluctuations in Urban Waterbird Species

During the study period, the Bengaluru region supported 42 aquatic bird species belonging to 32 genera and 15 families distributed along the rural–urban gradients with various disturbance lakes ("Appendix 2"). LDL harbor more species of waterbirds (36–40 spp.) than the HDL (26–29 spp.) (Table 2). Of recorded waterbird species, 40 (95.24%) were exclusive to LDL which contained multiple islands (Table 2). Consistently, the highest species diversity for waterbirds (Fisher's alpha and beta diversity −5.24 and

Table 1 Assessment of threats faced by the waterbird communities using Disturbance scores (1 = low; 2 = moderate and 3 = high) for 15 study lakes in the Bengaluru region, Karnataka, South India

Study lakes	Acroynms	Inflow of domestic sewage	Eutrophication	Lake soil bed/mud lifting	Brick making	Commercial fishing and aquaculture	Livestock grazing	Waste disposal	Construction of roads	Lake encroachment	Total disturbance scores	Relative disturbance scores (%)	Total disturbance levels (%)
Anekal lake	AKL	0	1	2	1	3	2	1	1	3	14	7.25	46.67
Chandapura lake	CPL	1	1	1	1	2	2	2	1	3	14	7.25	46.67
Gottigere lake	GGL	3	3	3	0	1	3	3	3	3	22	11.4	73.33
Hebbala lake	HBL	2	1	0	0	1	2	2	2	1	11	5.7	36.67
Hesaraghatta lake	HGL	0	0	0	1	3	3	0	0	0	7	3.63	23.33
Hoskote lake	HKL	0	3	2	2	3	2	2	2	1	17	8.81	56.67
Jakkuru lake	JKL	2	2	1	0	2	2	1	2	1	13	6.74	43.33
Kengeri lake	KGL	1	1	0	0	1	0	0	1	0	4	2.07	13.33
Lake of Lalbagh Botanical garden	LLBG	0	1	0	0	1	0	0	0	0	2	1.04	6.67
Medahalli lake	MHL	3	3	2	3	3	3	3	3	3	26	13.47	86.67
Nelamangala lake	NML	3	3	2	2	3	3	3	3	3	25	12.95	83.33
Somanahalli lake	SML	0	0	1	0	2	3	1	1	1	9	4.66	30.00
Thippagondanahalli lake	TGHL	0	0	0	0	1	0	0	0	0	1	0.52	3.33
Ulsooru lake	UL	0	1	0	0	1	0	0	2	0	4	2.07	13.33
Varthuru lake	VL	3	3	1	2	3	3	3	3	3	24	12.44	80.00

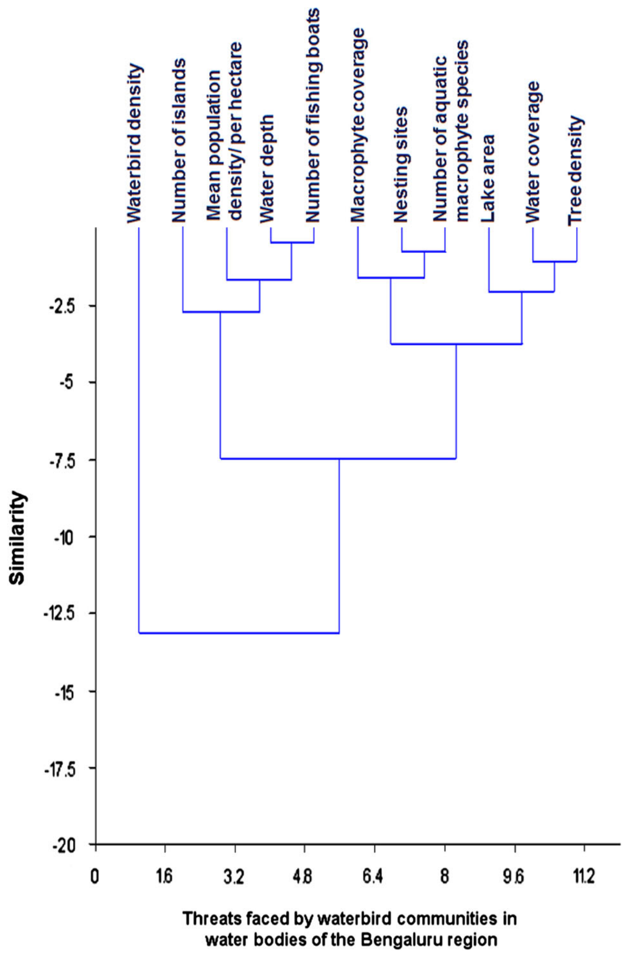

Fig. 2 Dendrogram showing the contribution of threats for waterbirds across the disturbance gradients of diverse lakes in the Bengaluru region, Karnataka, Southern India

2.00) was recorded in a lesser disturbed (LDL) (Lake of Lalbagh Botanical Garden—LLBG) compared to moderate (MDL) and highly disturbed lakes (HDL). In addition to 40 macrophyte species, moderate number of perching plants was exclusive to LDL with more canopy cover consisting of native plant/tree species (Table 2).

Bubulcus ibis (26.618) showed the highest species importance value index (SIVI), whereas *Sarkidiornis melanotos* (0.214) showed the lowest value ("Appendix 2"). Twenty-six species of waterbirds (61.90%) were confined to HDL with a predominance of generalist species, while 33 (78.57%) waterbird species were common to both MDL and LDL lakes ("Appendix 2"). Furthermore, Ardeidae had the highest family importance value index (FIVI) (58.340), relative species richness (22.681) and highest relative abundance (35.659%) with a higher number of bird genera and species (7 and 8 respectively) than the other families ("Appendix 3"). Ten families of waterbirds (1.00 each) showed the highest ratio of genera and species ("Appendix 3").

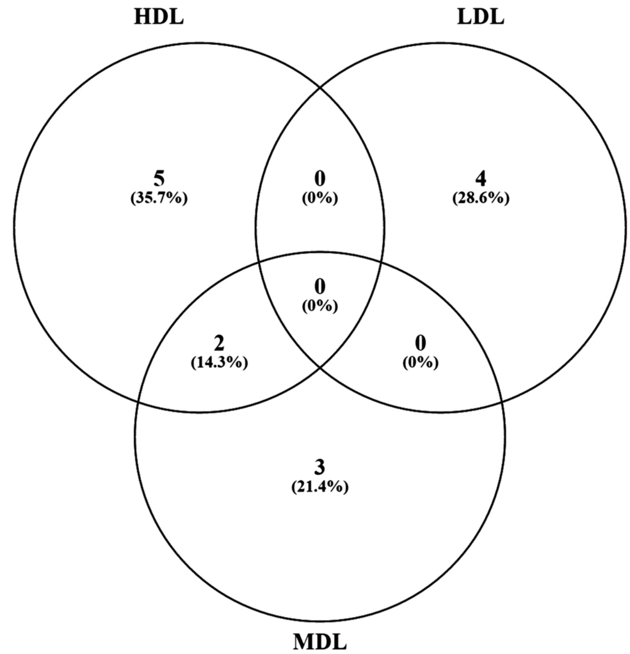

Fig. 3 Venn diagram depiction of threats (percentage-wise) for waterbirds across the disturbance gradients of urban lakes in the Bengaluru region, Karnataka, Southern India

Influence of Environmental Variables on Waterbird Species Richness and Diversity

Overall aquatic bird density showed significant positive correlation ($P < 0.05$) with the area of urban lakes in the Bengaluru region (Table 3). Mean population density of waterbirds showed significant positive correlation ($P < 0.05$) with the number of islands and macrophyte coverage, and significant negative correlation ($P < 0.01$) with the lake area. The size (area) of the lakes showed significant positive correlation ($P < 0.05$) with the total waterbird density and showed significant negative correlation ($P < 0.01$) with the mean population density of waterbirds and the number of islands. Number of macrophyte species had showed significant positive correlation ($P < 0.05$) with the macrophyte coverage. Also, macrophyte coverage of the lakes showed significant negative correlation ($P < 0.01$) with open water cover and showed significant positive correlation ($P < 0.05$) with the mean population density of waterbirds and the number of macrophyte species. Water coverage showed significant positive correlation ($P < 0.05$) with water depth and the number of fishing boats, and showed significant negative correlation ($P < 0.01$) with the macrophyte coverage. The number of islands showed significant positive correlation ($P < 0.05$) with the mean population density of waterbirds and showed significant negative correlation ($P < 0.05$) with the area of lakes (Table 3).

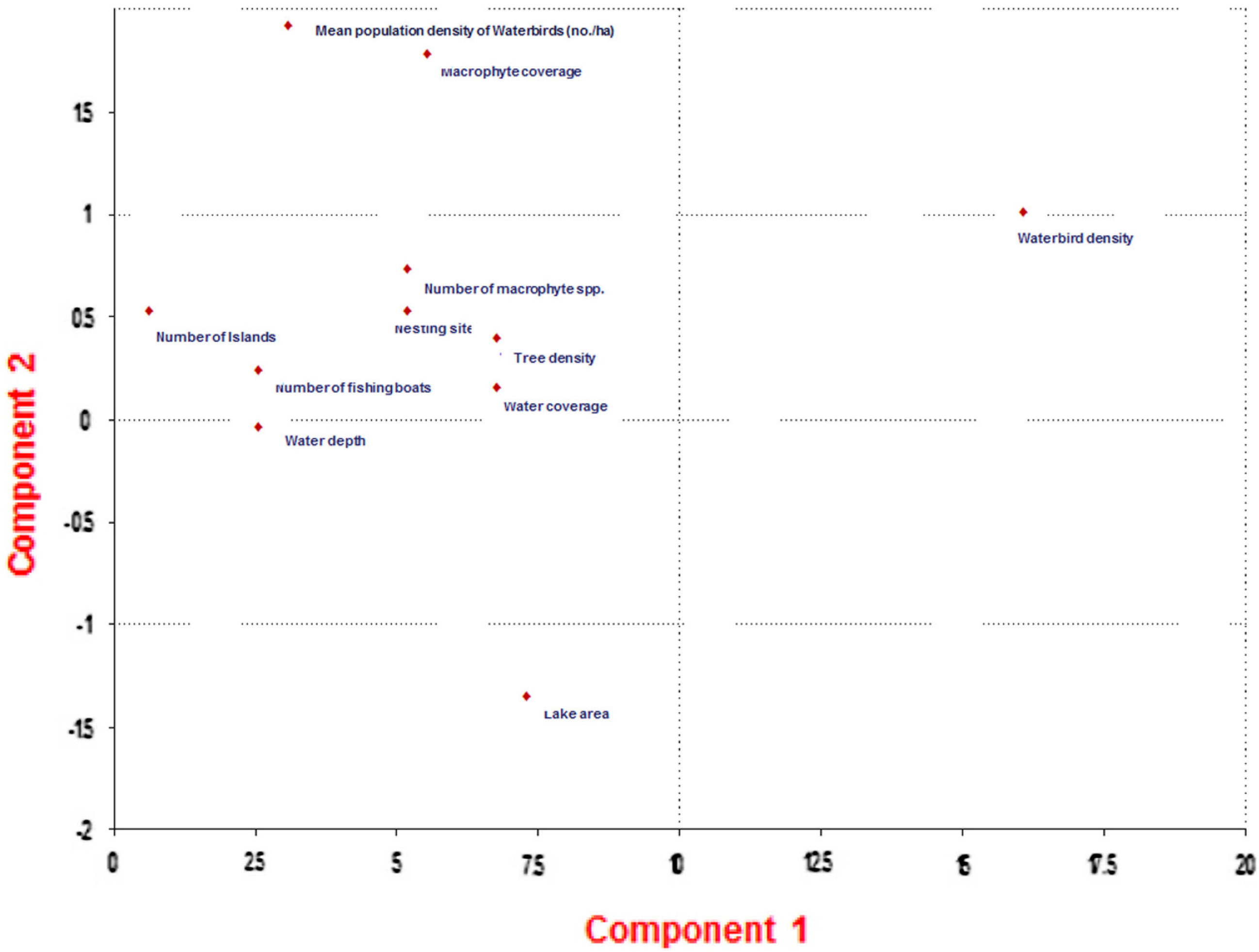

Fig. 4 PCA analysis of the threats faced by the waterbird communities in the urban lakes of the Bengaluru region

Discussion

Comparison of Indices for the Assessment of Threat Ranking in Urban Wetlands

We investigated aquatic bird species diversity and richness in lakes of the Bengaluru region, South India in relation to threats common to waterbirds in urban regions such as scarcity of food and water resources, human disturbance, commercial fishing, and dumping of domestic wastes. Extensive commercial fishing and aquaculture, and lake encroachment (habitat loss, fragmentation, degradation and shoreline development) was common in all 15 lakes as reported earlier in other regions of India (Bharucha and Gogte 1990; Reddy et al. 1993; Nagarajan and Thiyagesan 1998; Jayson 2001; Mukherjee et al. 2002; Chari et al. 2003; Sivaperuman and Jayson 2003; Gupta 2004; Islam 2006; Kumar 2006; Raghavaiah and Davidar 2006; Bhatnagar et al. 2007; Malkanna et al. 2007; Mazumdar et al. 2007; Patankar et al. 2007; Raghavaiah and Davidar 2007; Surana et al. 2007; Hussain and Pandav 2008; Verma 2008; Bhat et al. 2009; Khan 2010; Kumar and Choudhary 2010; Datta 2011; Rajashekar 2011; Bhattacharjee and Bargali 2012; Hussain et al. 2012; Gulzar and Kant 2015; Kanaujia et al. 2015; Kupekar et al. 2015; Mistry and Mukherjee 2015). Further, HDL harbored overall higher threat scores than other lakes. Additional threats to waterbird communities was water level fluctuations, tree density and aquatic macrophyte around the edges of lakes that were responsible for the survival of waterbirds in the Bengaluru region as reported by Reddy et al. (1993), DuBowy (1996), Davis and Smith (1998), Colwell and Taft (2000), and Takeuchi and Yoshida (2006).

Furthermore, the other threats includes lake silting, effluents other than sewage, varied degrees of eutrophication and blue green algal growth, mud lifting and brick making at the lake bed, and inlet of municipality sewage, which were detrimental to diverse productivity process in the urban lakes as reported by Jayson (2001), Kumar (2006), and Raghavaiah and Davidar (2007). In addition to these, extensive livestock grazing in and around the lakes,

Table 2 Species composition and other parameters of the waterbird communities across the disturbance gradients in urban water bodies of the Bengaluru region, Karnataka, South India

Waterbird composition	High Disturbance Lakes (HDL)			Moderate Disturbance Lakes (MDL)								Low Disturbance Lakes (LDL)			
Study Lakes	**SML**	**TGHL**	**UL**	**CPL**	**GGL**	**HBL**	**HGL**	**HKL**	**JKL**	**KGL**	**VL**	**AKL**	**LLBG**	**MHL**	**NML**
Species	28	29	26	34	31	34	34	33	32	34	32	38	40	39	36
Genera	22	21	19	25	25	20	23	23	23	24	23	29	27	27	29
Waterbird families	13	11	11	11	10	12	13	12	13	13	11	14	14	14	14
Number of Endangered species	2	3	2	3	3	3	3	3	3	3	3	3	3	3	3
Genera : Species	0.786	0.724	0.731	0.735	0.806	0.588	0.676	0.697	0.719	0.706	0.719	0.763	0.675	0.692	0.806
Family : Species	0.464	0.379	0.423	0.324	0.323	0.353	0.382	0.364	0.406	0.382	0.344	0.368	0.350	0.359	0.389
Family : Genera	0.591	0.524	0.579	0.440	0.400	0.600	0.565	0.522	0.565	0.542	0.478	0.483	0.519	0.519	0.483
Fisher's alpha Diversity	3.85	3.61	3.53	4.32	4.28	4.07	4.04	3.98	3.96	4.17	3.77	4.39	5.24	4.37	4.59
Whittaker's Diversity	1.40	1.45	1.30	1.70	1.55	1.70	1.70	1.65	1.60	1.70	1.60	1.90	2.00	1.95	1.80
Waterbird Density per hectare (n/ha)	12.86	0.51	21.22	7.84	21.09	9.29	4.18	1.27	6.68	20.16	4.27	15.64	34.83	10.16	8.39
Vegetation composition	**SML**	**TGHL**	**UL**	**CPL**	**GGL**	**HBL**	**HGL**	**HKL**	**JKL**	**KGL**	**VL**	**AKL**	**LLBG**	**MHL**	**NML**
Number of aquatic macrophyte species	27	29	25	34	31	34	34	33	32	34	32	38	40	39	36
Number of perching tree species	40	60	60	80	20	100	220	240	120	120	100	100	120	100	160
Canopy cover (Range= Minimum to Maximum)	78.52-97.52	78.49-99.99	70.68-100.00	81.67-97.52	70.68-100.00	81.67-97.26	74.04-100	75.14-100.00	70.68-100.00	81.00-99.73	70.68-100.00	78.59-97.26	78.52-97.14	81.67-97.14	76.12-97.26
Canopy cover (Mean ± Standard error)	87.39 ±1.40	91.05 ±1.80	87.14 ±1.53	89.47 ±1.39	87.97 ±1.74	89.26 ±1.29	88.12 ±1.16	87.14 ±1.53	87.97 ±1.74	89.65 ±1.79	87.99 ±1.74	88.45 ±1.35	87.34 ±1.14	87.14 ±1.53	86.47 ±1.79
Vegetation strata (meter)	>2.0	>2.0	>2.0	0.8 -1.2	0.0-0.4	>2.0	>2.0	1.2–1.6	0.0-0.4	1.2–1.6	0.0-0.4	1.6–2.0	0.4-0.8	>2.0	0.8-1.2
Classification of stratum	St 6	St 6	St 6	St 3	St 1	St 6	St 6	St 4	St 1	St 4	St 1	St 5	St 2	St 6	St 3

Table 3 Pearson's correlation analysis showing the threats faced by waterbird communities in water bodies of the Bengaluru region

Pearson correlation	Waterbird density	Mean population density of waterbirds (no./ha)	Lake area (hectare)	Nesting sites	Tree density	Number of macrophyte species	Aquatic macrophyte coverage	Water coverage	Water depth	Number of fishing boats	Number of islands
Waterbird density	1	−0.202	0.548*	0.366	−0.07	0.15	0.062	0.116	0.272	0.161	−0.248
Mean population density of waterbirds (no./ha)	−0.202	1	−0.930**	0.256	−0.021	0.493	0.557*	−0.114	0.025	0.24	0.525*
Lake area (hectare)	0.548*	−0.930**	1	−0.084	−0.008	−0.369	−0.454	0.141	0.081	−0.146	−0.538*
Nesting sites	0.366	0.256	−0.084	1	0.396	0.338	0.081	0.232	0.45	0.47	0.387
Tree density	−0.07	−0.021	−0.008	0.396	1	−0.145	−0.26	0.044	0.238	−0.235	0.405
Number of macrophyte species	0.15	0.493	−0.369	0.338	−0.145	1	0.710**	−0.411	−0.19	0.028	−0.13
Aquatic macrophyte coverage	0.062	0.557*	−0.454	0.081	−0.26	0.710**	1	−0.650**	−0.508	−0.166	−0.042
Water coverage	0.116	−0.114	0.141	0.232	0.044	−0.411	−0.650**	1	0.592*	0.634*	0.338
Water depth	0.272	0.025	0.081	0.45	0.238	−0.19	−0.508	0.592*	1	0.612*	0.32
Number of fishing boats	0.161	0.24	−0.146	0.47	−0.235	0.028	−0.166	0.634*	0.612*	1	0.196
Number of islands	−0.248	0.525*	−0.538*	0.387	0.405	−0.13	−0.042	0.338	0.32	0.196	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed) increasing level of human activities in and around the lake, and the presence of roads had negative impacts on the number and diversity of waterbird species as reported elsewhere in India by Bharucha and Gogte (1990), Jayson (2001), Bhatnagar et al. (2007), Raghavaiah and Davidar (2007), Hussain and Pandav (2008), and Verma (2008).

The habitat loss and its fragmentation, habitat degradation, decreased water quality due to contaminants, recreational pressure (e.g., bird-watching, photography, boating, bike trails), and building constructions, etc., were found to be the serious problems for the urban lake habitats in the Bengaluru region as reported in other regions (Zedler and Leach 1998; Treinys et al. 2008; Khan 2010; Zhijun et al. 2010). Moreover, expansion of agricultural lands including monoculture/polyculture or conversion of lake for agricultural practices, expansion of real state for houses/buildings, exploitation of lakes for the construction of roads to improve the urban wetland and greenery, and that leads to the dwindling of waterbird species (Rajashekar and Venkatesha 2010, 2014).

Population Fluctuations in Urban Waterbird Species

Low disturbance lakes (Anekal (AKL), Lake of Lalbagh Botanical Garden (LLBG), Medahalli (MHL) and Nelamangala (NML) lakes) harbored more species of aquatic birds than HDL. Also, the highest diversity of waterbirds (Fisher's alpha and Whittaker's diversity) was recorded in LDL with the highest genera and species compared to MDL and HDL. Lower diversity in disturbed urban lakes was mainly due to habitat, particularly the availability of safe roosting sites, foraging and nesting conditions, habitat size and its complexities, as well as direct human disturbance and recreational activities as reported by Mukherjee et al. (2002), Raghavaiah and Davidar (2006), and Raghavaiah and Davidar (2007). In addition, waterbirds benefit from treed islands to serve as colony sites, as reported by Hoffman et al. (1994). Maximum waterbird density in LDL was related to a lesser threats and greater tree density around the lakes of the Bengaluru region. Reduction of water levels in summer, macrophyte infestation, variations in food availability across different seasons and predation affected the waterbird diversity in Anekere wetland of Udupi district, Karnataka (Bhat et al. 2009). The highest number of aquatic macrophyte species was recorded at LDL, where the highest diversity and richness of waterbird species were recorded. In contrast, the lowest number of aquatic macrophyte species was found at HDL where the bird diversity and richness was lowest.

Influence of Environmental Variables on Waterbird Species Richness and Diversity

Correlation analysis indicated that the tree density, number of macrophyte species, water depth and open water coverage were the main factors influencing waterbird community composition in urban lakes of the Bengaluru region. López et al. (2009) and Sebastián-González et al. (2010) reported that lake characteristics had strong influences on waterbird density. Similarly, the vegetation coverage, water level, and open water area are positively correlated with abundance of waterbird species (Datta 2011), but, fishing activity has negative impact on the number, distribution and diversity of waterbird species as reported elsewhere by Ge et al. (2006) and Datta (2011). Khan (2010) reported that changes in the waterbird species and abundance were due to reduction in the open water area of a lake caused by the proliferation of water hyacinth (*Eichornia crassipes*). The waterbird abundance and community composition significantly correlated with the water hyacinth cover of the wetland of Santragachhi Lake, West Bengal (Khan 2010). Water depth was inversely correlated and aquatic vegetation was positively correlated with the abundance of waterbirds in the lake ecosystems as reported elsewhere (Hoyer et al. 2006; Zhijun et al. 2010) and also, the average depth of the water body has a negative impact on waterbird numbers (Datta 2011). The variation in population and the activities of waterbirds were mainly due to the difference in the availability of open water area and habitat size as reported elsewhere by DuBowy (1996), Davis and Smith (1998) and, Colwell and Taft (2000). The changes in the vegetation pattern, habitat fragmentation, exotic plants, nest predation, visitation disturbances, changes in food supply abundance, changes in predator assemblage, human activities and other factors contributes for the urbanization processes that lead to decline in avian communities (Chace and Walsh 2006). Wetland vegetation and faunal composition have a positive influence on waterbird abundance and diversity (Bellrose 1980; Helmers 1992), so that it can support a rich variety of waterbirds in sufficient numbers (Khan et al. 2016).

The size of the circles in the Venn Diagrams signified the relative importance of conservation. The circles are used to show relationships between different threats/percentage of threats sharing common resources and services. Quantity of all scores that illustrated the highest ranks in HDL expose into high level of anthropogenic disturbance and low ranks in LDL direct low disturbance. LDL bears similarity to the habitat, both in terms of vegetation composition as well as species composition and diversity of waterbirds. A strong positive association between the structure of native vegetation with waterbird diversity and its species richness consistently. Also, there is existence and a strong positive correlation between habitat size and species diversity of birds which consistently resembles with results of other studies in a variety of environments (Paracuellos and Telleria 2004; Gonzalez-Gajardo et al. 2009). Lower diversity and lower number of waterbird species in HDL was perhaps due to lower niche diversity with more human disturbances.

Species-specific studies focusing on population status, habitat requirements and assessment of threats are necessary for the implementation of conservation actions (Mukherjee et al. 2002). Both regional and lake-level resources remained important in shaping the distribution of waterbird species (*Anhinga rufa, Mycteria leucocephala and Pelecanus philippensis*) in the urban region. Thus, assessment of threats forms an important areas in correlating the diversity of aquatic bird fauna for biodiversity conservation. In spite of threats posed by urbanization, most of waterbirds can be found in cities (as well as elsewhere), thus providing opportunities for local, regional and global biodiversity conservation, restoration and education (Aronson et al. 2014).

Conclusion

Our method evaluated and ranked study lakes in terms of their conservation value, information that is needed to identify priority conservation areas. It helped provide a local plan for protecting lake habitat essential for the survival of waterbirds. Enhancement of biodiversity in wetlands promises to have a positive influence on the quality of the wildlife experience and education of city inhabitants and thus facilitate the preservation of aquatic biodiversity. We need to counter rapid urbanization happening in the Bengaluru region through improved monitoring and documentation.

Threats such as poaching, over fishing, land use change, drainage of lakes for agriculture etc., might pose threats lower waterbird diversity and decrease distributions. Also, invasions by species like water hyacinth, pollution by small industrial units, and conversion of lake beds for agricultural and nonagricultural purposes need to be addressed and countered. For the persistence of waterbird populations in urban lakes we need to conserve networks of wetlands (Abhisheka et al. 2013) and assess the value of particular sites through long-term monitoring.

Urban lakes provide the specialized microhabitats and food sources required by resident and migratory waterbirds. We recommend that lake perimeters be protected by iron fencing and shoreline development be avoided. Dumping of domestic sewage should be prohibited. Boating should also be avoided at least in the winter season with the arrival of migrants. Islands should be constructed and natural islands should be planted with trees for roosting site, foraging and nesting. Planting of trees along the shoreline urban lakes should be encouraged to attract roosting waterbirds. Aquatic macrophytes may need to be managed through mechanical harvesting from time to time. Economic encouragements should be offered to the local population to protect waterbirds and stop poaching. Education and environmental awareness activities should be offered to local people either through multidisciplinary development programs or through other non-governmental agencies.

Long-term planning for threat management is essential for operative conservation of avian biodiversity and biological resources through environmental education. Hence, there is a requirement to take compulsory steps to save them from all possible threats, primarily by ensuring safe and sufficient food, and rehabilitation of habitat, and a protected environment. This assumption is tested and carried out a lake-scale survey to understand diversity of waterbirds using urban lakes.

To date in India, conservation efforts have been directed towards protecting large wetlands/lakes that are assumed to be adequate to conserve the majority of species of focal taxa, usually waterbirds (Gopi Sundar and Kittur 2013). The protection and restoration of urban wetlands would certainly mark a prominent change in the administrative policy and strategies that allowed the deterioration and destruction of these habitats along with a loss of aquatic biodiversity. Adopting and implementing proper conservation measures to combat the many threats to urban wetlands in the Bengaluru region would serve as valuable step in a new direction.

Compliance with Ethical Standards

Conflict of interests The authors declare that they have no conflict of interest.

Author Declaration SR and MGV conceived and designed the experiments. SR performed the experiments. SR analyzed the data. SR wrote the manuscript and other author provide editorial advice.

Appendix 1

See Fig. 5.

Fig. 5 Some of the major threats to aquatic bird communities in the urban wetlands of the Bengaluru region. **a** Fish catching, **b** Fish harvesting, **c** Ganesha idol disposing/ immersion, **d** Lake encroachment, **e** Modern boating, **f** Construction of road and transport, **g** Solid waste disposal, **h** Local boating

Appendix 2

See Table 4.

Table 4 Species Importance Value Index (SIVI) for waterbird species in the wetlands of the Bengaluru region

Bird species	Species important value
Actitis hypoleucos	7.716
Alcedo atthis	7.512
Amaurornis phoenicurus	2.113
Anas acuta	1.600
Anas clypeata	1.001
Anas platyrhynchos	0.523
Anas poecilorhyncha	6.580
Anas querquedula	19.277
Anastomus oscitans	2.884
Anhinga rufa	3.802
Ardea cinerea	10.122
Ardea purpurea	6.966
Ardeola grayii	13.054
Bubulcus ibis	26.618
Casmerodius albus	7.095
Ceryle rudis	6.975
Charadrius dubius	7.904
Dendrocygna javanica	0.426
Egretta garzetta	22.002
Fulica atra	24.564
Gallinula chloropus	8.683
Halcyon smyrnensis	8.283
Himantopus himantopus	1.948
Hydrophasianus chirurgus	1.655
Mesophoyx intermedia	4.965
Metopidius indicus	1.993
Motacilla alba	6.845
Motacilla cinerea	7.676
Motacilla flava	6.993
Motacilla madaraspatensis	9.462
Mycteria leucocephala	4.635
Nycticorax nycticorax	3.193
Pelecanus onocrotalus	2.727
Pelecanus philippensis	5.577
Phalacrocorax carbo	18.578
Phalacrocorax niger	7.695
Porphyrio porphyrio	2.582
Sarkidiornis melanotos	0.214
Sterna aurantia	0.572
Tachybaptus ruficollis	7.534
Tringa nebularia	3.218
Vanellus indicus	6.237

Appendix 3

See Table 5.

Table 5 Family Importance Value Index (FIVI) for waterbird populations in the wetlands of the Bengaluru region

Waterbird family	No. of genera	Number of species belonged to genera (S)	Relative abundance (%) (RA)	Relative species richness (RSR)	Family importance value (FIV = RA + RSR)	Genera: species
Alcedinidae	3	3	4.914	7.864	12.778	1.000
Anatidae	3	7	11.520	21.608	33.128	0.429
Anhingidae	1	1	0.783	0.000	0.783	1.000
Ardeidae	7	8	35.659	22.681	58.340	0.875
Charadriidae	2	2	3.457	4.087	7.544	1.000
Ciconiidae	2	2	1.338	4.573	5.910	1.000
Jacanidae	2	2	0.562	5.131	5.692	1.000
Laridae	1	1	0.077	0.000	0.077	1.000
Motacillidae	1	4	7.117	11.343	18.460	0.250
Pelecanidae	1	2	1.491	4.511	6.002	0.500
Phalacrocoracidae	1	2	9.346	3.677	13.024	0.500
Podicipedidae	1	1	1.959	0.000	1.959	1.000
Rallidae	4	4	18.772	10.308	29.080	1.000
Recurvirostridae	1	1	0.387	0.000	0.387	1.000
Scolopacidae	2	2	2.619	4.218	6.837	1.000
Total	32	42	100	100	–	–

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