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Abundance, Assemblage, Habitat Characteristics and Seasonal Diversity of Waterbirds at Kalpakkam, South East Coast of India

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ABSTRACT

Patterns of spatial and temporal variation in waterbird species richness, abundance and their relationship with habitat variables were investigated in different wetlands at Kalpakkam, East coast plains of Southern India from June 2008 to July 2011. A total of 54 species, belonging to 41 genera, and 17 families were recorded, among these, the most representative families are Ardeidae, Scolopacidae and Anatidae. The interspecific difference in different wetlands used by waterbirds showed that the shallow marshes accommodate a larger number of species with greater abundance than the deeper lake. The water level fluctuation, depth and heterogeneity of wetlands were the key factors governing the waterbird assemblages in the present study. In addition it is observed that the wetland avian group such as dabbling ducks and wading birds were relatively high in shallow marshes, whereas diving birds preferred deeper lake. Moreover, the Canonical Correspondence Analysis (CCA) revealed that habitat characteristics such as aquatic vegetation cover, water level fluctuation (depth), dissolved oxygen, salinity and total nitrogen influenced the waterbird diversity, abundance and their distribution at various habitats. The information obtained through this study may be useful for management and conservation of waterbird species and their system at south east coastal plains of India.

Key words: wetlands, waterbirds, diversity, seasonality, water depth, aquatic vegetation, Kalpakkam

INTRODUCTION

Waterbirds are an important component of biotic community in wetland ecosystems and highly sensitive to changing habitat including climate and weather. They use the wetland habitats either throughout or during certain part of their life (Weller, 1981). Bird assemblages are affected by various factors such as availability of food sources, size of the wetland, structure of habitat heterogeneity (Eilers *et al.,* 2004; Cintra *et al.,* 2007; Gajardo *et al.,* 2009), productivity and hydrological periods (Nagarajan and Thiyagesan, 1996; Khan, 2010; Cintra, 2012). Within this context, we examined the patterns of waterbirds assemblage at several wetlands of well protected nuclear power plant Campus of Kalpakkam in relation to water quality, wetland physical and chemical factors and seasonality. Nagarajan and Thiyagesan (1996) stated that the consideration of water quality, climatic conditions, diversity of waterbirds and abundance are most important parameters for habitat evolutions. The magnitude of influence of the habitat parameters on waterbirds not only varies temporally, but also it is site or area specific. Global data on waterbirds and their relationship with habitat signifies its ecologically important. However such studies in India are limited and the available information is sporadic and incomplete.

Outside the system of protected areas, India's biodiversity has often found refuge in many private lands and such biodiversity refuges are becoming rarer day-by-day. A handful of biodiversity rich and privately managed refuges include the sprawling campuses of educational and research institutes in otherwise ecologically devastated urban landscapes. Institution campuses that shelter native biodiversity within cities are essential ecological islands. The Kalpakkam nuclear site is a well protected ecological island with native flora and fauna for last four decades. The unique habitat of this area constitutes high value biotic resources of the east coastal plains of India. The sustainable management of these ecological habitats is the greatest challenge that is currently faced by biodiversity conservationists. The current study is inevitable since rapid industrialization of Kalpakkam pose sever threat to the waterbirds habitat. The present study focuses on the needed for general principles on setting priorities for habitat protection, substantial ambiguity remains about how to implement these principles and which factor is more important for habitat improvements. Moreover, information about these relationships will contribute towards the understanding on waterbird ecology at eastern coastal plains of India, also to create better conservation strategies locally.

MATERIALS AND METHODS

Study Area

The Department of Atomic Energy campus (12º 33” N and 80º 11” E) premises at Kalpakkam comprising of about ~2500 acres, which lies on the east coastline of Kanchipuram district of Tamil Nadu, India. The coastal system forms the complex natural site where intense interactions occur among land, sea and atmosphere. The unique interaction forms biological

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Figure 1. Map of Kalpakkam showing different wetland habitat types

consortia peculiar to this system. The biological diversity of the productive habitat forms native flora and fauna and aesthetically blended with introduced vegetation inside the campus. Two marshy lands and a brackish water lake, namely Waste Immobilization Plant marsh (WIP), Kunnathur marsh (KUN) and Kokilamedu Lake (KKM) are within the campus. This campus is also bounded by two backwaters, namely Sadras in the southern side and Ediyur in the northern side of the campus (Figure 1). Weather conditions of Kalpakkam are that of typical coastal areas exposed to the different monsoons (northeast and southwest). This region is subjected to the northeast monsoon, with maximum rainfall occurring between Octobers to December.

Wetlands

Shallow marshland

The swallow marshy wetland viz., WIP and KUN marsh, have formed due to rainwater accumulation and are surrounded with semi-aquatic dry deciduous and scrub vegetation. The plants such as *Ceratophyllum demersum*, *Nymphaea pubescens*, *Fimbristylis* sp., *Typha latifolia, Spirogyra* sp. were predominant in the lands. These wetlands were prone to drying between April to June and a unique character of these marshes was low water depth, even during the rainy seasons. The morphological, physical features were measured regularly once in a month at each wetlands and the information on physical and chemical changes were given in Table 1.

Lake system

This campus also has a brackish water lake (KKM lake) situated approximately 200 m ashore Kalpakkam Coast, which is surrounded with grassy and riparian vegetation. The lake is about 1000 m long, 80 m wide and the maximum depth of the lake is about 7 feet. The anthropogenic impacts (human or industrial activities) on all the wetlands were almost negligible since they are located in a prohibited area.

Bird Surveys

To determine waterbird richness and abundance, three different water bodies were surveyed during June 2008 to July 2011 by using the fixed point count method as per Gregory et al (2004) with minor modification, which is a preferred sampling method for assessing avian abundance and composition in wetland habitats (Bibby *et al.,* 2000). This technique involved identifying all individuals seen or heard within a 25-m radius from a fixed point (Posa and Sodhi, 2006) for 15 minutes duration. Three point counts were done every month between 06.00 to 08.00 am at each wetland. Bird were observed by binocular (Brusian, 20x50; 168 ft. AT1000 yd) and documented. Confirmation of species status was done using bird identification manual (Kazmierczak, 2000; Salim Ali, 2002; Sashikumar *et al.,* 2004). Meteorology data such as temperature (C°), relative humidity (%), rainfall (mm) and rainy days (days/month) were collected from meteorological station, Indira Gandhi Centre for Atomic Research, Kalpakkam.

Table 1. Morphological and physical features for three wetlands in Kalpakkam

Habitat Types	Structure	Water depth (mean)	Dissolved oxygen (mg/l)		pH		Salinity (PSU)		Total nitrogen (µmol/l)		Total phosphate (µmol/l)	
			SUM	MON	SUM	MON	SUM	MON	SUM	MON	SUM	MON
WIP marsh	200-250 m long, 150 m wide	1-2 feet	4.4	8.25	9.6	8.6	3.1	1.05	3.47	2.27	12.03	6.35
KUN marsh	300-350 m long, 50 m wide	2-3 feet	5.4	7.55	8.8	7.7	1.02	0.46	2.05	0.9	4.7	2.68
KKM lake	800-1000 m long, 80 m wide	4-5.5 feet	6.7	7.3	8.2	8.08	8.52	5.6	21.32	14.84	2.32	1.9

Water Quality and Habitat Measurement at Wetlands

Water samples were collected once in a month from all the waterbodies during June 2008 to July 2011. In order to avoid the diurnal changes in pH, dissolved oxygen and other associated parameters the sampling time has been kept constant (09.00-10.00 hrs) during the study period. Parameters such as water temperature (°C), dissolved oxygen (mg/L), pH and salinity (PSU) of water were analyzed using multi parameter probe (HANNA, HI-9828). In addition total nitrogen (µmole/l) and total phosphate concentrations (µmole/l) in water samples were determined as per Strickland and Parsons (1968). The aquatic vegetation surveys were conducted as per Braun-Blanquet quadrat area method (1972) with minor modification (Schneider and Griesser 2009) at each wetland to integrate the effect of vegetation structure on avian richness and abundance. Aquatic floral species were identified in the field by using plant identification manual for local species (Gajendiran and Ragupathy, 2002) and cover density scores followed as Braun-Blanquet density scores (0-absent, <5% cover= 1, 5-25% cover= 2, 25-50%= 3, 50-75% cover= 4 and 75-100% cover= 5). The monthly water level fluctuations were registered with a graduated pole at fixed locations inside each wetland as per Colwell and Taft (2000).

Data Analysis

Species richness is the simplest and the most intuitive concept for characterizing community diversity. Among measures of α-diversity, the widely used indices such as Fisher's-α diversity, Shannon's and Simpson diversity indices were calculated by using BiodiversityPro version 2 (Neil McAleece *et al.,* 1997). In addition, the comparative studies of diversity wereoften impeded by the variety of methods used to display species abundance data. One of the best known and most informative methods is the rank abundance plot (Magurran 2004) and it was calculated by using BiodiversityPro version 2. The Canonical Correspondence Analysis (CCA) was performed by using CANACO version 4.5 (Ter Braak, 1987). There are eight environmental variables viz., (water depth (WDEP), water temperature (WTEM), dissolved oxygen (DO), vegetation cover (VECO), pH, salinity (SALI), total nitrogen (TN), total phosphate (TP)) were added into the model and the recurrent species of waterbird species were added. CCA provides a graphical representation of the relationships between species and environmental factors. In addition, Monte Carlo permutation tests were subsequently used within CCA, to determine which environmental variables were important in describing waterbirds distribution.

RESULTS

Community Composition of Waterbirds

A total of 19826 individuals belonging to 56 species 42 genera, 17 families, were observed from the three wetland habitats (Table 2). The family Ardeidae was the most dominant among the families in terms of generic and species richness (10 genera and 11species) followed by Scolopacidae (5 genera and 8 species). Interestingly, 9778 individuals observed were belong to family Anatidae (49.3 % of individuals) and it was the most dominant group in Kalpakkam, followed by Ardeidae (3424 individuals, 17.3 % of individuals) (Table 3). Species such as

Table 2. List of waterbirds observed in Kalpakkam during June 2008 to July 2011

S.no	Family	Scientific name	Common name	Code
1	**Podicipedidae**	*Tachybaptus ruficollis*	Little Grebe	LIGR
2	**Pelecanidae**	*Pelecanus philippensis*	Spot-billed Pelican	SPPE
3	**Phalacrocoracidae**	*Phalacrocorax niger*	Little Cormorant	LICO
4	**Phalacrocoracidae**	*Phalacrocorax fuscicollis*	Indian Shag	INCO
5	**Phalacrocoracidae**	*Phalacrocorax carbo*	Great Cormorant	GRCO
6	**Anhingidae**	*Anhinga melanogaster*	Darter	DART
7	**Ardeidae**	*Egretta garzetta*	Little Egret	LIEG
8	**Ardeidae**	*Ardea cinerea*	Grey Heron	GRHE
9	**Ardeidae**	*Ardea purpurea*	Purple Heron	PUHE
10	**Ardeidae**	*Casmerodius albus*	Large Egret	LAEG
11	**Ardeidae**	*Mesophoyx intermedia*	Median Egret	MEEG
12	**Ardeidae**	*Bubulcus ibis*	Cattle Egret	CAEG
13	**Ardeidae**	*Ardeola grayii*	Indian Pond-Heron	INHE
14	**Ardeidae**	*Butorides striatus*	Little Green Heron	LIHE
15	**Ardeidae**	*Nycticorax nycticorax*	Black-crowned Night-Heron	BLHE
16	**Ardeidae**	*Ixobrychus sinensis*	Yellow Bittern	YEBI
17	**Ardeidae**	*Dupetor flavicollis*	Black Bittern	BLBI
18	**Ciconiidae**	*Mycteria leucocephala*	Painted Stork	PAST
19	**Ciconiidae**	*Anastomus oscitans*	Asian Openbill-Stork	ASOP
20	**Threskiornithidae**	*Plegadis falcinellus*	Glossy Ibis	GLIB
21	**Threskiornithidae**	*Threskiornis melanocephalus*	Oriental White Ibis	ORIB
22	**Threskiornithidae**	*Platalea leucorodia*	Eurasian Spoonbill	SPBI
23	**Anatidae**	*Dendrocygna javanica*	Lesser Whistling-Duck	LEWH
24	**Anatidae**	*Anas penelope*	Eurasian Wigeon	EUWI
25	**Anatidae**	*Anas poecilorhyncha*	Spot-billed Duck	SPDU
26	**Anatidae**	*Anas clypeata*	Northern Shoveller	NOSH
27	**Anatidae**	*Anas acuta*	Northern Pintail	NOPI
28	**Anatidae**	*Anas querquedula*	Garganey	GARG
29	**Anatidae**	*Anas crecca*	Common Teal	COTE
30	**Rallidae**	*Gallirallus striatus*	Blue-breasted Rail	BBRA
31	**Rallidae**	*Amaurornis phoenicurus*	White-breasted Waterhen	WHHE
32	**Rallidae**	*Porphyrio porphyrio*	Purple Moorhen	PUMO
33	**Rallidae**	*Gallinula chloropus*	Common Moorhen	COMO
34	**Rallidae**	*Fulica atra*	Common Coot	COCO
35	**Jacanidae**	*Hydrophasianus chirurgus*	Pheasant-tailed Jacana	PHJA
36	**Rostratulidae**	*Rostratula benghalensis*	Greater Painted-Snipe	GRSN
37	**Charadriidae**	*Charadrius dubius*	Little Ringed Plover	LIPL
38	**Charadriidae**	*Vanellus malabaricus*	Yellow-wattle Lapwing	YELA
39	**Charadriidae**	*Vanellus cinereus*	Grey-headed Lapwing	GHLG
40	**Charadriidae**	*Vanellus indicus*	Red-wattled Lapwing	RELA
41	**Scolopacidae**	*Gallinago gallinago*	Common Snipe	COSN
42	**Scolopacidae**	*Limosa limosa*	Black-tailed Godwit	BLGO
43	**Scolopacidae**	*Numenius arquata*	Eurasian Curlew	EACU
44	**Scolopacidae**	*Tringa totanus*	Common Redshank	COSH
45	**Scolopacidae**	*Tringa stagnatilis*	Marsh Sandpiper	MASA
46	**Scolopacidae**	*Tringa ochropus*	Green Sandpiper	GRSA
47	**Scolopacidae**	*Tringa glareola*	Wood Sandpiper	WOSA
48	**Scolopacidae**	*Actitis hypoleucos*	Common Sandpiper	COSA
49	**Recurvirostridae**	*Himantopus himantopus*	Black-winged Stilt	BLST
50	**Laridae**	*Larus brunnicephalus*	Brown-headed Gull	BRGU
51	**Laridae**	*Gelochelidon nilotica*	Gull-billed Tern	GUTE
52	**Alcedinidae**	*Alcedo atthis*	Small Blue Kingfisher	SMKI
53	**Alcedinidae**	*Halcyon smyrnensis*	White-breasted Kingfisher	WHKI
54	**Alcedinidae**	*Ceryle rudis*	Lesser Pied Kingfisher	LEKI
55	**Motacillidae**	*Motacilla maderaspatensis*	Large Pied Wagtail	LAWA
56	**Motacillidae**	*Motacilla flava*	Yellow Wagtail	YEWA

Table 3. Statistics of waterbirds with respect to family, genus, species and number observed in Kalpakkam

S.no	Family Name	Genera (No.)	%	Species (No.)	%	Individuals (No.)	%
1	Podicipedidae	1	2.38	1	1.79	428	2.2
2	Pelecanidae	1	2.38	1	1.79	326	1.6
3	Phalacrocoracidae	1	2.38	3	5.36	1076	5.4
4	Anhingidae	1	2.38	1	1.79	465	2.3
5	Ardeidae	10	23.81	11	19.64	3425	17.3
6	Ciconiidae	2	4.76	2	3.57	1597	8.1
7	Threskiornithidae	3	7.14	3	5.36	315	1.6
8	Anatidae	2	4.76	7	12.50	9778	49.3
9	Rallidae	5	11.90	5	8.93	814	4.1
10	Jacanidae	1	2.38	1	1.79	48	0.2
11	Rostratulidae	1	2.38	1	1.79	15	0.1
12	Charadriidae	2	4.76	4	7.14	446	2.2
13	Scolopacidae	5	11.90	8	14.29	373	1.9
14	Recurvirostridae	1	2.38	1	1.79	317	1.6
15	Laridae	2	4.76	2	3.57	35	0.2
16	Alcedinidae	3	7.14	3	5.36	308	1.6
17	Motacillidae	1	2.38	2	3.57	60	0.3
	Total	**42**	**100**	**56**	**100**	**19826**	**100**

Porphyrio porphyrio, *Gallinula chloropus*, *Anas poecilorhyncha*, *Tachybaptus ruficollis*, *Ardeola grayii*, *Nycticorax nycticorax*, *Ceryle rudis*, *Alcedo atthis*, *Halcyon smyrnensis*, *Ardea cinerea, Ardea purpurea*, *Egretta garzetta*, *Mesophoyx intermedia* and *Casmerodius albus* were found residential. However, bird species viz., *Anhinga melanogaster*, *Anas querquedula*, *Anas clypeata*, *Anas penelope*, *Anas acuta*, *Anas crecca* and *Limosa limosa* were regular migrants to Kalpakkam during winter. Most of the birds were vagrants found occasionally on wetlands. *Gallirallus striatus, Vanellus cinereus, Rostratula benghalensis, Phalacrocorax fuscicollis*, *Dupetor flavicollis*, *Plegadis falcinellus*, *Amaurornis phoenicurus*, *Numenius arquata, Tringa ochropus* and *Motacilla flava* were represented by a few individuals during the entire study period. However, the predominant waterbird species was *Anas poecilorhyncha* (4246 individuals), followed by *Nycticorax nycticorax* (1016 individuals), *Anastomus oscitans* (904 individuals) and *Bubulcus ibis* (832 individuals). In addition, flocks of shore birds viz *Pluvialis fulva*, *Tringa totanus* and *Tringa nebularia*, *Gelochelidon nilotica*, *Sterna hirundo*, *Larus brunnicephalus, Sterna caspia*, *Larus ichthyaetus* species were predominant during winter and some solitary species such as *Numenius arquata*, *Esacus recurvirostris* and *Burhinus oedicnemus* were also encountered in the present study.

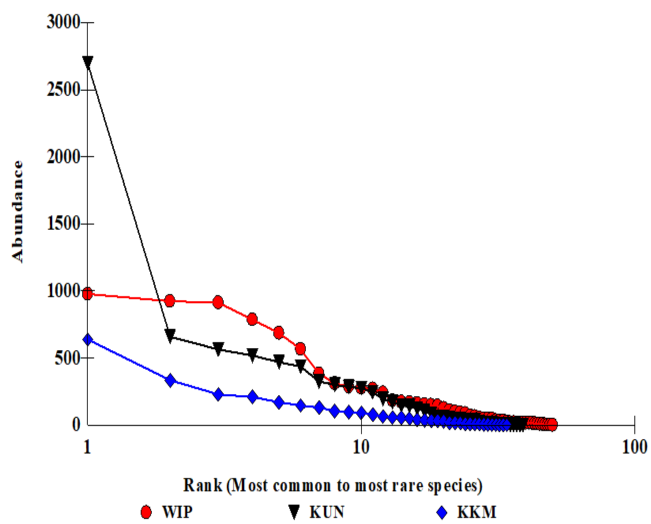

Figure 2. Species rank abundance plot of different wet habitats

Spatial Abundance and Diversity Patterns of Waterbird

The shallow marshy wetlands were supported with relatively significant numbers of avian species abundance than the deeper lake. Which is clearly showed in the analysis of diversity in the present study area (Table 4). The fisher alpha diversity indicated that the following wetlands in a decreasing order of waterbirds diversity in Kalpakkam; WIP (7.00), KKM (5.47) and KUN (5.32). The Shannon's diversity index showed the same pattern with minor variations. The Simpson and Shannon J (evenness) indices revealed that at swallow marsh, individuals were evenly distributed among the species in comparision to deeper lake. In addition the swallow marshes showed highest number of shared species (38 species) and very close similarity of species composition between the marshes. To find out the abundance pattern for different wetland habitats, the rank abundance curve was plotted (Figure 2). Species abundance of waterbirds has showed that, the single species occurred in relatively high number at KUN marsh. In the present study the overall abundance dominated by *Anas poecilorhyncha,* this is due to its local movement and aggregations, particularly at KUN marsh and KKM lake during summer. Furthermore, the dominance of a species in an ecosystem reveals its survival superiority over than other species. This is clearly showed that high numbers of rare and few abundant species at shallow marshes. This unevenness is clearly evident from Simpson index (Table 4). Which is also supported that the equitability of Shannon J.

Waterbird Abundance, Richness and their Correlation/ Association with Weather Parameters

The observed waterbird abundance and richness from all site counts were pooled and considered as a month of collection. Dynamic shift in monthly richness and abundance pattern was observed during the entire survey period. At Kalpakkam, major abundance peaks were

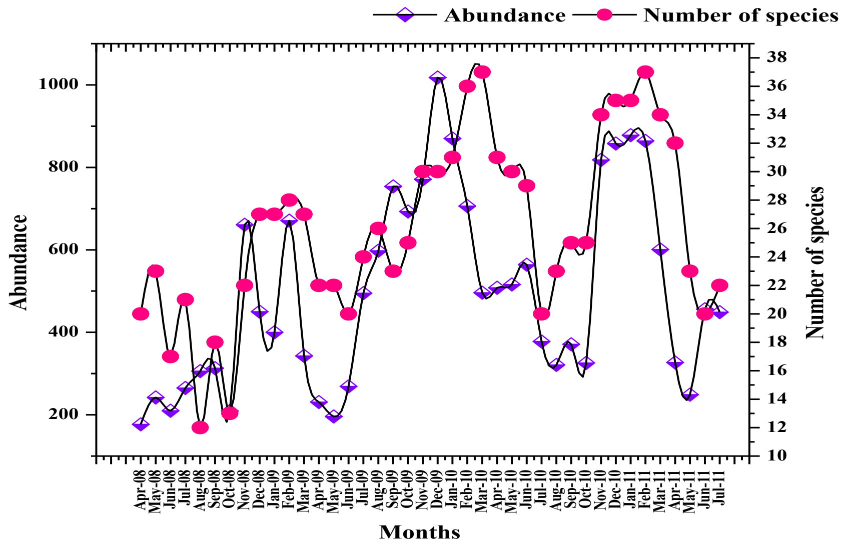

Figure 3. Abundance and richness profile of waterbirds observed in different months

Table 4. Diversity index and abundance scores for waterbirds communities along habitats

Diversity indices	WIP	KUN	KKM
Fisher α-diversity	7.00	5.32	5.47
Shannon (H')	1.363	1.137	1.194
Simpson (D)	0.061	0.138	0.098
Shannon (J)	0.802	0.714	0.779
Abundance (Nos.)	8894	8200	2731

observed in the period of November to February during the successive years and second major peak in the months of July and August. Similar trend was observed for richness too (Figure 3). Though the increased number of waterbird species was closely associated with wetter months and winter period, the abundance and richness fluctuation was not significantly correlated with rainfall factors (Table 5). But interestingly, temperature showed strong negative influence on waterbird abundance (r = -0.643, p = <0.01) and richness (r = -0.523, p= <0.01). The result of the CCA on the wetland bird communities at three different wetland locations are shown as a biplot of species along the first two axes of the ordination in Figure 4. The first two axes explained 7.8% and 11.4 % of the variance in the dataset respectively. The vectors for the species scores and environmental variables collectively explained 38.2 % of the variance in the species-environment relationship on the first axis and 17.9% along the second axis. The both axes explain a total variance of about 56.1%. The capacity to explain variation in wetland bird community composition is confirmed by species-environmental correlation coefficients, which were 0.809 for the first and 0.800 for the second axis. The Monte Carlo permutation tests were used to identify the environmental factors that influenced the variance of waterbirds assemblage and species abundance pattern significantly (p< 0.05 level). Axis 1 is strongly associated with aquatic vegetation cover (r = 0.634) and dissolved oxygen (r = 0.605), variable such as water depth is (r = 0.662) closely linked with axis 2. While salinity (r = 0.474) and total nitrogen (r = 0.441) are closely linked with axis 3. Single variable total phosphate characterized (r = 0.503) the fourth axis (Table 6). Variance, that most strongly associated to wetland community structure were the depth of the wetland (WDEP), aquatic vegetation cover (VECO), water temperature (WTEM) and dissolved oxygen (DO) (Figure 4). The abundance of *Larus brunnicephalus* (BRGU), *Gallinago gallinago* (COSN), *Anhinga melanogaster* (DART), *Alcedo atthis* (SMKI), *Ceryle rudis* (LEKI), *Phalacrocorax niger* (LICO) and *Phalacrocorax carbo* (GRCO) were plotted along water gradient with site preferability. However, *Tringa stagnatilis* (MASA), *Himantopus himantopus* (BLST), *Tringa glareola* (WOSA), *Casmerodius albus* (LAEG), *Charadrius dubius* (LIPL), *Mesophoyx intermedia* (MEEG), *Anastomus oscitans* (ASOP), *Vanellus malabaricus* (YELA), *Tringa ochropus* (GRSA), were plotted on the opposite side of the water depth gradient indicating their preference towards very shallow water bodies. Species namely *Platalea leucorodia* (SPBI), *Tringa totanus* (COSH), *Rostratula benghalensis* (GRSN), *Porphyrio porphyrio* (PUMO), *Gallinula chloropus* (COMO), *Amaurornis phoenicurus* (WHHE), *Ardea purpurea* (PUHE), *Tachybaptus ruficollis* (LIRG), *Dendrocygna javanica* (LEWH) and *Motacilla maderaspatensis* (LAWA) were found associated with increasing water temperature and pH gradient. Similarly species aggregated on the opposite side of the above gradient *Anas acuta* (NOPI), *Anas Penelope* (EUWI), *Anas clypeata* (NOSH) and *Anas querquedula* (GARG)) were positively increased with increasing aquatic vegetation cover during the present investigation.

DISCUSSION

Wetland Type and Waterbird Diversity at Different Wetlands

Seasonal fluctuations in abundance and number of waterbird species have been studied in several temperate, as

Table 5. Correlation analysis between waterbirds diversity, density with abiotic factor

Factors	Temperature (C°)	Rainfall (mm)	Humidity (%)	Rainy days (no)
Richness	-0.523*	0.102	0.086	0.111
Abundance	-0.643*	0.372	0.015	0.388

**significance at p < 0.05*

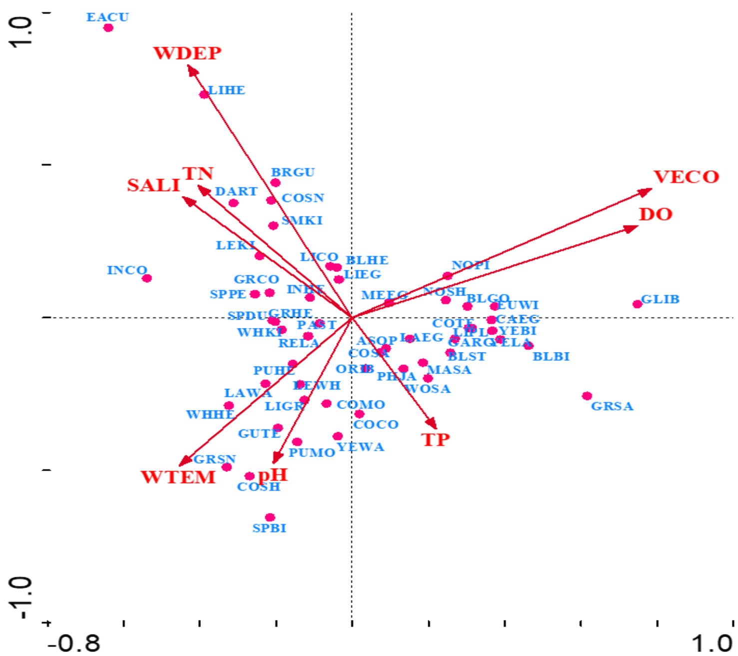

Figure 4. Distribution of species scores of waterbirds and environmental variables based on the first and second axes from CCA. Bird species scores are represented by points and environmental variables are represented by vectors. The vector lines represent the relationship of significant environmental variables to the ordination axes; their length is proportional to their relative significance. Furthermore, the direction of each arrow in relation to the axes indicates how well it is correlated with it. Locations of the individual bird species relative to the arrows display the environmental conditions associated with the occurrence of the species.

Table 6. CCA summary for waterbird community

	Axes				Total inertia
	1	2	3	4	
Eigenvalues	0.367	0.171	0.115	0.107	4.728
Species-environment correlations	0.809	0.800	0.700	0.668	
Cumulative percentage variance of species data	7.8	11.4	13.8	16.1	
Cumulative percentage variance of species-environment relation	38.2	56.1	68.0	79.1	
Correlation coefficient					
Water depth (WDEP)	-0.348	0.662*	0.070	0.000	
Water temperature (WTEM)	-0.366	-0.388	0.086	-0.075	
Dissolved oxygen (DO)	0.605*	0.240	0.101	-0.337	
pH	-0.166	-0.381	0.215	-0.174	
Salinity (SALI)	-0.359	0.316	0.474*	0.112	
Total nitrogen (TN)	-0.327	0.346	0.441*	0.162	
Total phosphate (TP)	0.178	-0.291	0.177	0.503*	
Aquatic vegetation cover (VECO)	0.634*	0.338	-0.165	0.002	

**significance at $p < 0.05$*

well as in tropical countries (Anderson *et al.,* 1981; Blake and Loiselle, 2000; Robinson *et al.,* 2000; Latta *et al.,* 2003; Blake, 2007). In India, the avian diversity was documented well at various places and most of the studies dealt with checklist, population dynamics and seasonality (Subramanean and Davidar, 2004; Jain *et al.,* 2005; Praveen and Joseph, 2006; Kannan *et al.,* 2008; Gupta *et al.,* 2009; Sreekumar *et al.,* 2011; Ramesh *et al.,* 2012). Very little is known about the waterbird diversity dispersion in different wetland habitats and ecological influences on their community. Hence, an attempt was made to survey the same at different type of water bodies viz., swallow marsh (WIP, KUN) and deeper lake (KKM), all of which attract large number of migrant birds (Hussain *et al.,* 2011). Totally 310 species of wetland birds were found in India (Arun Kumar *et al.,* 2005).Compared with this, 18% of species were observed in the present study area. This shows a remarkable diversity within a small patch of coastal plain. Moreover the avifaunal diversity is reported higher in this unique habitat not only because of protection in the high security zone of Kalpakkam, but also because of habitat heterogeneity and availability of different water sources viz., marshlands, lake ecosystem, backwaters, sea coast, and the riparian corridors.

However, the birds are the most conspicuous and significant component of freshwater ecosystem. Presence or absence of birds may indicate the ecological conditions of the wetlands (Rajpar and Zakaria, 2011). The interspecific difference in wetland habitats use by waterbirds showed that species abundance and richness, in which both were high at swallow marshes. Although the size of the wetland and distance among the wetlands were not much large in the present study area, the water birds clearly showed preference towards marsh habitat to deeper lake. The wading and dabbling birds are most dominant waterbird groups in most regions worldwide, the greatest waterbird diversity and abundance generally occur at relatively shallow waters (Colwell and Taft, 2000; Froneman *et al.* 2001; Isola *et al.* 2002; Taft *et al.* 2002; Elphick and Oring, 2003; Romano *et al.* 2005). The present observation was in accordance with earlier observation such as, the number of dabbling bird *viz. Tachybaptus ruficollis*, *Anas penelope*, *Anas poecilorhyncha*, *Anas clypeata*, *Anas acuta*, *Anas querquedula*, *Anas crecca* and wading birds such as *Anastomus oscitans*, *Bubulcus ibis*, *Egretta garzetta*, *Ixobrychus sinensis*, *Dupetor flavicollis*, *Platalea leucorodia*, *Plegadis falcinellus*, *Threskiornis melanocephalus*, *Limosa limosa*, *Himantopus himantopus*, *Charadrius dubius*, *Tringa stagnatilis*, *Tringa glareola*, *Actitis hypoleucos*, *Amaurornis phoenicurus*, *Porphyrio porphyrio*, *Gallinula chloropus*, *Fulica atra* were high in shallow marshy wetlands, whereas the abundance of diving birds namely Cormorants, Darter, Kingfishers were relatively high at comparatively deeper KKM lake. Ma *et al.* (2010) suggested that the non-diving waterbirds, such as wading and dabbling birds, generally require shallow water to forage, and their access to foraging habitat is limited by water depth. In contrast, diving waterbirds require deep water, and their access to foraging habitat is limited by the minimum water depth that allows them to dive. In addition, the water depth directly determines the accessibility of foraging habitats for waterbirds, because of the restrictions of bird morphology, such as the lengths of tarsometatarsi (Collazo, O'Harra and Kelly, 2002; Darnell and Smith, 2004) or necks (Poysa, 1983). Larger species with longer necks, bills, and legs can feed in deeper habitats than smaller taxa. Gajardo *et al.,* (2009) identified that, the wetland area and water level fluctuations are the most important variables to determine the waterbird abundance. Wetland areas lower than one meter depth is a significant environmental phenomenon in determining species diversity. With this context it is interesting to compare the WIP site which was most rich and abundant, and exhibited continuous water level fluctuations during different seasons of the year. During monsoonal period, the level of water was not more than 35cm (three years mean) and area size was increased horizontally with relatively high percentage of aquatic vegetation cover. This unique feature attracted more waders and dabbling birds. This marked high abundance (8894 individuals), high diversity (50 species) and habitat unique species (12 species) at WIP marsh. This pattern occurred throughout the year except summer. When the WIP marsh was totally dried up, the birds migrated to KUN marsh and this was clearly evident from the high number of shared species (38 species) observed between these two marshy lands. Although, the KKM lake was perennial and comparatively deeper than the other two water bodies, the diversity and abundance was relatively low.

The habitat characteristics such as vegetation composition (emergent and submerged vegetations, grasses, shrubs, and trees), vegetation structures, (tree diameter and height) microclimate variables (temperature and relative humidity) and prey availability were the key factors that influenced the distribution, diversity and abundance of the wetland bird species (Martinez, 2004; Rajpar and Zakaria, 2011). Furthermore, the species richness and diversity were associated with resource availability and with environmental heterogeneity (Keddy, 2000). The aquatic plants and associated insects are ideal food source for many of migratory ducks and local avian fauna. Additionally, the aquatic vegetation also provides a suitable habitat for many invertebrate and fish production (Haag *et al.,*1987; Brendonck *et al.,* 2003). In the present study aquatic floral species such as *Ceratophyllum demersum*, *Hydrilla verticillata*, *Bacopa monnieri* and *Nymphaea pubescens* were important food sources that were relatively more predominant at marshy lands. Earlier studies suggested that the saline wetland water level is inversely correlated with the salt concentration. These conditions influence the presence, abundance and diversity of food resources such as fishes, submerged macrophytes, invertebrates and algae, which are in turn affecting the wetland bird abundance (Bucher *et al.,* 2000). Thus the present study clearly indicated that the aquatic vegetation cover was very low in the centre and periphery region of deeper lake and was dominated by the salt tolerant *Enteromorpha* sp. This could be due to the fact that the KKM lake isless shallow and saline (8-10 ppt). In addition, *Typha latifolia* was present only at marshy wetlands which were important surrounding vegetation and it acts as biofence to the wetland and thereby attracted many of the birds during nesting period.

Temporal Abundance and Seasonality of Waterbirds

A total number of 56 waterbirds species were recorded in many months across different areas, and it showed distinct diversity and abundance patterns during entire investigation. The numbers of species and abundance were high during November to March. Similarly, species abundance was significantly higher during the same period, and also during May and June, which corroborates with findings of researchers from other areas in India (Bhupathy *et al.,* 1998; Nirmala, 2002; Jayson, 2002; Padhye *et al.,* 2007). Elmberg *et al.* (1993) found that the local abundance of food, water levels and habitat structure are the most important factors associated with the spatio-temporal dynamics of many aquatic birds. However, the abundance fluctuation were due to the local movements within and among habitats in response to food availability, less disturbance and conducive weather, which probably attracted huge numbers of waterbirds during this period to Kalpakkam.

Abiotic Factor Influence on Waterbird Community

There are many significant environmental factors such as air temperature, rainfall, relative humidity and habitat parameters that influence the wetlands and waterbirds directly and indirectly (Colwell and Taft, 2000; Romano *et al.,* 2005; Ma *et al.,* 2010; Cintra 2012). Thus in the present study the waterbird diversity and their abundance were proportionate to the negative relationship with air temperature and moderately with rainfall and rainy days. Temperature being primary driving force for seasonal migration of waterbirds and primary productivity of wetlands, affects the development physiology of the invertebrates in the wetland system and the waterbird abundance (Rehfisch, 1994). CCA analysis of present study (Figure 6) confirms the above fact as more weightage were given to the aquatic vegetation, water depth and water temperature vectors. These were considered as major factors driving the waterbird communities in the wetland ecosystem at Kalpakkam. The Monte Carlo permutation tests also confirmed significant association ($p < 0.05$) between these environmental variables and waterbirds distribution. Frost, Schleicher and Craft (2009) stated that the enhancement of nitrogen and phosphorous levels in water bodies increases productivity, which improves the species richness and abundance of waterbirds (Acuna *et al.,* 1994; Hoyer and Canfield, 1994; Holm and Clausen, 2006). CCA of present study also confirmed the close association of waterbirds with the Total Prosperous (TP) and moderately with Total Nitrogen (TN) and salinity (SALI). Furthermore, the organic matter content in water and sediments affects the growth of aquatic plants, and determines invertebrate abundance (Rehfisch, 1994). Particle size of sediments determines the penetration of water and oxygen in sediments and their by influencing the meiofauna and epifaunal invertebrates (Little, 2000). There are other variables which influence the habitat use of waterbirds that might be difficult to regulate and practice in wetland management (Ma *et al.,* 2010). The findings of present study strongly suggest that level of waters at the lake, aquatic vegetation cover, habitat richness, seasonal rainfall and other physical properties are the most important determinants, governing the waterbird richness, abundance and community composition in the Eastern coastal plains of India.

The number of quantitative studies of how the habitats affect the use of wetlands by waterbirds has been rapidly increasing over the past few decades. The habitat variables interact to indirectly influence the waterbird use of wetlands (Ma *et al.,* 2010). However, the wetlands management usually focuses on very few habitat variables and other microclimate variables. The interaction of these variables remains largely unexplored in both research and practice around the world, especially in India. Consequently, the present investigation viewed the outline of overall waterbird diversity, abundance, other governing important variables and also the seasonality. This will possibly be of great use to understand the wetland system and implementation of effective management.

LIST OF ABBREVIATION USED

KKM- Kokilamedu Lake, KUN- Kunnathur Marsh, Waste Immobilization Plant- WIP Marsh, WTEM- Water Temperature, SALI- Salinity, TN- Total Nitrogen, WDEP- Water level, VECO- Vegetation Cover, DO- Dissolved Oxygen, TP- Total Phosphate, MON- Monsoon, SUM- Summer.

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