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PATTERNS OF SEASONAL ABUNDANCE AND DIVERSITY IN THE WATERBIRD COMMUNITY OF NAL LAKE BIRD SANCTUARY, GUJARAT, INDIA[1]

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Abstract. We studied the waterbird community of Nal Lake Bird Sanctuary (NLBS), Gujarat State, India, a proposed Ramsar Site and Wetland of International Importance, to determine site-specific seasonal variation in abundance and diversity. The study was conducted at eight selected sites in NLBS from March 2004 to February 2005. Data were gathered monthly to ensure quantification of seasonal changes in diversity and density. Overall, 109 waterbird species belonging to 64 genera and 18 families were documented, including 42 year-round residents and 67 seasonally present or migratory species. Among these, 8 species were considered to be abundant, 51 common, and 50 rare. Overall waterbird density was highest where resident species such as Grey Heron (*Ardea cinerea*), Little Egret (*Egretta garzetta*), Median Egret (*Mesophoyx intermedia*), Red-wattled Lapwing (*Vanellus indicus*) and Black-winged Stilt (*Himantopus himantopus*) were present; some migratory species such as Greater Flamingo (*Phoenicopterus ruber*), Graylag Goose (*Anser anser*), Common Coot (*Fulica atra*) and Whiskered Tern (*Chlidonias hybridus*) contributed to areas of high density. Diversity was high where profuse growth of emergent aquatic vegetation and low human disturbance was evident; it was low at sites that experience high levels of pollution and tourism. The abundance and composition of the waterbird assemblage was affected by the interplay of several factors, including site-specific presence of certain species,

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habitat fragmentation and the presence of core refugial habitats. Recommendations for management and research are made to ensure the effective conservation of waterbird populations and their habitats in this region.

Key words: Nal Lake Bird Sanctuary, Gujarat, India, species diversity, waterbird community, waterbird management.

PATRONES DE ABUNDANCIA Y DIVERSIDAD ESTACIONAL EN LA COMUNIDAD DE AVES ACUÁTICAS DEL SANTUARIO DE AVES DEL LAGO NAL, GUJARAT, INDIA

Resumen. Estudiamos la comunidad de aves acuáticas del Santuario de Aves del Lago Nal (Nal Lake Bird Sanctuary, NLBS), Gujarat State, India, un lugar propuesto como Sitio Ramsar y Humedal de Importancia Internacional, para determinar la variación estacional local en abundancia y diversidad. El estudio fue llevado a cabo en ocho sitios del NLBS entre marzo de 2004 y febrero de 2005. Los datos fueron colectados mensualmente para asegurar la cuantificación de cambios estacionales. En conjunto, documentamos la presencia de 109 especies acuáticas pertenecientes a 64 géneros y 18 familias, incluyendo 42 residentes permanentes y 67 especies estacionales o migratorias. Entre estas, 8 especies fueron consideradas abundantes, 51 comunes, y 50 raras. La densidad general de aves acuáticas fue mayor donde especies residentes como *Ardea cinerea, Egretta garzetta, Mesophoyx intermedia, Vanellus indicus*, e *Himantopus himantopus* estaban presentes; algunas especies migratorias como el flamenco *Phoenicopterus ruber, Anser anser, Fulica atra* y *Chlidonias hybridus* contribuyeron también en áreas de alta densidad. La diversidad fue alta donde eran evidentes la profusión de vegetación acuática emergente y la baja perturbación humana; fue baja en lugares que experimentan altos niveles de polución y turismo. La abundacia y composición de la comunidad de aves acuáticas se vieron afectadas por la interacción de diversos factores, entre ellos la presencia local de ciertas especies, la fragmentación del hábitat y la presencia de zonas de hábitats relictuales. Aportamos recomendaciones para el manejo y la investigación a fin de asegurar la conservación efectiva de las poblaciones de aves acuáticas y sus hábitats en esta región.

Palabras clave: comunidad de aves acuáticas, manejo de aves acuáticas, diversidad de especies, Nal Lake Bird Sanctuary, Gujarat, India

INTRODUCTION

The conservation of wetlands has become a frequent topic among wildlife managers. Wetlands are important conservation sites due to their rich biodiversity, they are among the most productive ecosystems in the world, and they harbor many globally threatened species (Casado and Montes 1995, Green 1996, Petrie 1998, Getzner 2002). Diverse wetland complexes are of greatest value in providing habitat for wetland bird species (Miller 2003).

Over 90% of Earth's wetlands have been lost during the past 150 years (Kempka et al. 1991), along with increased habitat fragmentation within those that remain (Van Vessem et al. 1997).

The major problem is agricultural expansion and urban development (Shuford et al. 1998; Shine and Klenm 1999). One associated result is the loss of native aquatic seeds consumed by waterbirds (Petrie and Rogers 1996). These historical reductions in water and food availability have forced most waterbirds to migrate towards riverine systems of semi-arid areas and subtropical regions during winter (Raeside 2005).

Current efforts to increase wetland habitats are hampered by a paucity of biological data (Streeter et al. 1993, Shuford et al. 2004). One key type of information involves the factors that affect the abundance of aquatic birds in a given wetland, an abundance that may differ depending on the time of day, season or year in which the bird surveys are conducted (Miller 2003). To address this data gap in India, we coordinated counts of waterbirds at Nal Lake Bird Sanctuary (NLBS) from March 2004 to February 2005, and report here the pattern of seasonal, site-specific variation in species abundance and diversity for this Ramsar Site and Wetland of International Importance (Davis 1994, Frazier 1996, GSFD 2005). Similar studies have been carried out, for example, in such areas as the altiplano wetlands of north-western

Argentina (Colwell and Taft 2000, Caziani et al. 2001), after which we modeled our investigations. We make recommendations for management and future research to ensure effective conservation of waterbirds in this region of India.

MATERIALS AND METHODS

STUDY AREA

Nal Lake Bird Sanctuary is located between 22º 78′ N to 22º 96′ N latitude and 71º 92′ E to 72º 64′ E longitude, amidst the semi-arid lands of Ahmedabad and Surendranagar districts, 65 km from Ahmedabad. Biogeographically, the area falls in the 4-B Gujarat-Rajwara biotic province of the semi-arid biogeographical zone (Rodgers and Panwar 1988). The legal area of the sanctuary is 120.89 km^2. The sanctuary supports more than 300 islets, most of which fringe its western boundary. It receives water mainly from two rivers, Brahmini and Bhogavo, flowing from its northern border (Fig. 1). The entire area experiences three distinct seasons: winter (November to February), summer (March to May), and monsoon (mid-June to mid-October). Average temperature varies from 45º C during summer to 7º C during winter. Annual rainfall ranges from 500 to 600 mm.

The unique geographical location, climate and topography have endowed NLBS with great floral and faunal diversity. This natural shallow lake flourishes with 48 species of phytoplankton, 76 species of zooplankton and 71 flowering plants, including more than 30 species of aquatic macrophytes. The lake fauna includes >20 species of fish, 11 species of herpetofauna, 216 species of birds, including 160 species of waterfowl of both resident and migratory species, and 13 mammalian species including the threatened Indian Wild Ass (*Equus hemionus khur*) and Blackbuck (*Antelope cervicapra*) (GEER 1998).

SITE SELECTION

As NLBS includes an extensive geographical and hydrobiological regime, preliminary visits were made to assess sites that could be consistently surveyed (see Nirmal Kumar and Rita Kumar 2000). The entire area was assessed from all directions by approaching peripheral boundaries by road, walk-ways on banks and by boats. Discussions with knowledgeable local experts were included in the reconnaissance. In total, eight survey sites were selected (15 to 20% of NLBS) so as to cover the longitudinal cross-section of the entire lake ecosystem: Site-1 (upstream of Brahmini River) and Site-2 (Downstream of Brahmini River) fringe the northern boundary of the lake; Site-3 (Bendi Bet) is an unperturbed site; Site-4 (Dharbla Bet) is a tourist spot for recreational activities; Site-5 (Core Zone/*Sanctum sanctorum*), is an 8 km^2 area forming the central portion of the lake; Site-6 represents the south-west border (Mahatal Bet); Site-7 represents the lake's southern limit (Bajot Bet) and Site-8 (Dakthali) occurs at the southeastern periphery of the sanctuary.

SURVEYS

We counted waterbirds by species from March 2004 to February 2005, visiting each site monthly. We surveyed only settled birds present in and around each site, and did not include flying individuals in order to minimize over- or underestimation (Javed and Kaul 2002).

The total surface area of large sites was estimated using width, length and configuration dimensions acquired from 1:50,000 base maps (Raeside 2005). Small site-dimensions were estimated by pacing lengths and widths. In order to derive a consistent measure of waterbird abundance among sites of different sizes, raw abundance values were divided by the total area of the site for a measure of waterbird density (Reynolds et al. 1980). Because of the huge expanse of the study area and varying logistical constraints among sites and habitats, we used a combination of survey methods (Bibby et al. 1992, Miller 2003, Shuford et al. 2004) including sampling of nesting and breeding grounds. Large flocks of birds were estimated by 10's or 100's; if necessary, on occasion we flushed birds to count them in the air (Guadagin et al. 2005).

Sites 3, 4, 6, 7 were covered by walking on the island and sites 1, 2, 5, 8 by canoe. Sites with thick emergent vegetation were walked in order to flush birds into view. However, to avoid unnecessary flushing, binoculars and spotting scopes were used to observe as much as possible from a distance (Buckland et al. 1993). To prevent double counting, all birds flushed from a wetland were watched for ingress and egress.

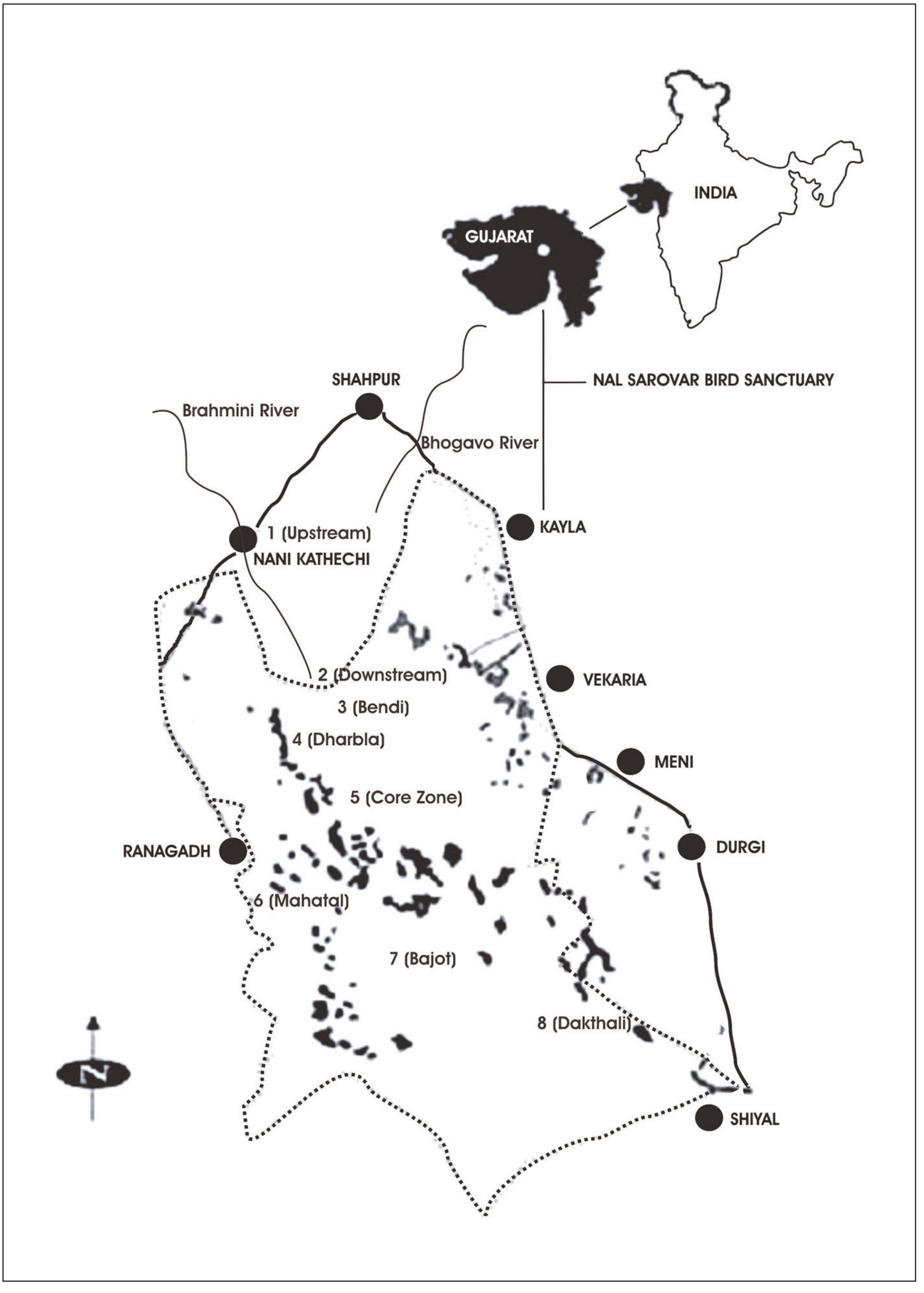

FIGURE 1. Surveyed sites in Nal Lake Bird Sanctuary (NLBS); the numbers preceding various place names are used in other tables and figures in this report.

All wetland birds seen or heard during the first 15 min following arrival were recorded for later analysis. We proceeded to adjacent sites in a direction that avoided the counting of displaced birds; however, the direction around each site was alternated to procure maximum possible species diversity. In total, 10 surveys were conducted in 2004 and 2 in 2005 for all eight sites. Some sites required more time than others. The time needed to complete surveys ranged from 3 to 6 hrs either in the morning or evening (06:00 to 10:00, 16:00 to 18:00 hrs). Some passerines and purely terrestrial birds were not included. The occurrence status of the species was determined as per GEER (1998).

STATISTICAL METHODS

A Station Index Method (SIM) was used in the assessment (see Verner 1985). Therefore, the density of birds (per km^2) was calculated for those recorded within 250 m^2 (in all four directions) of each viewing site.

A comprehensive list of recorded avian species was prepared (Appendix I). All surveys were pooled for analyses (Ludwig and Reynolds 1988). Site-specific total abundance, mean total abundance, total density and mean total density, along with number of species of all eight sites were calculated in order to evaluate how wetland bird abundance differed among sites and seasons (Conover 1980, Ott 1984). Total abundance (number of birds per site) and species richness (number of species per site) were included in the summaries. The unilateral *F*-test compared totals among all eight sites and seasons against overall species richness to check if significant differences existed in the number of species by season.

The 12-months of data were pooled to compare various indices of species diversity, i.e. "concentration of dominance" over the entire community (Odum 1996). These indices included (A) Dominance (Simpson's Index; 1949) and (B) Species Diversity/Species Richness Indices: Odum's (1962), Margalef's (1958), Menhinick's (1964), Brillioun's (1951), Shannon–Weaver (H) (1963), and Evenness Index (Hill 1973) index.

Birds recorded with <100 individuals were considered as rare, those between 100 to 500 individuals as common, and those recorded >500 individuals as abundant (GEER 1998).

We referred to Magurran (1988), Colwell (1997) and other texts for statistical methods, performed using SPSS Version 12.0 (SPSS Inc., Chicago, IL) (Norusis 1993) and PC-ORD Version 4.0 Multivariate Analysis of Ecological Data (MJM Software Design, Gleneden Beach, OR) statistical software.

RESULTS

During the present study, 109 species of waterbirds were documented, represented by 64 genera of 18 families. Of these, 42 species (38.5%) were resident and 67 species (61.5%) were found to be migratory or seasonally resident. Abundant species (8, or 7.3%) included resident waterbirds such as Asian Openbill (*Anastomos oscitans*) and Glossy Ibis (*Plegadis falcinellus*), and migratory birds such as Greater Flamingo (*Phoenicopterus ruber*), Graylag Goose (*Anser anser*), Common Coot (*Fulica atra*), Black-tailed Godwit (*Limosa limosa*), Ruff (*Philomachus pugnax*) and Whiskered Tern (*Chlidonias hybridus*). What we considered to be common birds totalled 51 species (46.8%), while only 50 species (45.9%) were found to be rare (Appendix I).

Community composition varied by season (Fig. 2). The highest number (100%) of families was recorded during summer and winter, followed by 83.3% during the monsoon period. On the basis of genus, the highest number (100%) occurred during winter, followed by summer (79.7%) and monsoon (65.6%); a similar pattern was evident among species: winter (94.5%), followed by summer (72.5%) and monsoon (53.2%). Resident species made their greatest contribution during winter (97.6%), followed by 85.7% each during summer and monsoon. All species considered to be abundant occurred during winter and summer (100% each), followed by 87.5% during monsoon, while peak values of species of common occurrence occurred during winter (98.04%), followed by summer (96.1%) and monsoon (78.4%). Among rare species, 90% were present during winter, followed by summer (44%) and monsoon (22%). Overall, waterbirds were most abundant during summer (67.3%), followed by winter (36.7%) and monsoon (10.4%). The abundance of waterbirds recorded during different seasons at NLBS largely corresponded to their density. The density of waterbirds was

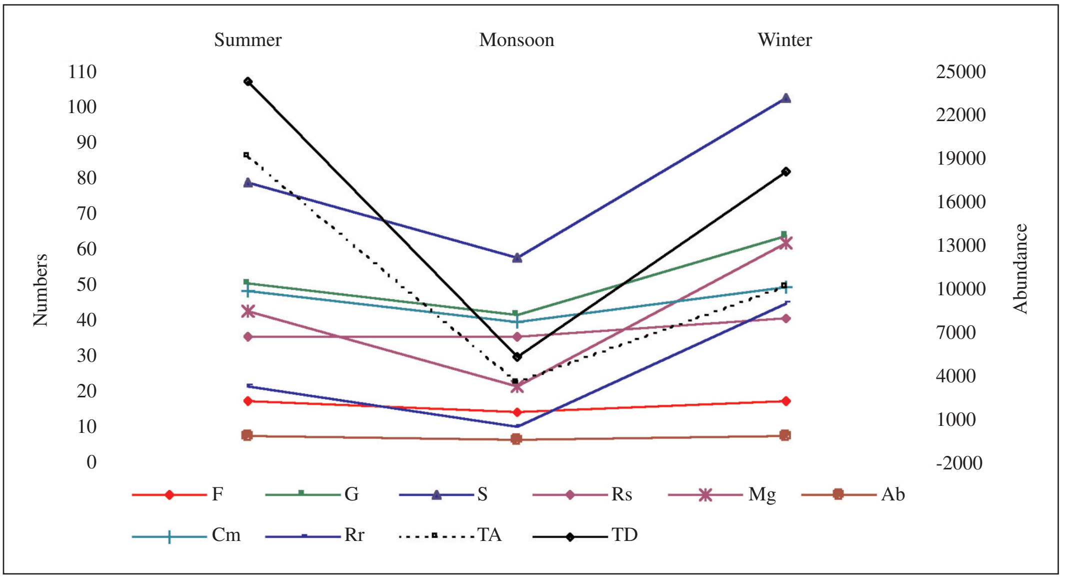

FIGURE 2. Seasonal patterns of overall waterbird abundance at NLBS. F refers to Family, G to Genera, S to Species, Rs to Resident, Mg to Migrant, Ab to Abundant, Cm to Common, Rr to Rare; and TA= Total Abundance, TD = Total Density.

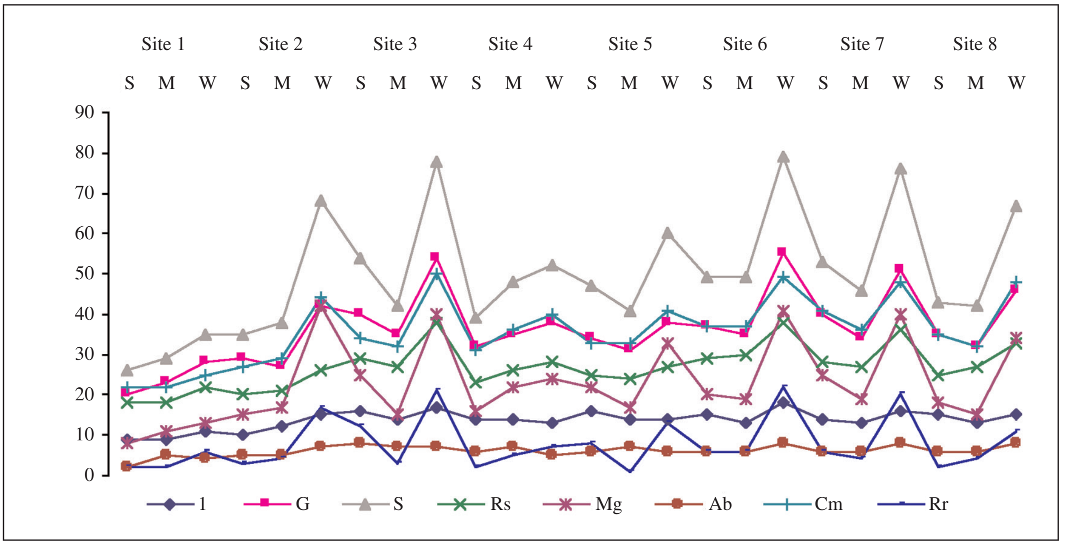

FIGURE 3. Site-specific occurrence of waterbirds at NLBS by season; see Methods for description of Sites and Figure 2 for definition of symbols.

maximum during summer (69.66%), followed by winter (52.0%) and monsoon (15.6%). Similar observations were made by Ericia et al. (2005).

The lowest number of families was recorded at Site 1 (50%) during summer and monsoon, while the highest was documented at Site 6 (100%, all families) during winter (Fig. 3). Among genera, abundance was lowest at Site 1 (31%) during summer and highest at Site 6 (86%) during winter. On the other hand, Site 1 had the lowest number of species (24%) during summer, while Site 6 (72%) had the highest during winter. Only 43% of resident species were recorded at Site 1 during summer, and almost 90% at Sites 3 and 6 during winter. Low numbers of migratory species were documented at Site 1 (12%) during summer, while almost 63% of migratory species were present at Site 2 during winter. Among abundant species, only 25% were recorded at Site 1 during summer, but sites 3, 6, 7 and 8 were found to support all the abundant species during winter. Only 43% of common species were found at Site 1 during summer, while almost 98% were at Site 3 during winter. As for rare species, Site 5 had only 2%, but Site 6 had 44% during winter. In general, Site 1 harbored the lowest number of waterbirds during summer in contrast to Site 6, which supported highest waterbird populations during winter. Thus the gradient of waterbird numbers among study sites was: site 1 < sites 2, 3, 4, 5, 7 < site 6.

The waterbird populations of NLBS fluctuated among sites in different seasons due to local, environmentally dependent factors (see also Hill et al. 1993; Tables 1, 2). Abundance was low at Site 1 (141 birds) during monsoon and was highest at site 5 (5,601) during summer. Mean abundance per month was 35.2 birds, total density was 191.3 birds/km^2 and mean density per month was 47.83 birds/km^2. By and large, the overall population of waterbirds during monsoon was low due to greater water depth, which favors only diving ducks, e.g. *Tachybaptus, Anas*, etc. The highest waterbird populations were recorded during summer (Masero et al. 2000) owing to low water depth and exposure of shores, banks, muddy islands and mudflats, which increases habitat complexity. The latter factors encourage larger numbers especially of large birds, e.g. *Pelecanus, Ardea, Ardeola, Anastomus, Mycteria, Phoenicopterus, and Grus* spp., as well as small waders, e.g. *Capella, Gallinago, Actitis, Calidris*, and *Tringa* spp. Overall, the total abundance of waterbirds was low (3,675 individuals) during monsoon, and high during summer (19,151), with the mean abundance per month of 919 birds, mean total density of 5,468 birds/km^2 and mean density per month of 1,367 birds/km^2. Considered by site, during monsoon the region supported low numbers at Site 1 and highest numbers at Site 6 (see Table 2).

The unilateral *F*-test on the overall species richness at NLBS in different seasons (separately against all three seasons), indicated significant

TABLE 1. Waterbird abundance and density in different seasons at NLBS.

Sites	TA			MA / Month			TD			MD / Month		
	S	M	W	S	M	W	S	M	W	S	M	W
1	262	141	220	65.5±12.0	35.2±4.27	55.0±5.9	334.2	191.3	1315.0	83.6±9.7	47.8±4.7	328.8±50.3
2	430	289	1693	107.5±14.7	72.2±7.32	423.2±73.2	548.5	414.5	2047.2	137.1±14.2	103.6±9.2	511.8±66.8
3	2478	282	1484	619.5±124.1	70.5±5.81	371.0±36.8	3160.7	428.6	1991.1	790.2±121.1	107.1±8.4	497.8±31.5
4	1763	515	456	440.8±98.9	128.8±10.62	114.0±11.7	2248.7	656.9	1395.4	562.2±84.3	164.2±12.8	348.8±30.3
5	5601	1089	1206	1400.2±392.1	272.2±80.13	301.5±45.8	7144.1	1503.8	1821.4	1786.0±354.9	376.0±79.2	455.4±41.2
6	3608	496	2514	902.0±273.0	124.0±8.30	628.5±74.3	4602.0	1103.3	3091.8	1150.5±251.8	275.8±32.6	773.0±64.1
7	3490	582	1799	872.5±129.2	145.5±13.71	449.8±33.5	4451.5	788.3	2309.9	1112.9±127.7	197.1±15.8	577.5±30.2
8	1519	281	825	379.8±44.5	70.2±5.28	206.2±18.7	1937.5	381.4	4256.8	484.8±44.6	95.3±6.7	1064.1±100.0
Mean	2393.9	459.4	1274.6	598.5±610.8	114.8±80.90	318.7±222.9	3053.4	683.5	2278.5	763.4±89.4	170.9±14.3	569.6±43.5
NLBS	19151	3675	10197	4787.8	918.8	2549.2	24427.3	5468.1	18228.3	6106.8	1367.0	4557.1

TA: Total Abundance; MA: Mean Abundance; TD: Total Density; MD: Mean Density; S: Summer; M: Monsoon; W: Winter; means expressed ± standard error

TABLE 2. Seasonal abundance and density of waterbirds at NLBS by Site.

	Summer			Monsoon			Winter		
Sites	Mean	AD	SD	Mean	AD	SD	Mean	AD	SD
1	6.8	5.4	9.7	2.6	3.4	4.7	10.9	15.3	50.3
2	5.6	7.8	14.2	5.7	6.2	9.2	16.9	22.2	66.8
3	32.6	46.4	121.1	5.9	6.1	8.4	16.5	19.2	31.5
4	23.2	33.4	84.3	9.0	7.7	12.8	11.5	14.9	30.3
5	73.6	115.4	354.9	20.6	27.8	79.2	15.0	19.5	41.2
6	47.4	66.6	251.8	15.1	15.1	32.6	25.6	30.5	64.1
7	45.9	63.4	127.7	10.8	10.7	15.8	19.1	20.3	30.2
8	20.0	26.2	44.6	5.2	5.3	6.7	35.2	43.6	100.0
NLBS	31.5	39.7	89.4	9.4	8.7	14.321	18.8	23.2	51.8

AD: Average Deviation; SD: Standard Deviation

differences in the number of species among three different seasons ($p<0.05$) as follows: summer 4.790, monsoon 1.099, and winter 1.151. Based on this result, it is obvious that the monsoon season supports lowest abundance of waterbirds compared to summer. This might be due to site fidelities, site-specific environmental factors and the amount of anthropogenic interventions (Ericia et al. 2005).

During our study, 16 (14.7%) species were abundant at some time during the year (Figs. 4a, b). These species, *Phoenicopterus ruber, Plegadis falcinellus, Anastomus oscitans, Anser anser, Fulica atra, Chlidonias hybridus, Limosa limosa, Himantopus himantopus, Philomachus pugnax, Phoenicopterus minor, Actitis hypoleucos, Mycteria leucocephala, Threskiornis melanocephalus, Sterna albrifrons, Calidris minuta* and *Mesophoyx intermedia*, occurred widely in the study area (see also Dolman et al. 1995). They contributed almost 7.3% to the total species richness, and 82.1% to the total abundance.

Among all abundant waterbirds, the highest population (5,942 individuals), that of *Phoenicopterus ruber*, was recorded in July (1,869), followed by *P. falcinellus* (5,156) in May, *A. oscitans* (1,524) in February, *A. anser* (1,326) in June, *F. atra*, (1,276) in January, *C. hybridus* (1,163) in March, *L. limosa* (960) in June, *H. himantopus* (871) in March, *P. pugnax* (756) in April, *P. minor* (715) in May, *A. hypoleucos* (705) in March, *M. leucocephala* (636) in June, *T. melanocephalus* (609) in June, *S. albrifrons* (602) in March, *C. minuta* (571) in March and *M. intermedia* (536) in May. All 16 of these species, except *F. atra* (migrant, abundant in winter), were widely present during the post-winter period (February to March) due to low water levels, open mudflats and shallow banks (Atkinson-Willies 1976).

During this study, some waterbirds exhibited a very low frequency of occurrence and low abundance (Burton et al. 2000a, 2000b) (Appendix I). Only 9 species were sighted occasionally and showed sporadic distribution at NLBS: *Ixobrychus flavicollis, Tringa nebulari, Calidris ferruginea, Pelicanus crispus, Larus heuglini, Anas platyrhynchos, Calidris temminckii, Xenus cinereus* and *Ixobrychus sinensis* (Fig. 5). They were scattered in and around NLBS only during some months [frequency (n=1); abundance (N=1)]. Of these, *I. flavicollis* and *L. heuglini* were recorded in November; *T. nebulari* in April; *C. ferruginea, C. temminckii*, and *X. cinereus* in January; *P. crispus* and *A. platyrhynchos* in March; and *I. sinensis* in December. These rare species contributed only 0.8% to the total richness, and only 1.2% to the total abundance.

Overall, the values of various diversity indices varied from 0.10 to 0.63 for NLBS. Site-specific variations were as follows: Odum's index (0.11-Site 4 in winter; 0.99-Site 1 in summer), Margalef's index (0.10-Sites 6, 7, 8; 0.90-Site 2 in winter), Menhinick's Index (0.25-Site 1; 0.78-Site 6 in winter), Brillioun's Index (0.49-Site 1 in monsoon; 0.49-Site 5 in summer), Simpson's Index (0.10-Sites 6,7,8; 0.90-Site 2 in winter), Shannon–Weaver's Index (0.10-Site 4 in winter, Site–8 in monsoon; 0.97-Site 2 in monsoon), and Evenness Index (0.12- Site 1 in summer; 0.89-Site 6 in winter) (Fig. 6). A similar relationship was established by Elmberg et al. (1994) and

Walther and Martin (2001), respectively, with reference to estimation of species diversity and species richness.

DISCUSSION

In our study, counting methods, frequency of counting, and experience of field ornithologists were heterogeneous. Despite the integration of all data into one dataset, caution is still needed when interpreting trends and patterns (Ericia et al. 2005). This is especially true in the case of the effect of differences in monitoring frequencies that might bias the patterns for migrants that pass through the area only briefly or that use the area irregularly as a refuge (Goss-Custard 1991). The number of species observed in the 12-month census tended to reach an asymptote, however, suggesting that efforts recorded the true number of species at NLBS (Appendix I). Species composition differed among areas and months because of habitat differences, seasonal movement patterns, local and regional habitat changes, large-scale population changes and climatic conditions (see also Ericia et al. 2005). However, our results confirmed and indicated the importance of NLBS as a foraging and resting habitat for migratory waterbirds.

SPATIAL PATTERNS

Available habitat surface, the amount and type of food resources (which in turn are affected by water quality, salinity, hydrodynamic regime, sediment, soil texture and moisture), and the configuration of particular sites affected the number and species of waterbirds present (Hill et al. 1993). In the same way, proximity to suitable habitat is essential as high-water roost and additional feeding grounds, also contributing to the maintenance of high densities of foraging waders on mudflats (Masero et al. 2000).

At the scale of an entire freshwater wetland, a clear change in waterbird population was observed along a habitat gradient related to available surface area, habitat heterogeneity and food resources (Goss-Custard et al. 1995). Most waders (benthivores) were present during summer because of the presence of extensive mudflats, cultivated fields in surrounding areas, and a high benthic biomass (see Long and Ralph 2001). In contrast, geese and wigeons (herbivores), teal and gadwall were concentrated mainly during winter due to their migratory habits (see Kushlan 1993). Such groups of waterbirds may be considered as “wetland bioindicators” for an accurate assessment of the health of a particular wetland (Green 1995). In summary, the differences among waterbird populations at selected sites was related to their position along freshwater gradients, habitat type, shape and suitability and human land use in the vicinity (Ericia et al. 2005; Fig. 3, Table 2).

Due to monotonous reed vegetation, lack of inland roosts and available feeding grounds, sites 1 (upstream), 2 (downstrem) and 4 (recreation spot), offered the least interesting foraging and resting habitats for both herbivores and benthivores. On the other hand, large mudflats, exposed muddy islands and open shores at Sites 3, 6 and 7 provided ideal refuge and resting place for high numbers of waders during summer. Along with waders, the most heterogeneous mudflats and muddy banks hosted the most diverse assemblages of large waterbirds, including storks, flamingoes, herons, egrets, spoonbills, and pelicans. These findings agree well with the work of Ericia et al. (2005) in Lower Zeeschelde of the East Atlantic Region and of Demetrio et al. (2005) in fragmented wetlands of southern Brazil.

SEASONALITY

During our study, some species showed very distinct winter and/or migration peaks, but others exhibited a variable seasonal pattern according to winter severity. Varied winter effects were noticed during the study period for ducks like wigeon, Common Teal, pintail and Gargeny. In addition, the higher numbers of waders and large birds at the onset of summer could be related to the low water depth and the availability of exposed islands, which could be refuges (Appendix I). Such open muddy islands might serve as sites of population overflow when numbers are high (Melftofte et al. 1994). Seasonality and response to the above-mentioned factors differed greatly for all sites; sites were important at specific times and/or for different functions among resident as well as migrant species.

In the case of dominant species, our investigation revealed that certain species, such as flamingo, reached peak numbers during one

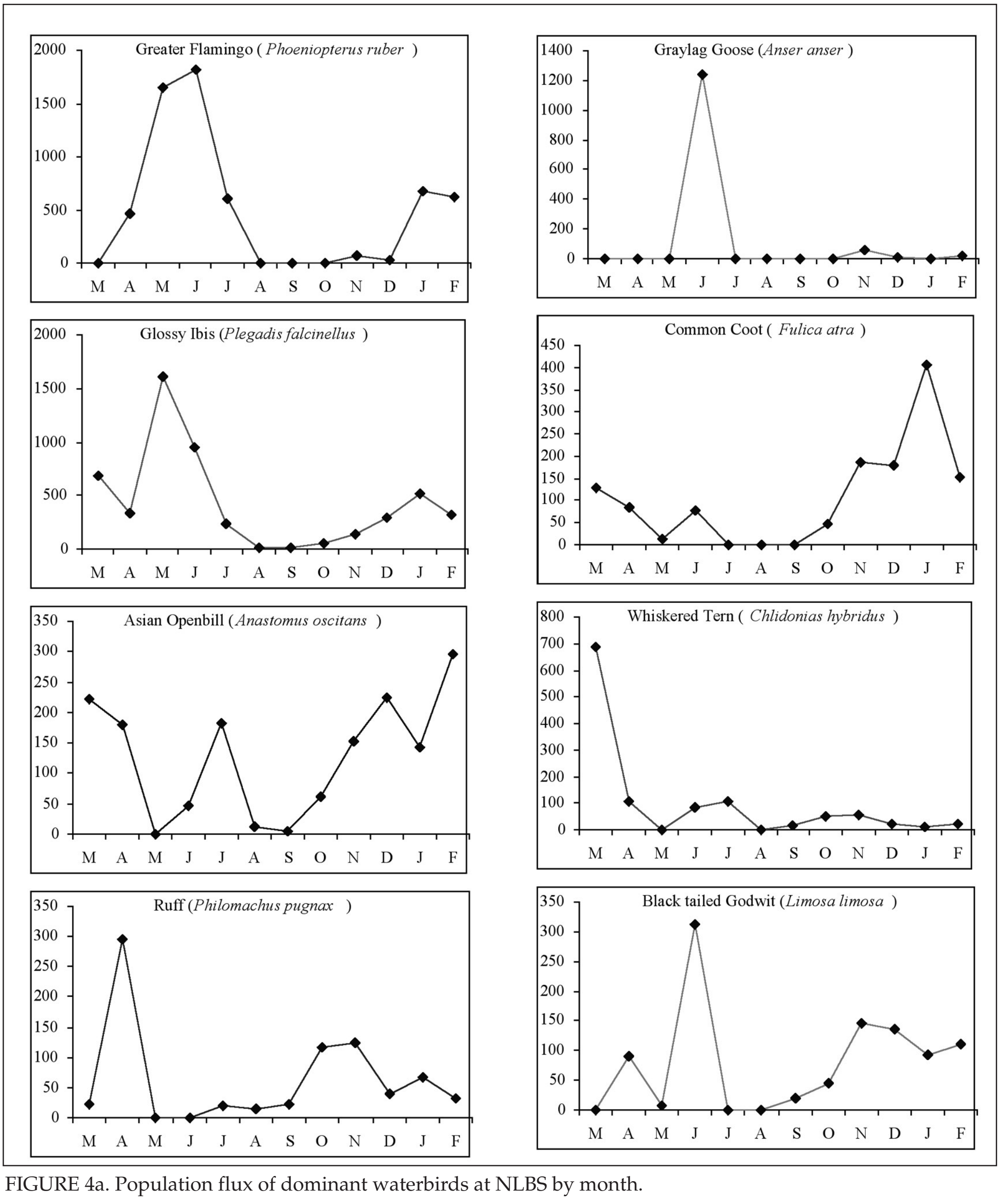

FIGURE 4a. Population flux of dominant waterbirds at NLBS by month.

season (summer) to then diminish gradually in the next season (winter). Similar observations have been made elsewhere, e.g. in the High Andes wetlands of South America (Virginia and Bonaventura 2002), the Tugas Estuary of Portugal (Susana et al. 2003), in the Mississippi Delta (King and Werner 2001), and in the fragmented wetlands of southern Brazil (Demetrio et al. 2005).

FINAL THOUGHTS

Nal Lake Bird Sanctuary, a Wetland of International Importance, has recently been

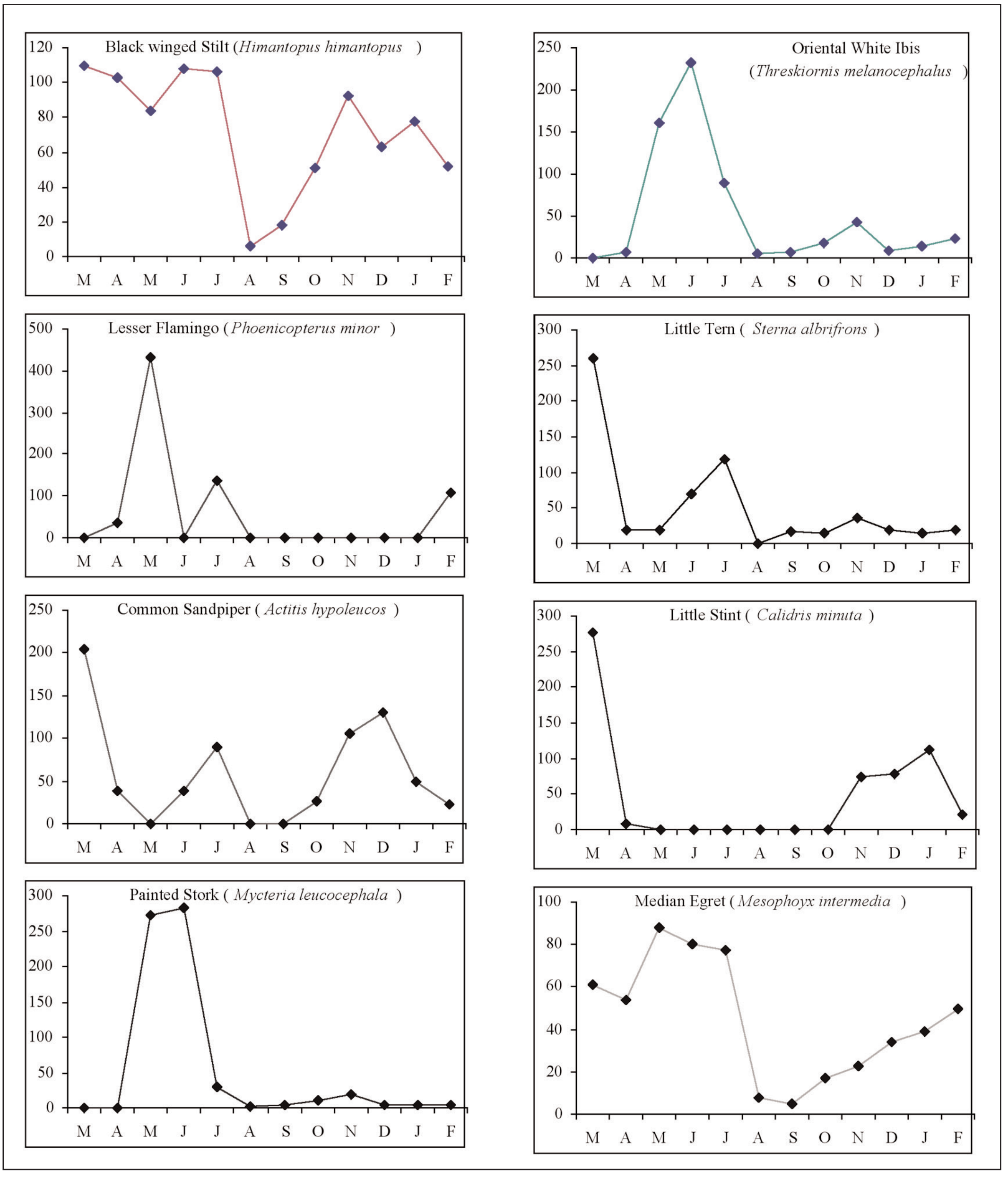

FIGURE 4b. Annual population flux of dominant waterbirds at NLBS by month; the y-axis is average numbers.

proposed as a Ramsar Site on the basis of its internationally important populations of migratory birds, numbering in the millions (GSFD 2004). Our study was carried out in a single annual cycle, a fact that could raise questions about the generality of the patterns found. The patterns exhibited during the present investigation, however, are strong and consistent with other studies in Rio Grande do Sul (see Accordi 2003). The turnover between winter and summer migrants resulted in small seasonal variations in the number of species, but drastic declines during monsoon (Colwell and Codington 1995). In addition, the huge

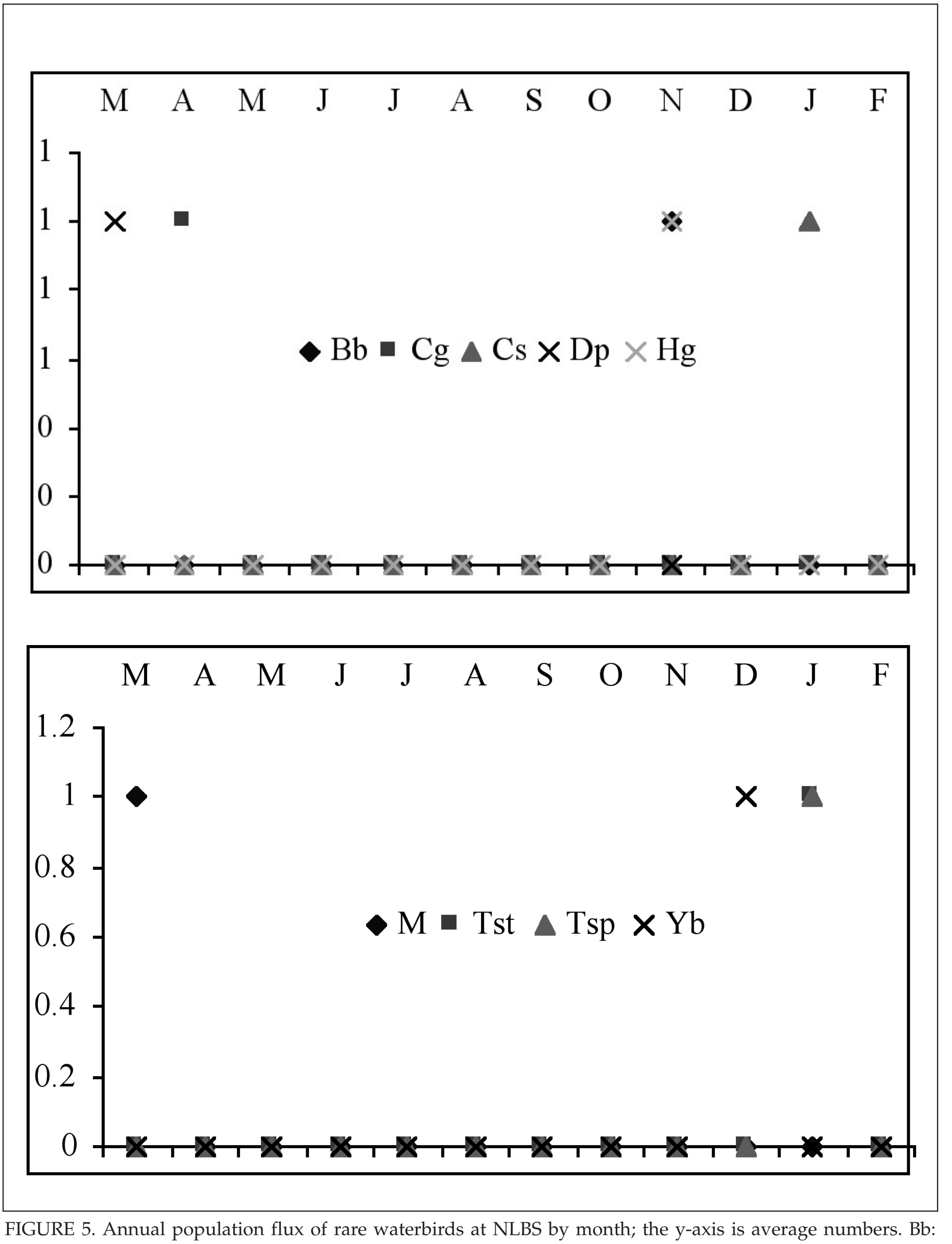

FIGURE 5. Annual population flux of rare waterbirds at NLBS by month; the y-axis is average numbers. Bb: Black Bittern (*Ixobrychus flavicollis*), Cg: Common Greenshank (*Tringa nebularia*), Cs: Curlew Sandpiper (*Calidris ferruginea*), Dp: Dalmatian Pelican (*Pelicanus crispus*), Hg: Heuglin's Gull (*Larus heuglini*), M: Mallard (*Anas platyrhynchos*), Tst: Temminck's Stint (*Calidris temminckii*), Tsp: Terek Sandpiper (*Xenus cinereus*), Yb: Yellow Bittern (*Ixobrychus sinensis*).

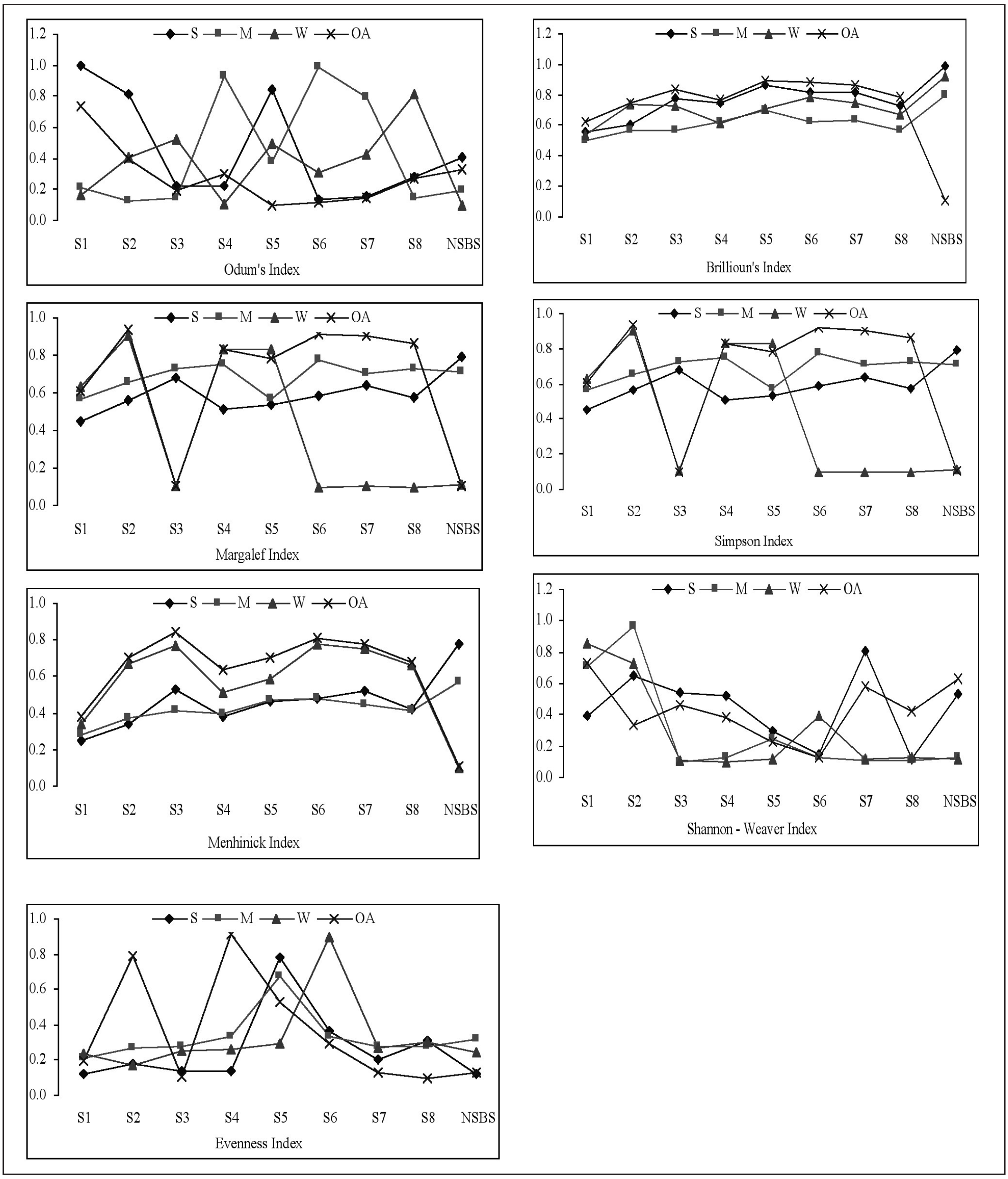

FIGURE 6. The variation in site-specific diversity indices among seasons at NLBS.

wintering aggregations we saw are commonplace in waterbird communities in temperate regions (Kershaw and Cranswick 2003).

Several factors other than area have been associated with the richness and abundance of waterbirds, such as physico-chemical conditions, food resources, vegetation cover and interspersion, and habitat and landscape configuration (Caziani et al. 2001, Stickney et al. 2002). Also contributing are the regional pool of species (Telleria et al. 2003), their particular abundance of range patterns (Murray et al. 1999), the site and landscape structures (especially the area: Fairbairn and Dinsmore

2001), the presence of core refuges (Guillemain et al. 2002), and the influence of the surrounding physiographic matrix (Czech and Parsons 2002). All these factors are probably involved in the species gradients found at NLBS and therefore deserve further attention. Therefore, we suggest that working toward a landscape and trans-boundary perspective is essential for building sound management strategies for waterbird assemblages at NLBS (Erwin 2002).

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APPENDIX I. Aquatic birds found during different seasons at NLBS, Gujarat, India.

Groups / Common Name	Family / Species	MS	PS	Summer F	Summer A	Summer MA	Summer D	Summer MD	Monsoon F	Monsoon A	Monsoon MA	Monsoon D	Monsoon MD	Winter F	Winter A	Winter MA	Winter D	Winter MD
GREBES*	*PODICIPEDIDAE*																	
Great crested grebe	Podiceps cristatus	2	R	0	0	0	0	0	0	0	0	0	0	1	2	1	10	3
Little grebe	Tachybaptus ruficollis	1	C	12	110	28	561	140	17	48	12	245	61	29	118	30	602	151
Pelicans*	Pelecanidae																	
Dalmatian pelican	Pelecanus crispus	2	R	1	1	0	5	1	0	0	0	0	0	0	0	0	0	0
Great white pelican	Pelecanus onocrotalus	2	R	0	0	0	0	0	0	0	0	0	0	4	22	6	112	28
Cormorants#	Phalacrocoracidae																	
Great cormorant	Phalacrocorax carbo	1	R	1	0	0	0	0	1	8	2	41	10	0	0	0	0	0
Indian cormorant	Phalacrocorax fuscicollis	1	C	20	141	35	719	180	22	71	18	362	91	31	194	49	990	247
Little cormorant	Phalacrocorax niger	1	C	26	223	56	1138	284	25	89	22	454	114	32	169	42	862	216
Herons#, Egrets#, Bitterns#	Ardeidae																	
Grey heron	Ardea cinerea	1	C	32	77	19	393	98	24	38	10	194	48	31	61	15	311	78
Purple heron	Ardea purpurea	1	C	31	77	19	393	98	23	45	11	230	57	31	59	15	301	75
Indian pond heron	Ardeola grayii	1	C	30	159	40	811	203	26	78	20	398	99	32	81	20	413	103
Little green heron	Butorides srtiatus	1	R	0	0	0	0	0	2	2	1	10	3	6	6	2	31	8
Black crowned night heron	Nycticorax nycticorax	1	R	1	9	2	46	11	2	7	2	36	9	10	20	5	102	26
Cattle egret	Bubulcus ibis	1	C	23	69	17	352	88	21	42	11	214	54	28	59	15	301	75
Large egret	Casmerodius albus	1	C	28	117	29	546	136	22	28	7	143	36	20	22	6	112	28
Little egret	Egretta garzetta	1	C	32	282	71	1439	360	24	75	19	383	96	31	86	22	439	110
Western reef egret	Egretta gularis	1	R	1	1	0	5	1	0	0	0	0	0	3	3	1	15	4
Median egret	Mesophoyx intermedia	1	C	32	283	71	1444	361	25	107	27	546	136	32	146	37	745	186
Black bittern	Ixobrychus flavicollis	2	R	0	0	0	0	0	0	0	0	0	0	1	1	0	5	1
Yellow bittern	Ixobrychus sinensis	1	R	0	0	0	0	0	0	0	0	0	0	1	1	0	5	1
Storks#	Ciconiidae																	
Asian openbill	Anastomus oscitans	1	A	11	450	113	2296	574	23	260	65	1327	332	28	814	204	4153	1038
European white stork	Ciconia ciconia	2	R	1	1	0	5	1	0	0	0	0	0	1	1	0	5	1
White necked stork	Ciconia episcopus	1	R	3	5	1	26	6	8	15	4	77	19	14	18	5	92	23
Painted stork	Mycteria leucocephala	1	C	16	554	139	2872	718	21	47	12	240	60	19	35	9	179	45
Ibises#, Spoonbill#	Threskiornithidae																	
Black ibis	Pseudibis papillosa	1	C	9	37	9	189	47	12	37	9	189	47	19	50	13	255	64
Glossy ibis	Pegaldis falcinellus	1	A	26	3571	893	18219	4555	24	306	77	1561	390	32	1279	320	6526	1631
Oriental white ibis	Threskiornis melanocephalus	1	C	17	400	100	2041	510	22	119	30	607	152	30	90	23	459	115
Eurasian spoonbill	Platalea leucorodia	1	C	6	79	20	403	101	2	5	1	26	6	18	47	12	240	60

APPENDIX I. Continued.

Groups / Common Name	Family / Species	MS	PS	Summer F	Summer A	Summer MA	Summer D	Summer MD	Monsoon F	Monsoon A	Monsoon MA	Monsoon D	Monsoon MD	Winter F	Winter A	Winter MA	Winter D	Winter MD
FLAMINGOS#	*PHOENICOPTERIDAE*																	
Lesser flamingo	*Phoenicopterus minor*	2	C	5	469	117	2393	598	3	137	34	699	175	1	109	27	556	139
Greater flamingo	*Phoenicopterus ruber*	2	A	9	3941	985	20107	5027	3	609	152	3107	777	17	1392	348	7102	1776
GEESE**, DUCKS*	*ANATIDAE*																	
Gray lag goose	*Anser anser*	2	A	3	1237	309	6311	1578	0	0	0	0	0	5	89	22	454	114
Northern pintail	*Anas acuta*	2	C	1	19	5	97	24	5	22	6	112	28	26	208	52	1061	265
Northern shoveler	*Anas clypeata*	2	C	1	11	3	56	14	5	48	12	245	61	21	114	29	582	145
Common teal	*Anas crecca*	2	C	1	136	34	694	173	0	0	0	0	0	18	124	31	633	158
Eurasian wigeon	*Anas penelope*	2	C	0	0	0	0	0	0	0	0	0	0	24	160	40	816	204
Mallard	*Anas platyrhyncos*	2	R	1	1	0	5	1	0	0	0	0	0	0	0	0	0	0
Spot billed duck	*Anas poecilorhyncha*	1	C	6	68	17	347	87	10	27	7	138	34	16	63	16	321	80
Gargeny	*Anas querquedula*	2	C	5	265	66	1352	338	5	18	5	92	23	23	235	59	1199	300
Gadwall	*Anas strepera*	2	C	2	38	10	194	48	0	0	0	0	0	25	282	71	1439	360
Common pochard	*Aythya ferina*	2	C	3	48	12	245	61	4	21	5	107	27	24	158	40	806	202
Tufted pochard	*Aythya fuligula*	2	R	0	0	0	0	0	0	0	0	0	0	3	9	2	46	11
Ferruginous pochard	*Aythya nyroca*	2	R	0	0	0	0	0	0	0	0	0	0	2	18	5	92	23
Lesser whistling duck	*Dendrocygna javanica*	1	C	1	2	1	10	3	8	118	30	602	151	14	46	12	235	59
Cotton teal	*Nettapus coromandelianus*	1	C	12	75	19	383	96	4	17	4	87	22	25	132	33	673	168
Red crested pochard	*Rhodonessa rufina*	2	R	0	0	0	0	0	0	0	0	0	0	1	2	1	10	3
Comb duck	*Sarkidiornis melantos*	1	C	1	8	2	41	10	7	45	11	230	57	17	118	30	602	151
Ruddy shelduck	*Tadorna ferruginea*	2	R	3	10	3	51	13	0	0	0	0	0	4	34	9	173	43
CRANES#	*GRUIDAE*																	
Sarus crane	*Grus antigone*	1	C	5	77	19	393	98	4	6	2	31	8	7	19	5	97	24
Common crane	*Grus leucogeranus*	2	C	2	153	38	781	195	9	54	14	276	69	13	93	23	474	119
Demoiselle crane	*Grus virgo*	2	C	0	0	0	0	0	9	56	14	286	71	10	195	49	995	249
RAILS#, GALLINULES, COOT**	*RALLIDAE*																	
Brown crake	*Amaurornis akool*	1	R	4	5	1	26	6	1	1	0	5	1	5	5	1	26	6
Baillon's crake	*Porzana pusilla*	2	R	0	0	0	0	0	0	0	0	0	0	4	4	1	20	5
White breasted water hen	*Amaurornis phoenicurus*	1	R	2	2	1	10	3	14	22	6	112	28	15	22	6	112	28
Ruddy breasted crake	*Gallicrex cineria*	1	R	0	0	0	0	0	1	1	0	5	1	2	2	1	10	3
Indian moorhen	*Gallinula chloropus*	1	C	4	26	7	133	33	12	37	9	189	47	13	44	11	224	56
Purple swamphen	*Porphyrio porphyrio*	1	C	23	295	74	1505	376	16	101	25	515	129	21	116	29	592	148
Common coot	*Fulica atra*	2	A	17	305	76	1556	389	6	47	12	240	60	28	924	231	4714	1179

APPENDIX I. Continued.

Groups / Common Name	Family / Species	MS	PS	Summer					Monsoon					Winter				
				F	A	MA	D	MD	F	A	MA	D	MD	F	A	MA	D	MD
JACANAS*	*JACANIDAE*																	
Pheasant tailed jacana	*Hydrophasianus chirurgus*	1	C	11	98	25	515	129	17	55	14	281	70	26	175	44	893	223
Shorebirds - Waders 1#	*Burhinidae*																	
Great thick knee	*Esacus recurvirostris*	1	R	1	1	0	5	1	0	0	0	0	0	2	2	1	10	3
SHOREBIRDS - WADERS 2#	*CHARADRIIDAE*																	
Red wattled lapwing	*Vanellus indicus*	1	C	32	221	55	1128	282	24	118	30	602	151	28	62	16	316	79
White tailed lapwing	*Vanellus leucurus*	2	R	2	6	2	31	8	0	0	0	0	0	6	13	3	66	17
Yellow wattled lapwing	*Vanellus malarbaricus*	1	R	0	0	0	0	0	13	23	6	117	29	8	10	3	51	13
Kentish plover	*Charadrius alexandrinus*	2	R	0	0	0	0	0	0	0	0	0	0	5	8	2	41	10
Little ringed plover	*Charadrius dubius*	2	C	5	168	42	857	214	0	0	0	0	0	8	59	15	301	75
Common ringed plover	*Charadrius hiaticula*	2	R	1	2	1	10	3	0	0	0	0	0	0	0	0	0	0
Greater sand plover	*Charadrius leschenaultii*	2	R	0	0	0	0	0	0	0	0	0	0	1	3	1	15	4
Pacific golden plover	*Pluvialis fulva*	2	R	0	0	0	0	0	0	0	0	0	0	2	12	3	61	15
Black winged stilt	*Himantopus himantopus*	1	C	32	405	101	2066	517	25	181	45	923	231	32	285	71	1454	364
Avocet	*Recurvirostra avosetta*	2	R	1	21	5	107	27	0	0	0	0	0	1	1	0	5	1
SHOREBIRDS - WADERS 3#	*GLAREOLIDAE*																	
Small pratincole	*Glareola lactea*	1	C	4	49	12	250	63	0	0	0	0	0	2	86	22	439	110
Oriental pratincole	*Glareola maldivarum*	1	R	10	57	14	291	73	0	0	0	0	0	2	21	5	107	27
SHOREBIRDS - WADERS 4#	*ROSTRATULIDAE*																	
Pintail snipe	*Capella stenura*	2	R	0	0	0	0	0	0	0	0	0	0	2	5	1	26	6
Common snipe	*Gallinago gallinago*	2	C	4	113	28	577	144	0	0	0	0	0	17	152	38	776	194
Greater painted snipe	*Rostratula benghalensis*	1	R	0	0	0	0	0	1	1	0	5	1	1	1	0	5	1
SHOREBIRDS - WADERS 5#	*SCOLOPACIADAE*																	
Common sandpiper	*Actitis hypoleucos*	2	C	13	282	71	1439	360	12	115	29	587	147	28	308	77	1571	393
Curlew sandpiper	*Calidris ferruginea*	2	R	0	0	0	0	0	0	0	0	0	0	1	1	0	5	1
Wood sandpiper	*Tringa glareola*	2	C	12	133	33	679	170	16	110	28	561	140	30	171	43	872	218
Marsh sandpiper	*Tringa stagnatilis*	2	R	0	0	0	0	0	0	0	0	0	0	14	31	8	158	40
Terek sandpiper	*Xenus cinereus*	2	R	0	0	0	0	0	0	0	0	0	0	1	1	0	5	1
Little stint	*Calidris minuta*	2	C	5	285	71	1454	364	0	0	0	0	0	28	286	72	1459	365
Temminck's stint	*Calidris temminckii*	2	R	0	0	0	0	0	0	0	0	0	0	1	1	0	5	1
Spotted redshank	*Tringa erythropus*	2	C	3	59	15	301	75	0	0	0	0	0	13	45	11	230	57
Common greenshank	*Tringa nebularia*	2	R	2	1	0	5	1	0	0	0	0	0	0	0	0	0	0
Common redshank	*Tringa totanus*	2	R	7	82	21	10	3	0	0	0	0	0	4	5	1	26	6

APPENDIX I. Continued.

Groups / Common Name	Family / Species	MS	PS	Summer F	Summer A	Summer MA	Summer D	Summer MD	Monsoon F	Monsoon A	Monsoon MA	Monsoon D	Monsoon MD	Winter F	Winter A	Winter MA	Winter D	Winter MD
Bar tailed godwit	*Limosa lapponica*	2	R	7	105	26	0	0	0	0	0	0	0	1	3	1	15	4
Black tailed godwit	*Limosa limosa*	2	A	11	411	103	2832	708	14	64	16	327	82	32	485	121	2474	619
Eurasian curlew	*Numenius arquata*	2	R	8	15	4	0	0	1	3	1	15	4	14	26	7	133	33
Whimbrel	*Numenius phaeopus*	2	R	8	22	6	0	0	0	0	0	0	0	3	3	1	15	4
Ruddy turnstone	*Arenaria interpres*	2	R	7	46	12	61	15	0	0	0	0	0	1	1	0	5	1
Dunlin	*Calidris alpina*	2	R	0	0	0	0	0	0	0	0	0	0	1	4	1	20	5
Great knot	*Calidris tenuirostris*	2	C	6	176	44	898	224	0	0	0	0	0	0	0	0	0	0
Ruff	*Philomachus pugnax*	2	A	11	317	79	4801	1200	18	173	43	883	221	20	266	67	1357	339
GULLS#, TERNS#	*LARIDAE*																	
Brown headed gull	*Larus brunnicephalus*	2	C	3	7	2	36	9	0	0	0	0	0	23	200	50	1020	255
Yellow legged gull	*Larus cachinnans*	2	R	0	0	0	0	0	0	0	0	0	0	2	2	1	10	3
Lesser black backed gull	*Larus fuscus*	2	R	1	2	1	10	3	0	0	0	0	0	17	25	6	128	32
Great black backed gull	*Larus marinus*	2	R	1	1	0	5	1	0	0	0	0	0	4	4	1	20	5
Heuglin's gull	*Larus heuglini*	2	R	0	0	0	0	0	0	0	0	0	0	1	1	0	5	1
Black headed gull	*Larus ridibundus*	2	R	1	1	0	5	1	0	0	0	0	0	16	25	6	128	32
Whiskered tern	*Chlidonias hybridus*	2	A	12	880	220	4490	1122	18	174	44	888	222	30	109	27	556	139
White winged black tern	*Chlidonias luecopterus*	2	R	0	0	0	0	0	0	0	0	0	0	1	2	1	10	3
Gull billed tern	*Gelochelidon nilotica*	2	C	4	16	4	82	20	14	29	7	148	37	30	56	14	286	71
Black bellied tern	*Sterna acuticauda*	1	C	9	114	29	117	29	0	0	0	0	0	11	95	24	485	121
Little tern	*Sterna albifrons*	2	C	20	365	91	1862	466	20	148	37	755	189	31	89	22	454	114
River tern	*Sterna aurantia*	1	C	15	33	8	168	42	25	56	14	286	71	32	57	14	291	73
Caspian tern	*Sterna caspia*	2	R	1	2	1	10	3	0	0	0	0	0	1	1	0	5	1
Common tern	*Sterna hirundo*	2	C	10	134	34	684	171	12	22	6	112	28	17	28	7	143	36
WAGTAILS#	*MOTACILLIDAE*																	
White wagtail	*Motacilla alba*	2	C	5	7	2	36	9	16	56	14	286	71	31	88	22	449	112
Grey wagtail	*Motacilla cinerea*	2	R	5	23	6	117	29	9	24	6	122	31	20	38	10	194	48
Citrine wagtail	*Motacilla citreola*	2	C	15	101	25	515	129	16	46	12	235	59	32	80	20	408	102
Yellow wagtail	*Motacilla flava*	2	C	15	130	33	663	166	15	75	19	383	96	32	95	24	485	121

MS - Migratory status; PS - Population status; F - Frequency; A - Abundance; MA - Mean abundance; D - Density; MD - Mean density;
* = Waterbirds; ** = Waterfowl; # = Water-dependant birds