

POPULATION DYNAMICS AND HABITAT PREFERENCES OF WATERBIRDS ACROSS SIX WETLANDS AT DIFFERENT GEOGRAPHICAL SCALES OF PAKISTAN

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Abstract. Wetlands are vital ecosystems for waterbirds and are experiencing a global decline due to human activities. Our study investigated the population dynamics and habitat preferences of waterbirds in six geographically distinct wetlands (Chashma, Dhap Chapak, Taunsa, Haleji, Raja, and Uchali) along the Indus River flyway, Pakistan. Point count methods were used during five consecutive migratory seasons (September and March from 2017 to 2022) using point count method. In total, 73 waterbird species from 19 families and 11 orders were detected. Species richness varied significantly ($F_{5, 437} = 8.14$, $p < 0.000$) across wetlands. We recorded species richness ($R = 73.0$), species diversity ($H' = 3.714$), population trend ($\lambda = 0.031$), and species dispersion ($E = 0.865$). Chashma wetland exhibited the highest species richness ($S = 52$), as well as the highest relative abundance and diversity. Uchali had the highest population of waterbirds (45,095 individuals), while Raja displayed the most uniform species dispersion (8711 individuals). The detection of endangered species, i.e., Pallas fish eagles (*Haliaeetus leucorphyus*) and Black-bellied terns (*Sterna acuticauda*) in these wetlands is crucial. “Additionally, seven nearly threatened waterbird species were recorded, i.e., Black-tailed Godwit (*Limosa limosa*), Great Painted Snipe (*Rostratula benghalensis*), Oriental Darter (*Anhinga melanogaster*), Northern Lapwing (*Vanellus vanellus*), Indian River Tern (*Sterna aurantia*), Asian Woolly-necked Stork (*Ciconia episcopus*), and Lesser Flamingo (*Phoeniconaias minor*). This highlights the significance of the wetland”. We recommend regular monitoring by wildlife authorities to track population trends, assess habitat suitability, and identify

threats. Conservation efforts should prioritize water regime maintenance, pollution control, and community engagement for long-term wetland management and waterbird conservation.

Keywords: *Indus River, species diversity, habitat preference, conservation status, species richness, dispersion*

Introduction

Wetlands have been considered fragile and highly productive habitats for a wide array of faunal species due to the richness of food resources and diversity of floral structures compared to forests or coral reefs (Gurung and Sah, 2016; Lorenzón et al., 2019). These areas act as biological supermarkets, hosting diverse flora and fauna, especially waterbirds (Donatelli et al., 2017). Waterbirds face numerous threats from anthropogenic activities, including habitat loss and degradation due to water abstraction, land transformation for agriculture, human settlements, domestic and industrial pollution, illegal hunting, and climate change (Ma et al., 2009; Galewski and Devictor, 2016; Zou et al., 2017; Rosenberg et al., 2019; Zhang and Ouyang, 2019). As a result, waterbird species become critically endangered (CE), endangered (E), threatened (T), nearly threatened (NT), and vulnerable (V) due to these detrimental factors (Chen et al., 2011; Khan and Arshad, 2014). Pakistan is endowed with 225 wetland sites, including rivers, lakes, marshes, tidal swamps, reservoirs, canals, aquaculture ponds, paddy fields, and waterlogged areas, covering 7.80 million ha, or 9.70% of the country's total land surface. Of these, 19 wetland sites have been designated as Ramsar sites due to their significant global importance, particularly for harboring a wide variety of waterbird species (Chaudhry, 2010). Pakistan hosts 207 species of waterbirds, both native and migratory, that exploit these aquatic resources. Notably, out of 202 waterbird species, 73 species were detected in the study area, highlighting the crucial importance of these wetlands for a wide range of waterbird species (Lepage, 2024).

Wetlands provide essential habitats for a variety of waterbird species, belonging to 30 families. Waterbird populations often occur in spectacular concentrations due to their motility and activity, and their preference for areas with diverse food resources. They serve as excellent bioindicators and habitat specialists of wetland ecosystems, responding quickly to environmental changes as compared to other species (Ippi et al., 2009; Cumming et al., 2012). Currently, 55.0% of the world's waterbird species are threatened because of habitat degradation and climate change (Baker et al., 2004; Nebel et al., 2008). In Pakistan, according to World Avibase data, there are 2 critically endangered, 4 endangered, 4 vulnerable, and 18 nearly threatened waterbird species (BirdLife International, 2024; Lepage, 2024). As a result of effective conservation efforts and protection, waterbird populations have increased 16.0% globally (BirdLife International, 2017).

Waterbirds occupy a prominent position in wetland habitats, playing crucial roles in the trophic structure and food web by controlling aquatic vegetation, serving as food for predators, and providing aesthetic beauty and livelihood for local communities (Kingsford et al., 2004; Garg, 2015; Lorenzón et al., 2016). They tend to concentrate in wetland areas rich in food resources, diverse aquatic vegetation, favorable microclimate conditions (temperature, rainfall, and humidity), free from hunting and encroachment pressure, and possessing various water levels and shallow water edges (Raeside et al., 2007; Johnson et al., 2007; Seymour and Simmons, 2008; Weyland et al., 2012; Krause et al., 2016; Gómez et al., 2018). In addition, altered microclimatic conditions and habitat structure harbored lower waterbird population due to scarce food resources, disturbances,

unsuitable breeding and foraging grounds (Hawkins et al., 2003; Bellocq et al., 2005; Wrona et al., 2006; Sonal et al., 2010).

In spite of the fact that waterbirds are vital components of wetland habitats as well as human survival, they face many threats worldwide, including illegal hunting, trapping, habitat loss, and degradation, especially in non-developed countries like Pakistan (Studds et al., 2017; Wang et al., 2018). Due to the effects of these detrimental factors waterbird assemblages significantly changed from time to time and habitat to habitat. This could be that the requirement of waterbird species varied from species to species, i.e., they adapt to compete effectively against other species in each habitat (Sonal et al., 2010; Bacaro et al., 2011; Price et al., 2013; Mohanraj and Pandiyan, 2015). Insufficient food resources, unsuitable breeding grounds, and habitat disturbance reduce waterbird populations (Schlatter et al., 2002; Kim and Byrne, 2006; White et al., 2010; Mingozzi et al., 2013).

In Pakistan, the conservation of wetlands and waterbird habitats has received little attention, leading to the gradual disappearance of wetland areas and the decline of waterbird populations. The population and habitat preferences of waterbirds across different wetland habitats in Pakistan have not been sufficiently quantified. Few studies have investigated some wetland habitats, focusing on comparative avian faunal diversity (Ali et al., 2011), bird species diversity measurement (Dauda et al., 2017), factors affecting waterfowl diversity (Bhatti et al., 2019), diversity and abundance of seasonal migratory waterbirds (Bibi et al., 2021), field validation of avian diversity (Kazam et al., 2024) and avian diversity and abundance (Haider et al., 2022).

The null hypothesis of this research was that there is no significant difference in population trend, diversity indices and dispersion of waterbirds among six wetland habitats. Therefore, ascertaining the population dynamics and habitat preferences of waterbirds in heterogeneous wetlands located at different geographical scales is crucial for understanding wetlands' habitat suitability and population trends. The main objective of this research was to ascertain the population dynamics, i.e., relative abundance, diversity indices, conservation status, foraging guilds, relationship, temporal pattern, seasonal variation and habitat preference of waterbirds among six wetland habitats located in different geographical scales among six different wetland habitats, e.g., Chashma, Dhap Chapak, Taunsa, Uchali, Raja and Haleji by point count from September 2017 to March 2022. Using this information, a management plan based on a holistic approach and ecological integrity can be prepared for the conservation of wetlands and waterbirds that inhabit a wide range of wetlands across the country.

Materials and methods

Study area

Study sites in Pakistan were Uchali Wetland, Taunsa Wetland, Chashma Wetland, Dhap Chapak Wetland, Haleji Wetland, and Raja Wetland, which are all potential wetland habitats located at different geographical scales. The detail of each site description is as under:

Chashma wetland

It is huge water reservoir that covers an area of 0.327 million ha and is located 25 km southwest of Mianwali, Punjab province. In aquatic vegetation, *Hydrilla verticillata*, *Nelumbium speciosum*, *Nymphaea lotus*, *Typha angustata*, *Phragmites australis*,

Potamogeton crispus, *Vallisneria spiralis* and *Zannichellia palustris* are among the species. The terrestrial vegetation comprised of *Acacia nilotica*, *Dalbergia sissoo*, *Olea ferruginea*, *A. modesta*, *Adhatoda vasica*, *Dodonaea viscosa*, *Gymnosporia royleana*, *Heteropogon contortus*, *Ziziphus nummularia*, *Chrysopogon aucheri*, *Lasiurus hirsutus*, and *Panicum glandulosa* (Fig. 1).

Dhap Chapak Wetland

The Dhap Chapak wetland is located along the Indus River in Dera Ismail Khan Khyber Pakhtunkhwa, Pakistan. This wetland receives water from the River Indus and is rich in vegetation that comprised aquatic vegetation, i.e., *Alternanthera sessilis*, *Ceratophyllum demersum*, *Eleocharis palustris*, *Hydrilla verticillata*, *Marselia quadrifolia*, *Nelumbium nelumbo*, *Nymphaeoides cristata*, *Phragmites karka*, *Polygonum flaccidum*, *Potamogeton crispus*, *Spirodela polyrrhiza*, *Typha domingensis*, and *Typha elephantia*. This wetland is crucial habitat for wide array of migratory waterbirds, especially waterfowl. A hot climate is characterized by sweltering summers and mild winters. Usually, precipitation occurs in the early spring months of February and April, and in the monsoon season of July and August (Fig. 1).

Taunsa Wetland

The wetland is located along the Indus River in the south-western district of Muzaffargarh, Punjab, Pakistan. The wetland is situated along the “Indus flyway,” which serves as a hotspot for migrating waterbirds, including waterfowl, waders, and shorebirds. It was home to a multitude of vegetation, including *Dalbergia sissoo*, *Populus euphratica*, *Tamarix dioica*, *Acacia nilotica*, *Prosopis cineraria*, *Eleusine compressa*, and *Panicum antidotale*. Among the aquatic plants found here are *Carex fedia*, *Nelumbium speciosum*, *Phragmites karka*, *Potamogeton crispus*, *Ranunculus aquatilis*, *Typha angustata*, and *Zannichellia palustris*. It is a fragile habitat that contains a variety of wildlife species, including fish, reptiles, and mammals like the Indus river dolphin. Temperatures ranged from 5°C to 43°C, and rainfall ranged from 150 to 400 mm (Fig. 1).

Uchali Wetland

This brackish and saline water body is located in Khushab district’s Soon Valley, Punjab, Pakistan. In total, it covers an area of 943 ha at an altitude of 764 m and a depth of 0.2 m to 6 m. The wetland is a globally important habitat for diverse waterbird species particularly ducks and waders, along the Indus flyway. Wetland is mainly fed by rainwater, seepage, and spring water from hill torrent catchment areas. A variety of aquatic vegetation thrives in the wetland, such as *Carex fedia*, *Juncus* sp., *Phragmites australis*, *Potamogeton pectinatus*, *Spergularia marina*, *Suaeda fruticoso*, *Haloxylon multiflorum*, *Phyla nodiflora*, and *Scirpus* sp. There is a considerable amount of fluctuation in water level depending on rainfall in the catchment area. Wetlands perform a variety of functions, including recharge of aquifers, regulation of local climate, and wintering and staging grounds for migrating waterbirds (Fig. 1).

Haleji Wetland

An artificial wetland covers 1704 ha of land in Thatta, Sindh, approximately 21 km away from Thatta and 70 km from Karachi, surrounded by brackish seepage lagoons and

marshes. Native and migrant waterbird species rely on the ecosystem for refuge because it is a warm water ecosystem threatened by water shortages, sedimentation, and pollution. The aquatic vegetation is encompassing of *Typha domogensis*, *Phragmites karka*, *Nelumbo nucifera*, and *Potamogeton pectinatus* that serve as breeding, staging, foraging, and wintering grounds for wide range of waterbird species. Diverse aquatic life thrives in this wetland because of its seasonal ebbs and flows, influenced by local runoff and agricultural drainage (Fig. 1).

Raja Wetland

It is a man-made wetland in Khairpur Mirs, Sindh, Pakistan that covers an area of 93.07 ha, receives water from the Indus River, and surrounded by agricultural fields and woodland. Vegetation is dominated by *Potamogeton spirillus*, *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Cyperus* sp., *Eleocharis palustris*, *Dulichium* sp., *Juncus tenuis*, *Scirpus fluviatilis*, *Typha angustifolia*, *Panicum virgatum*, *Setaria glauca*, and *Phragmites australis* are among the aquatic vegetation. Terrestrial vegetation is encompassing of *Vachellia nilotica*, *Prosopis cinerea*, *Prosopis juliflora*, *Cordia dichotoma*, and *Saccharum munja* which occupy the wetland edges. Temperatures range from 7.0°C to 44.4°C, and rainfall amounts to 148 mm/year (Fig. 1).

Figure 1 and Appendix 1 give a detailed description of each habitat.

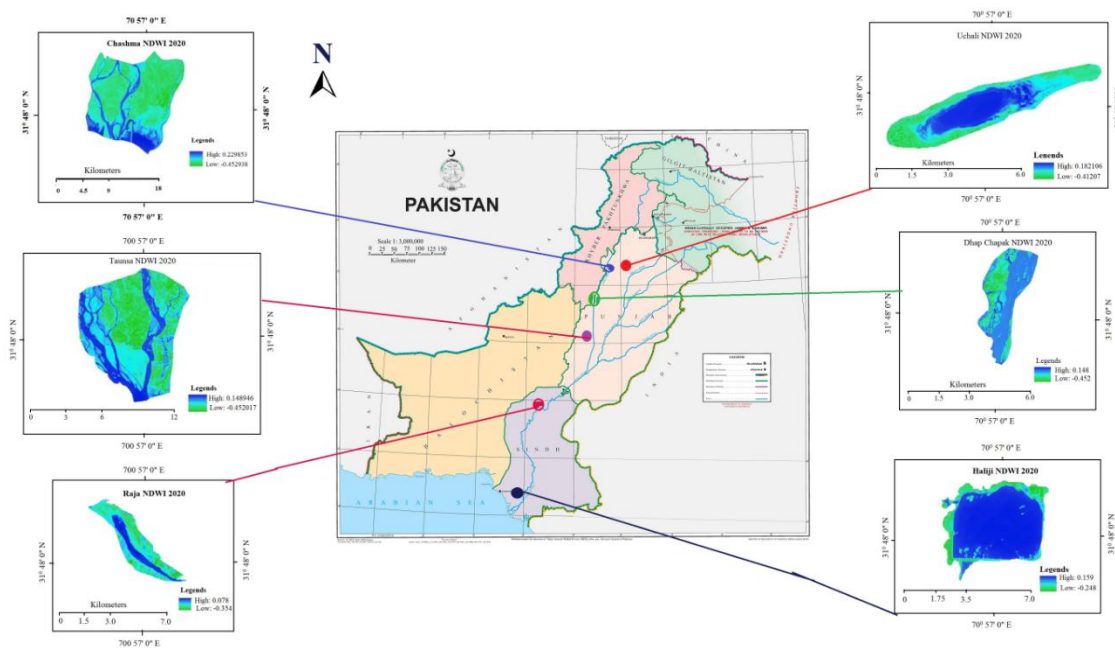


Figure 1. Location map of the study areas

Waterbird survey

Waterbird surveys were performed for five subsequent migratory seasons (September and March) from 2017–18 to 2021–22. The study involved setting up 300 point-counting stations in six different wetlands (i.e., 50 points in each study site). To avoid counting the same waterbird more than once, each point count station was set 250 m apart. When setting up point count stations in each wetland habitat, topography, accessibility, vegetation structure, and observer safety were taken into account. Waterbird occurrences

were recorded at each point count station for 10 min, following recommendations from Bibby et al. (2000) and Buckland et al. (2008). To complete one wetland habitat four days of waterbird surveys were performed and 24 days in a month to cover six wetland habitats. During the early morning hours, between 7:00 am and 11:00 am, waterbird surveys were conducted. Because, during this time, most of the waterbirds were actively engaged in foraging and other activities, it was more convenient to ascertain the higher relative abundance of water birds in dwelling wetlands. In hot weather, waterbirds seek shade in the thick foliage of aquatic vegetation and trees, or shrubby vegetation occurs along the wetland edges for resting and perching. By the methodology described by Dawson et al. (2004), Choi et al. (2008) and Thomas et al. (2010) this study was conducted. The waterbirds were identified using field guide book “Birds of Indian Subcontinent” by Grimmett et al. (2019).

Data analysis

The population parameters of waterbird species, i.e., Species Richness (S), Species Abundance (N), Species diversity (H'), Population trend (λ), and Species Dispersion (E) were quantified to understand the population trends year-wise and habitat wise among six potential wetland habitats.

Relative abundance

Waterbird relative abundance (Preston, 1948) in six wetland habitats was examined through *Equation 1*:

$$\text{Relative Abundance (\%)} = \text{Isi} / \sum \text{Nsi} \times 100 \quad (\text{Eq.1})$$

where Isi = denote the total number of detected particular waterbirds, $\sum \text{Nsi}$ = is denoted as the total detected numbers of waterbirds of all species.

Diversity indices

PCA (Community Analysis Package) Software (Version 4.0) was used to determine the waterbird diversity indices, such as species diversity, richness, and evenness in six wetland habitats (Henderson and Seaby, 2007).

Bird species diversity index

Shannon–Weiner diversity index is widely used to compare diversity between different habitats (Clarke and Warwick, 2001). It takes a random sample of individuals from a large, independent population, and each species is represented in the sample (Shannon and Weaver, 1949). We used the Shannon–Weiner index; H' to analyze the diversity index to ascertain the variation and variability of waterbird species among six wetland habitats using *Equation 2*:

$$\text{Shannon–Weiner index; } H' = \sum [(\text{pi}) \times \ln(\text{pi})] \quad (\text{Eq.2})$$

where H' = designate Shannon–Weiner index, S = number of waterbird species, i = specifies the waterbird relative abundance, N = denotes as total number of all detected

waterbird individuals, p_i = is the relative abundance of each waterbird species, and \ln = is the natural logarithm.

Species richness index

Wetland species richness is the number of species of waterbirds detected in a particular wetland habitat. It provides data on the homogeneity and irregularity of waterbird distributions and occurrences in six wetland habitats. For instance, Margalef's Richness Index (Margalef, 1958):

$$R = (S - 1)/\ln N \quad (\text{Eq.3})$$

where S is the total number of waterbird species and N is the total number of individuals in the sample.

Species evenness (distribution)

Waterbird distribution in six wetland habitats was quantified using Pielou J Evenness Index (Pielou, 1966) by below given Equation 4:

$$J = H/\log(S) \quad (\text{Eq.4})$$

where H = denote the observed Shannon–Wiener index and S = denote a total number of waterbird species detected in six wetland habitats.

Data analysis

Moreover, by geographical region, the waterbird species were categorized into Palearctic, Oriental, and Cosmopolitan. The waterbirds were further classified as native, migrant, and vagrant species and conservation status as Nearly Threatened, Least Concern, Endangered, and Vulnerable species according to IUCN Conservation Status (Rajpar et al., 2022).

Likewise, the waterbirds were categorized into different foraging guilds based on similar food consumption and habitat use. The methodology was followed as explained by Paszkowski and Tonn (2006), Perez-Crespo et al. (2013) and Chatterjee et al. (2020).

The waterbird relative abundance and distribution among six wetland habitats were compared employing the Kruskal–Wallis–Way Nonparametric and All–Pairwise ANOVA to determine the significant difference by Statistix 8.1 Analytical Software; Version 8.1 (Steel and Torrie, 1997; McGraw–Hill, 2008). Furthermore, the hierarchical clustering –the link between the waterbird foraging guild and conservation status was determined using CAP analysis. PCA (Community Analysis Package) Software (Version 4.0) was used to determine the hierarchical clustering – the link between waterbird foraging guild and conservation status in six wetland habitats (Henderson and Seaby, 2007).

In addition, R software; version 3.6.3 was used to ascertain the correlations of waterbird species with wetland vegetation (Lander, 2013; Rogers et al., 2017). A non-metric multidimensional scaling (NMDS) was performed to examine spatial variations in the waterbirds due to region and flyway differences across the country with the help of the function “metamds” in the R package vegan (McArdle and Anderson, 2001; Faraway, 2006; Laiolo, 2010; Legendre and Gallagher, 2017).

Results

Waterbird species composition and its relative abundance

In total, 73 wintering waterbird species representing 11 orders and 19 families were detected from six potential wetland habitats between 2017 and 2022 (Fig. 2; Appendix 2). In addition, waterbird orders were categorized according to the families to understand which order possessed higher waterbird families. Based on the results, Charadriiformes was the dominant order containing the 5 families (26.31%), followed by Pelecaniformes (3 families, 15.78%), Suliformes, and Gruiformes (2 families, 10.52%). As opposed, there was only one family (26.67%) for each order: Accipitriformes, Anseriformes, Coraciiformes, Ciconiiformes, Passeriformes, Phoenicopteriformes, and Podicipediformes. In addition, the waterbird orders were classified based on the species composition. As far as waterbird species are concerned, the Charadriiformes (21.19%) held the highest number (20 species), followed by the Pelecaniformes (11 species; 15.06%), Suliformes (8.5%), Passeriformes (4 species; 5.47%), Coraciiformes Gruiformes and Podicipediformes (each 3 species; 4.10%), and Phoenicopteriformes (2 species; 2.73%). However, Accipitriformes attracted only one waterbird (1.36%).

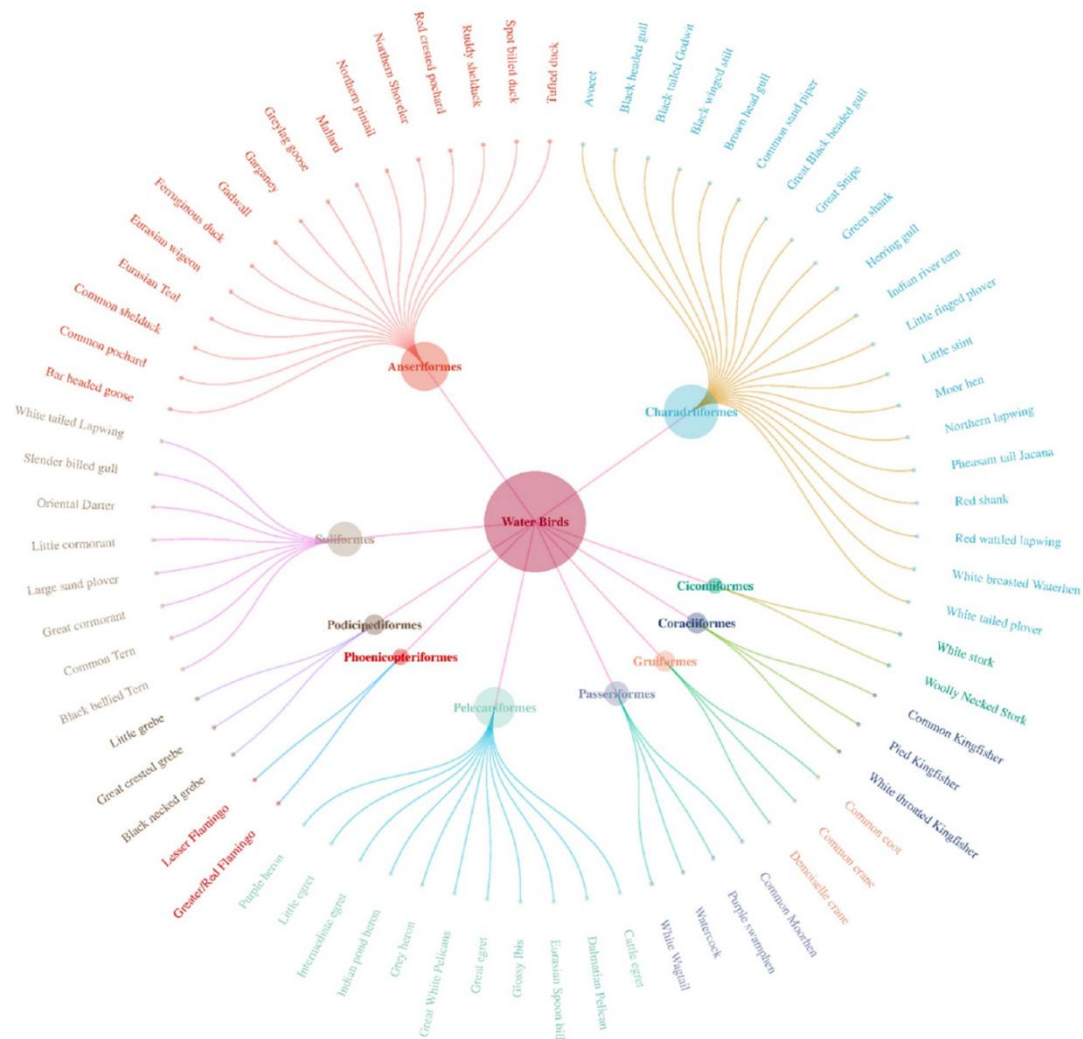


Figure 2. Taxonomic classification of wintering waterbirds

According to the observations recorded, the most prevalent waterbird species were gadwall – *M. strepera* (5.969%), little cormorant – *M. niger* (5.747), Great cormorant – *P. carbo* (5.531%), Great egret – *A. alba* (4.473%), northern pintail – *A. acuta* (4.348%), and Eurasian wigeon – *M. penelope* (4.148%). Contrarily, Common crane – *Grus grus* (0.029%), Watercock – *Gallicrex cinerea* (0.028%), Common kingfisher – *Alcedo atthis* (0.019%), Large sand plover – *Charadrius leschenaultii* (0.015%), Little crane – *Porzana parva* (0.013%) and Yellow-wattled lapwing – *Vanellus malabaricus* (0.007%) were the rarest waterbird species detected with few individuals (*Appendix I*). The relative abundance of waterbird in six wetland habitats was compared using Kruskal–Wallis One–Way Nonparametric and All–Pairwise ANOVA. The results shows that waterbird relative abundance in six wetland habitats located at heterogeneous localities were significantly different ($F_{5, 437} = 8.14, p < 0.000$).

The geographical distribution of wintering bird species in the study areas was categorized into Palearctic realm, Oriental realm, and Cosmopolitan species. In our study, Cosmopolitan species (56.2%) and Palearctic realm species (27.4%) were the most widespread species. Conversely, the Oriental realm species were distributed on few regions (16.4%; *Fig. 3*).

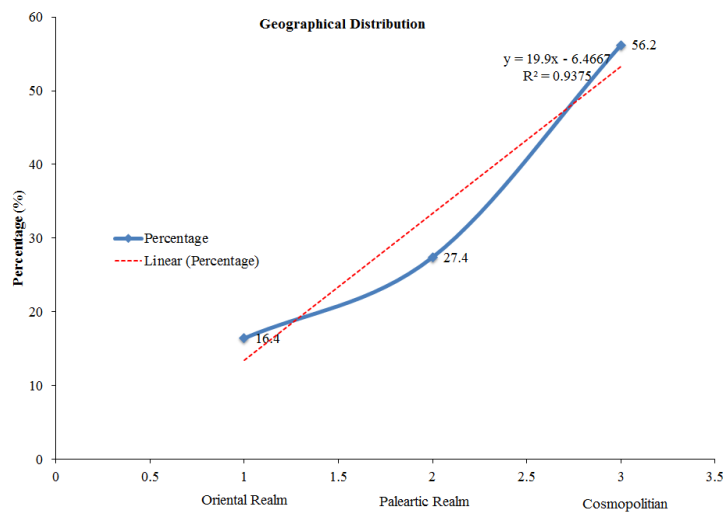


Figure 3. Geographical distribution of waterbirds in six potential wetland habitats

Furthermore, based on the findings, the waterbird species were categorized as migrant, resident and vagrant. The finding stated that migrant waterbirds (61.60%) and native waterbird species dominantly utilized the wetland areas (38.40%). However, vagrant birds rarely preferred to exploit the wetland areas (0.036%; *Fig. 4*).

Conservation status

Out of 73 waterbird species, 10 species were identified as nearly threatened (NT = 9.812%), 2 species as endangered (EN = 0.229%), 3 species as vulnerable (VA = 5.682%), and 58 species as least concern (LC = 84.277% (*Fig. 5a*)). Dendrogram hierarchical cluster analysis revealed that waterbird species belong to four clusters among six wetland habitats. The branch lengths and topological changes on a dendrogram graph demonstrated the waterbird heterogeneity of IUCN conservation status in six wetland habitats (*Fig. 5b*).

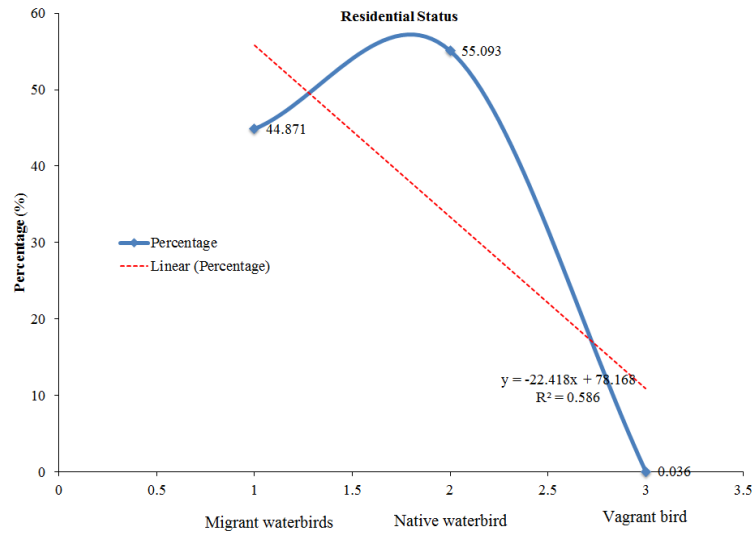


Figure 4. Residential status of the waterbirds detected during the study period

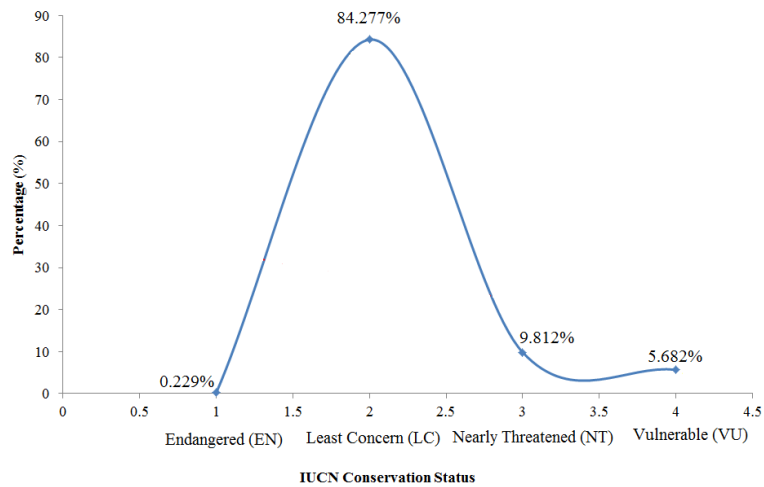


Figure 5a. IUCN Conservation status of the waterbird species recorded in six wetland habitats

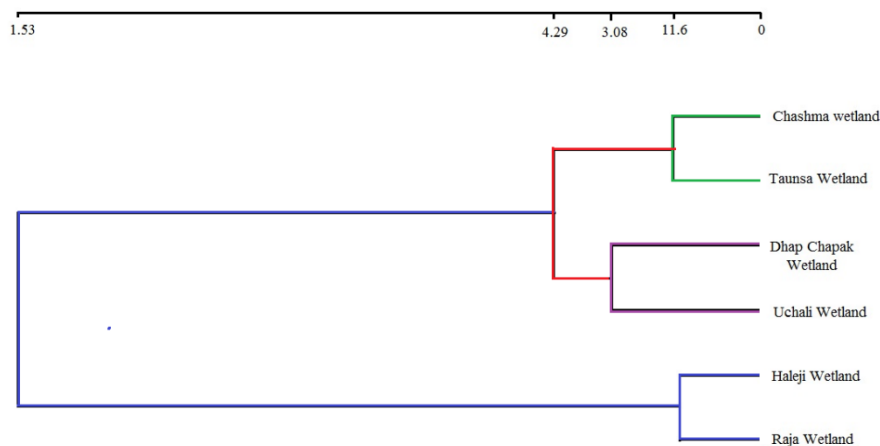


Figure 5b. Dendrogram hierarchical clustering chart indicating the waterbird IUCN conservation status among six wetland habitats

Foraging guilds

Seven foraging guilds of waterbirds were detected based on the consumption of similar food items and foraging techniques. The Insectivore/Piscivore/Carnivore (47.548%) and omnivores (34.836%) was the most dominant foraging guild in study areas. Contrarily, Carnivore (0.326%) and Piscivore (0.319%) were the rarest foraging guilds (*Fig. 6a*).

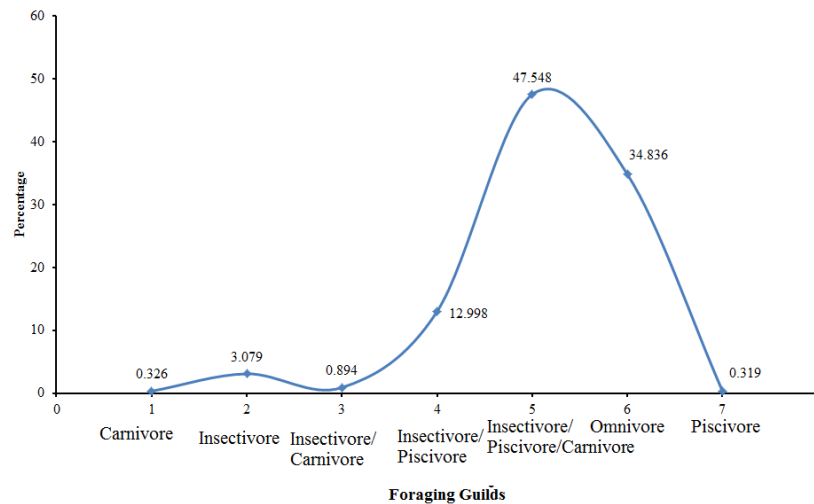


Figure 6a. Foraging guilds of waterbirds among six wetland habitats

Dendrogram hierarchical clustering chart demonstrated that waterbird foraging guilds belong to four clusters. The branch lengths and topological changes on a dendrogram graph reflected the heterogeneity that waterbird foraging guilds among six wetland habitats. Foraging clusters differ based on habitat characteristics, food availability, and wetland location within the region. A dendrogram of Haleji wetland and Raja wetland is completely different from those of the other four wetlands. It may be because Haleji Wetland and Raja Wetland are located in low-altitude and southern regions of the country, which have low productivity and insufficient food resources. The dendrogram of the Uchali wetland was also different from that of other wetlands. This saline and productive ecosystem harbors a greater number of waterbird species to exploit. Foraging guild clusters in Chashma and Taunsa wetlands were similar, according to the dendrogram. This may be due to the fact that these wetlands are water reservoirs that harbor almost the same species of waterbird. The dendrogram clusters of Dhap Chapak and Uchali wetland were significantly different. It is characterized by different landscapes, water levels, and food sources that are used by different types of waterbirds depending on the site (*Fig. 6b*).

Waterbird abundance and diversity indices

Clearly, habitat differences contributed to variation in waterbird abundance and distribution. In Chashma wetland there were three of the most plentiful waterbird species, namely little cormorants (1.446%), Gadwalls (1.406%), and Great cormorants (1.330%). In contrast, the rarest species were the common crane (0.017%), Dalmatian pelican (0.011%), and Great white pelican (0.009%). Most frequently detected waterbirds in Dhap Chapak wetland include Great white pelicans (1.093%), Dalmatian pelicans (1.069%), and Eurasian teals (1.044%). As well, Taunsa wetland had the greatest

abundance of common pochard (1.626%), tufted ducks (1.557%), and brown-headed gulls (1.518%), while black-winged stilts and common greenshanks (each; 0.163%) were the rarest water birds. The Uchali wetland harbored the highest number of Garganeys (0.566%) and Eurasian spoonbills (0.446%). However, little crakes (0.011%), Greylag geese (0.011%), and Dalmatian pelicans (0.007%) are rare visitors to the Uchali wetland. Haleji wetland harbored Eurasian widgeons (0.254%) and Avocets (0.227%). In contrast, Haleji wetland was found to have a very low number of little-ringed plover (0.006%) and ferruginous duck (0.003%). Moreover, Raja wetland attracted the highest numbers of Pallas's gulls (17,859%), Common redshanks (16,658%), and Eurasian spoonbills (1520%) to exploit it. However, there were very few black-winged stilts in this wetland (0.007%) (Fig. 7).

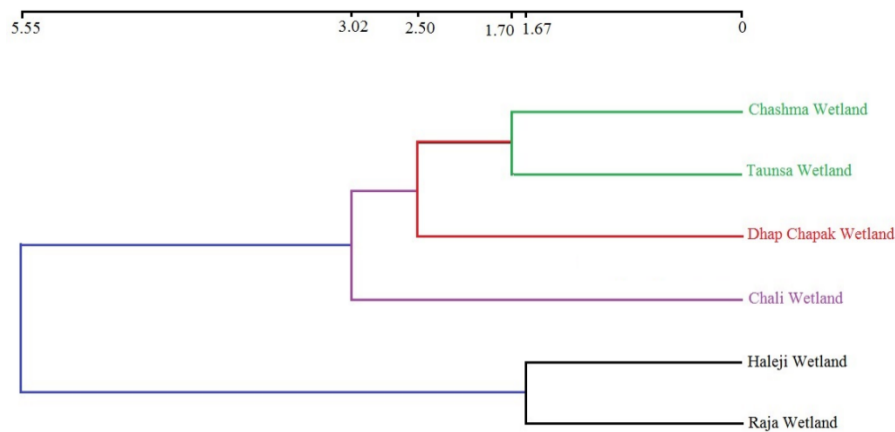


Figure 6b. Dendrogram hierarchical clustering chart indicating the waterbird foraging guilds among six wetland habitats

The outcomes of the population parameters, i.e., species diversity, species richness, relative abundance, population trend, and species dispersion varied among six wetland habitats. Overall, the waterbirds have species diversity (Shannon's Index; $H' = 3.710 \pm 0.097$), species richness (Margalef's Index; $R = 5.88 \pm 0.530$), population trend ($\lambda = 0.031$), and species evenness (Pielou's J index; $E = 0.865 \pm 0.023$) in all six potential wetland habitats. Waterbird species richness ($R = 4.724$) was highest in the Chashma wetland, with relative abundance ($RA = 26.612\%$), and species diversity ($H' = 3.740$) in Taunsa wetland. As well, the highest increase in population was determined in the Uchali wetland and the species dispersion in the Raja wetland. Contrary to this, the lowest species richness ($R = 2.893$) and species distribution ($E = 0.766$) was recorded in Uchali wetland, species relative abundance ($RA = 4.184\%$) in Raja wetland, species diversity ($H' = 3.288$), population trend ($\lambda = 0.027$) in Taunsa wetland (Table 1; Fig. 8).

It is noteworthy that the hierarchical analysis found that many species of waterbirds were widely dispersed in habitats used for habitation and had habitat links at the appropriate geographical scales. Many waterbird species demonstrated significant seasonal and temporal variation in their occurrence and habitat usage. Time and space may cause changes in the parameters of a waterbird population (Fig. 9).

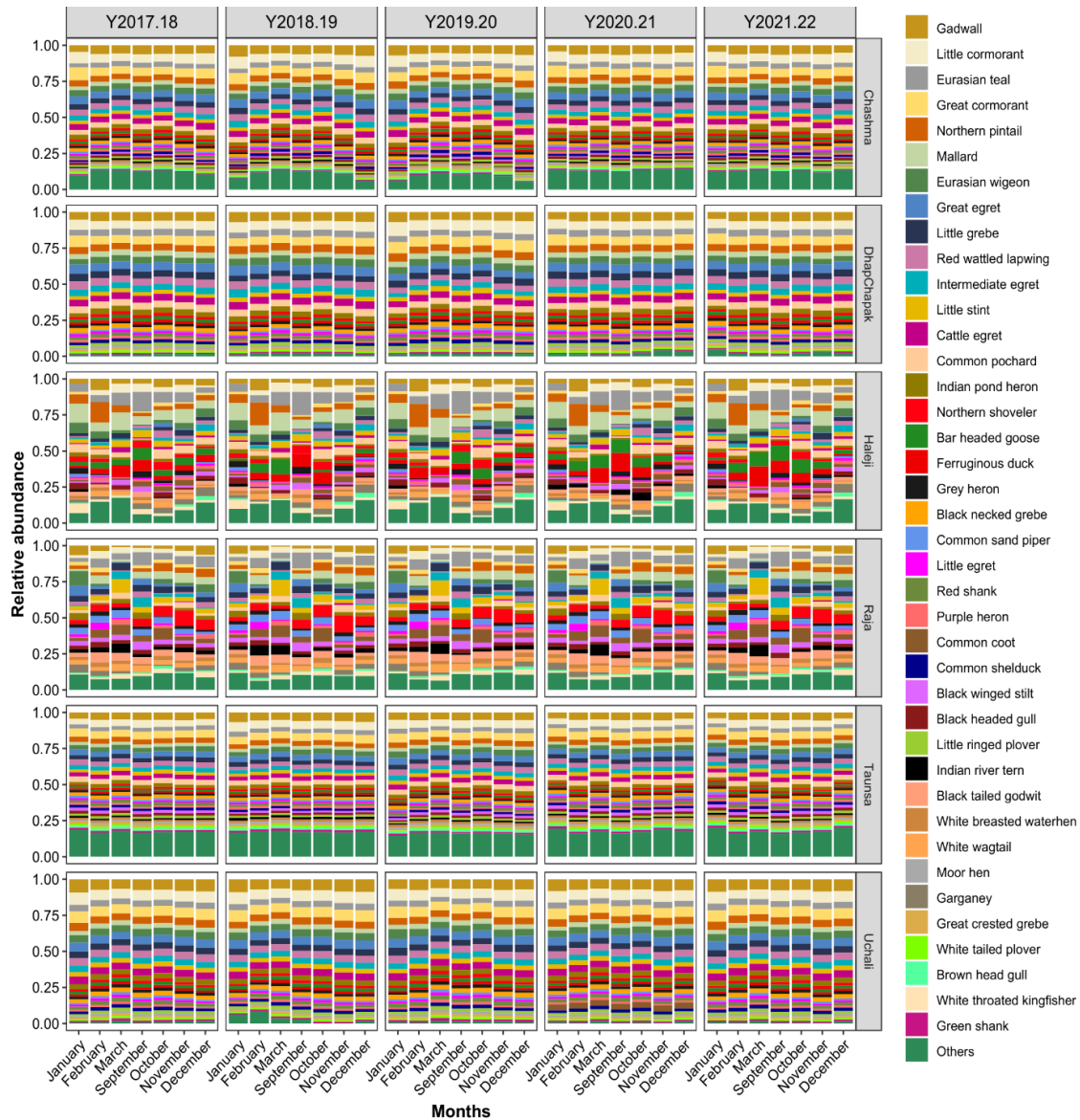


Figure 7. Demonstration of total waterbird abundance in six potential wetland habitats

Table 1. Waterbird population parameters among six potential wetland habitats

Name of wetland habitat	Total no. of species	Total detection and relative abundance (%)		Species diversity (Shannon's index; H')	Population trend (λ)	Species richness (Margalef's Index; R)	Species dispersion (Pielou J index; E)
Chashma wetland	52	48,767	23.423%	3.637	0.0321	4.724	0.848
Dhap Chapak wetland	35	35,552	17.076%	3.318	0.041	3.245	0.773
Taunsa wetland	50	55,406	26.612%	3.740	0.027	4.486	0.872
Uchali wetland	32	45,095	21.659%	3.288	0.043	2.893	0.766
Haliji wetland	47	14,671	7.046%	3.558	0.034	4.797	0.829
Raja wetland	37	8711	4.184%	3.448	0.034	3.978	0.804
Overall	73	208,202		3.710 ± 0.097	0.031	5.88 ± 0.530	0.865 ± 0.023

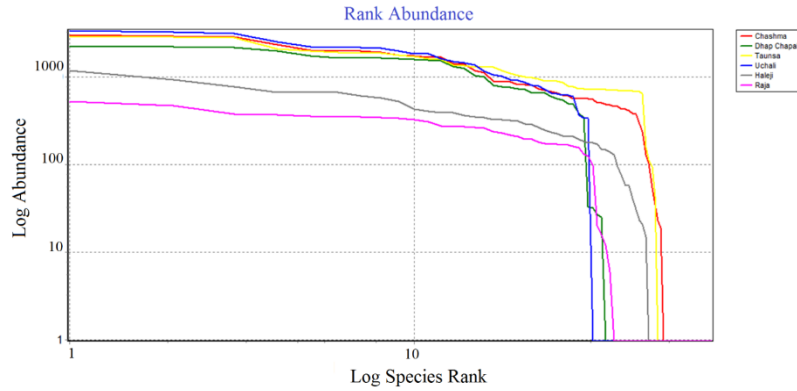


Figure 8. Comparison of species rank abundance among potential wetland habitats

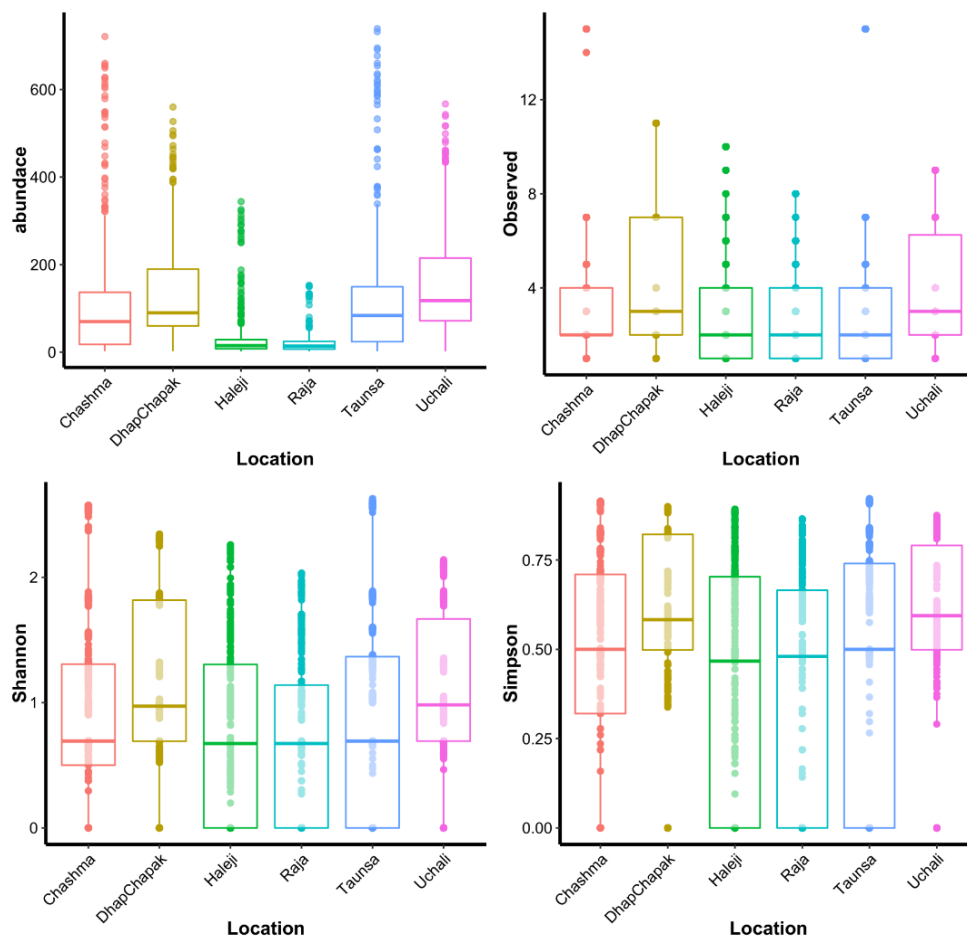


Figure 9. Showing the diversity of species at conducted sites

Estimating the population size and distribution of waterbird species at appropriate spatial and temporal scales is crucial. Identifying geographical and temporal variations in waterbird populations among heterogeneous habitats was crucial to understanding the distribution, population dynamics, and habitat preferences of waterbirds. The results indicated a substantial correlation between the occurrence of waterbird species composition and suitable sites (Fig. 10).

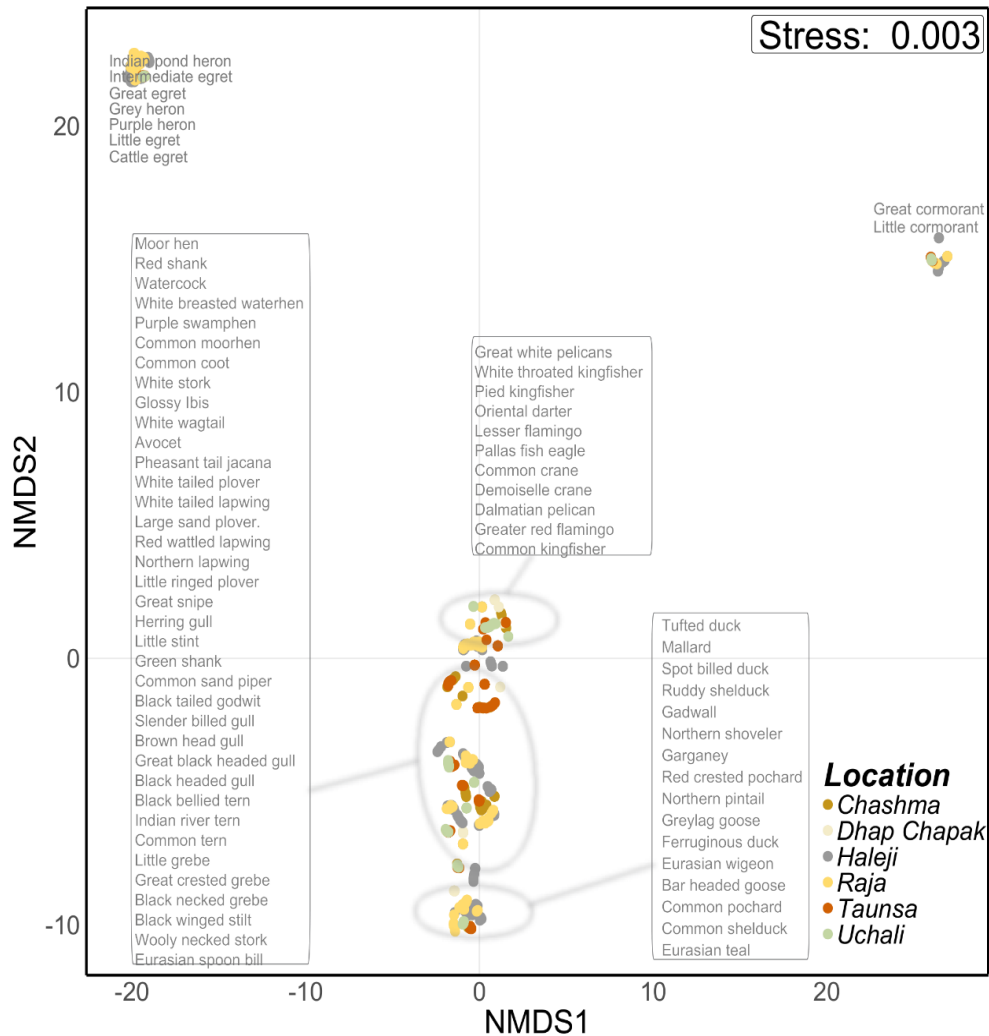


Figure 10. Non-metric multidimensional scaling (NMDS) ordination of the waterbird community structure at conducted sites

Temporal pattern of migratory waterbirds

Interestingly, the parameters of the waterbird population varied yearly. It was evident from this study that the numbers of migrant waterbird species fluctuate from year to year depending on the location of the wetland habitat along the migration route (Table 2).

Table 2. Year-wise waterbird diversity indices during five consequent migratory seasons

Year	Total no. of species	Total detection (N)	Shannon diversity index (H')	Population trend (λ)	Species dispersion (E)
2017-18	69	41,560	3.7077	0.0309	0.8757
2018-19	69	40,052	3.7005	0.0317	0.8740
2019-20	69	45,166	3.6856	0.0317	0.8704
2020-21	73	40,831	3.7380	0.0304	0.8712
2021-22	73	40,593	3.7192	0.0309	0.8669
Overall	73	208,202	3.7141	0.0311	0.8657

A Kruskal–Wallis one–way nonparametric and All–pairwise ANOVA analysis shows significant differences in waterbird detection in six wetland habitats at heterogeneous localities over five subsequent migration seasons ($F_{5, 29} = 98.10$, $p < 0.000$). Waterbird species diversity ($F_{5, 29} = 176.00$, $p < 0.000$) and population trend ($F_{5, 29} = 126.00$, $p < 0.000$) varied significantly as well. Further, waterbird species dispersion among six wetland habitats varied significantly over five subsequent migratory seasons ($F_{5, 29} = 18.20$, $p < 0.000$). This clearly indicated that waterbird species richness, species diversity, population trend, and dispersion varied spatially among six potential wetlands, namely Chashma, Dhap Chapak, Taunsa, Uchali, Haleji, and Raja wetlands over five subsequent migratory seasons. Based on statistical results, we reject our null hypothesis (Table 3).

Table 3. Year–wise and habitat–wise waterbird diversity indices during five consequent migrant seasons

Location	Year	Total no. of species	Total detection (N)	Shannon diversity index (H')	Population trend (λ)	Species dispersion (E)
Chashma	2017-18	47	9728	3.6272	0.0319	0.9421
	2018-19	47	9335	3.6034	0.0331	0.9359
	2019-20	47	10,687	3.6134	0.0322	0.9385
	2020-21	52	9526	3.6591	0.0317	0.9261
	2021-22	52	9491	3.6459	0.0320	0.9227
Dhap Chapak	2017-18	31	6845	3.3059	0.0404	0.9627
	2018-19	31	7072	3.2882	0.0416	0.9575
	2019-20	31	8332	3.3042	0.0411	0.9622
	2020-21	35	6646	3.3304	0.0402	0.9367
	2021-22	35	6657	3.3311	0.0402	0.9369
Taunsa	2017-18	48	11,452	3.7385	0.0267	0.9657
	2018-19	48	10,215	3.7292	0.0275	0.9633
	2019-20	48	11,663	3.7109	0.0280	0.9586
	2020-21	50	10,955	3.7492	0.0268	0.9584
	2021-22	50	11,121	3.7470	0.0267	0.9578
Uchali	2017-18	31	8861	3.2601	0.0438	0.9494
	2018-19	31	8836	3.2737	0.0433	0.9533
	2019-20	31	9797	3.2861	0.0419	0.9569
	2020-21	32	8984	3.2861	0.0425	0.9482
	2021-22	31	8617	3.2494	0.0442	0.9462
Haleji	2017-18	47	2940	3.5359	0.0358	0.9184
	2018-19	47	2901	3.5722	0.0343	0.9278
	2019-20	47	2925	3.5796	0.0338	0.9297
	2020-21	47	2961	3.5729	0.0341	0.9280
	2021-22	47	2944	3.5523	0.0351	0.9226
Raja	2017-18	37	1734	3.4602	0.0342	0.9583
	2018-19	37	1693	3.4709	0.0337	0.9612
	2019-20	37	1762	3.4816	0.0331	0.9642
	2020-21	37	1759	3.4779	0.0334	0.9632
	2021-22	37	1763	3.4767	0.0335	0.9628

Discussion

Quantifying the diversity and dispersion of waterbirds is a cornerstone tool for understanding the wetland habitat appropriateness, productivity, and population trends of waterbird species. Our comprehensive data on waterbird population dynamics and habitat preferences was collected during five subsequent migratory seasons (September and March of 2017-2022) among six wetland habitats located on different geographical scales: Chashma, Dhap Chapak, Taunsa, Haleji, Raja, and Uchali, ascertained by point count technique.

The findings of our study demonstrated that the waterbird population, including species composition, relative abundance, diversity indices, and habitat preferences, varied yearly and habitat-wise. We observed that a wide variety of waterbird species (73 species) utilized wetland habitats, preferably exploiting areas dominated by sufficient vegetation cover, richness in food resources, and minimal human disturbance. This indicated that floristic structure, wetland size, topography, water level, occurrence of food resources, and human disturbances play crucial roles in attracting diverse waterbird species. Similar findings were reported by Krause and Farina (2016), who noted that the complexity of vegetation structure and composition and food resources harbor a higher waterbird population in wetland habitats.

Another explanation is that waterbird species used diverse vegetation cover and heterogeneous landscape proxies to track land-use patterns, wetland productivity, and food resources in wetland habitats over time and space, as reported by Laiolo (2010), Boggie et al. (2018) and Haig et al. (2019). Our findings revealed that variations in floristic structure and species composition are key factors that ensure wetland habitat suitability and productivity. As a result, population structure, habitat preferences, and diversity indices of water birds may vary from habitat to habitat. Such findings have also been determined by Schlatter et al. (2002), Standford et al. (2005) and Mingozzi et al. (2013).

Our study also detected temporal changes in waterbird diversity due to variations in weather conditions, water level fluctuations, habitat alterations, and the distribution of food resources. These findings align with previous studies which reported that weather, water levels, and habitat modifications can influence wetland structure, food resources, and, consequently, waterbird diversity (Kim and Byrne, 2006; White et al., 2010; Cumming et al., 2012). Furthermore, our results indicated that the diversity and distribution of waterbirds differed within six wetland habitats in each season. The Taunsa wetland harbored the highest diversity of waterfowls, such as ducks, waders (egrets and herons), divers (cormorants and grebes), surface foragers (pelicans and gulls), mud and shallow water explorers (snipes, stilts, plovers, and lapwings), edge foragers (swampheens and moorhens), and sallying birds (fish eagles and terns) during the 2020 and 2021 seasons. This high diversity might be attributed to factors like complex aquatic vegetation, rich food resources, and shallow water. We found the little cormorant to be the most abundant species (10.59%), while species like the barred buttonquail and peregrine falcon were rare. The most frequently detected waterbird in our study was the gadwall (2919 individuals), with the Dalmatian pelican being the rarest.

However, a previous study by Haider et al. (2022) used the line transect method to assess bird diversity and abundance in the Taunsa wetland located in Punjab, Pakistan. They documented a total of 19,529 bird individuals belonging to 150 species across 53 families and 19 orders. Their study reported 66 migrant and 84 resident bird species. Notably, they identified 10 globally threatened species and categorized 140 as least

concern. In contrast to their findings, our study detected a higher number of waterbird individuals (55,410) but a lower number of species (50) detected in Taunsa wetland.

The Uchali wetland supported a diverse assemblage of waterbirds in the present study, including waterfowl, cormorants, egrets, lapwings, herons, grebes, geese, plovers, moorhens, shanks, and flamingos in 2019–20, while other wetlands exhibited lower species richness. This highlights the importance of wetland characteristics for waterbird communities. Shallow water depth, minimal vegetation, and scarce food resources likely limit the carrying capacity of these less diverse wetlands. Additionally, the lack of floodwater can lead to sections drying out and becoming unsuitable foraging grounds due to reduced aquatic vegetation and food availability (Shurin, 2007; Mori et al., 2013).

Previous research by Dauda et al. (2017) documented a bird species diversity of 47 in the Uchali wetland, with the Eurasian coot (*Fulica atra*) being the dominant species and the black stork (*Ciconia nigra*) the rarest. In comparison, our study detected 32 waterbird species, with the mallard (*Anas platyrhynchos*) being the most abundant and the yellow-wattled lapwing (*Vanellus malabaricus*) the rarest. Notably, our study also observed higher diversity, species richness, and evenness indices in the Uchali wetland, suggesting a potentially healthier ecosystem compared to the previous study. This variation could be attributed to methodological differences or a genuine increase in Uchali's productivity over time.

This study has revealed that waterbirds are habitat specialists. They select wetland habitats based on the availability of natural resources, i.e., habitat productivity, distribution of food resources, occurrence of suitable foraging and breeding grounds, seasonal variation, exploitation, occurrence of predators, and human disturbance. The waterbird population fluctuates temporally due to natural and anthropogenic activities. Waterbirds often select the resource-rich mosaic wetlands habitat that offers suitable foraging and safe breeding nesting and chick rearing grounds. Such types of findings were also previously quantified by Maclean et al. (2011) and Bradfer-Lawrence et al. (2020), which highlighted the importance of habitat characteristics for waterbird communities. In addition, Microclimate change, alteration in land-use patterns, as well as human disturbances, such as habitat loss and fragmentation, caused the shift in waterbird population and habitat use, as reported by Dirnböck et al. (2011), Muscarella et al. (2016), Ceballos et al. (2020) and Wang et al. (2022). Moreover, fluctuations in microclimate conditions, alterations in floral structure, and composition rise and fall in water levels are key factors that significantly affect waterbird habitat selection and diversity indices (Fleskes and Gregory, 2010; Koons et al., 2014; Donnelly et al., 2020, 2021; Gonçalves–Souza et al., 2020). Various scientists also have reported that a seasonal variation in microclimate illustrated significant changes in species composition and structure of flora, which in turn influences waterbird abundance, diversity, and distribution among six wetland sites (Shimadzu et al., 2013; Sueur et al., 2014; Fuller et al., 2015; Patrick et al., 2021). Water level and water quality are crucial parameters influencing aquatic vegetation growth, food resource distribution, and, ultimately, waterbird habitat use. Fluctuations in water level from the wetland edge to the interior or across different sites can affect floristic composition and food accessibility, impacting waterbird preferences (Roscher et al., 2014; Tapp and Webb, 2015; Myers et al., 2015; Xu et al., 2017). Consequently, waterfowl abundance, diversity, and distribution may exhibit geographical variations over time. Water depth also plays a role, with deeper areas potentially becoming inaccessible to waterfowl.

According to our results, waterbird populations at six potential wetland sites are temporally changing with time as well as wetland characteristics. These findings illustrated that waterbirds serve as bio-indicators of habitat productivity as well as changes in floristic structure, water level, water quality, and microclimate variables (Wei Zhang and Zhang Ma, 2011; Gregory and van Strien, 2010; Egwumah et al., 2017; Li et al., 2021).

Conclusions

Based on the findings it is concluded that wetlands provide a vital lifeline to a wide range of waterbird species, i.e., they exploit these wetland areas to satisfy their needs to perform multiple activities. It was evident, that waterbird population parameters varied among six wetland habitats during five consequent migratory seasons. Detection of endangered (E), nearly threatened (NT), Vulnerable (VU), and least concern (LC) waterbird species showed that these wetland habitats are vitally important for them. Moreover, the hierarchical analysis of waterbird species demonstrated that they belong to different cluster groups which are widely dispersed among these wetland habitats and significantly varied. The findings also indicated that the parameters of a waterbird population could change with time and space. It was observed that Pakistan's current management practices are inadequate. Based on the findings of this research, the wildlife department will be able to conserve and protect wetland habitats across the country in the future. Hence, an appropriate management plan or wetland ecosystem could be prepared to keep in view ecological integration based on a holistic approach to reduce human intervention and increase the waterbird population across the region (*Appendix 3*). Moreover, we recommend that these wetlands should be declared as Ramsar sites (Global Importance) for conservation and protection.

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APPENDIX

Appendix 1. Descriptions of each wetland habitat type

Description	Name of wetland habitats					
	Chashma	Dhapchapak	Taunsa	Uchali	Haleji	Raja
Latitude	N; 32° 26' 54.79"	N; 31° 44' 15"	N; 30° 32' 20.78"	N; 32° 33' 16.54"	24°48' 41.90"	27°39' 42.30"
Longitude	E; 71° 26' 21.64"	E; 70.9° 41' 12"	E; 70° 49' 35.51"	E; 72° 1' 9.28"	67°47' 15.62"	68°36' 0.47"
Area (ha)	4099 ha	2562 ha	6567 ha	1943 ha	1660 ha	175 ha
Landscape	Reservoir, riverine forest, shrublands, agriculture fields, and grasslands	Reservoirs, floodplains, semideserts, and agriculture fields	Reservoir, alluvial plans, adjacent fields, and grasslands	Reservoirs, reedbeds, marsh swamps, mountains, scrub forest, and salt ranges	Reservoirs, islands, reedbeds, rocky plains, and waterlogged areas	Reservoir, scrubby vegetation, reedbeds, and agricultural fields
Hydrologic characteristics						
Water temperature (°C)	14.6–16.3	21.5–24.68	23.2–25.6	20.8–25.8	28.6–38.8	25.2–30.36
Salinity (g/L)	0.18–0.21	0.20–0.24	0.14–0.26	0.19–22	0.22–0.27	0.18–0.24
pH	8.2–9.95	7.9–8.9	8.7–9.5	8.4–9.12	7.71–8.75	8.2–9.5
TDS (mg/L)	185–330	220–340	280–620	155–286	256–548	230–420
Dissolved oxygen (mg/L)	7.2–8.9	7.4–8.2	7.4–8.6	7.8–9.6	7.5–9.1	7.7–9.8
Color	Greenish muddy	Greenish	Greenish muddy	Bluish light green	Yellowish green	Light green
Most dominant tree species	<i>P. cineraria</i> , <i>P. glandulosa</i> , <i>A. modesta</i> , <i>Vachellia nilotica</i> , <i>Slavadora oleoides</i>	<i>V. nilotica</i> , <i>Olea ferruginea</i> , <i>Z. mauritiana</i> , <i>T. aphylla</i> , <i>A. modesta</i>	<i>Populus euphratica</i> , <i>Acacia modesta</i> , <i>A. nilotica</i> , <i>P. cineraria</i> , <i>T. aphylla</i> , <i>Salsola baryosama</i>	<i>Acacia modesta</i> , <i>A. nilotica</i> , <i>Prosopis cineria</i> , <i>Tamarix aphylla</i> , <i>Zizyphus mauritiana</i> , <i>Dalbergia sissoo</i>	<i>Vachella nilotica</i> , <i>Zizyphus mauritiana</i> , <i>Tamarix aphylla</i>	<i>Vachellia nilotica</i> , <i>Prosopis cinerea</i> , <i>Prosopis juliflora</i> , <i>Cordia dichotoma</i> , <i>Saccharum munja</i>
Most dominant shrub species	<i>Z. nummularia</i> , <i>T. dioica</i> , <i>Cocculus laeba</i> , <i>Saccharum bengalense</i> , <i>N. nucifera</i>	<i>Withania coagulans</i> , <i>R. buxifolia</i> , <i>Rhazya stricta</i> , <i>S. bengalense</i> , <i>D. viscoa</i>	<i>Zizyphus nummularia</i> , <i>Suaeda fruticosa</i> , <i>Tamarix dioica</i> , <i>S. bengalense</i>	<i>Ehretia laenis</i> , <i>Gymnosporia royleana</i> , <i>Reptonia buxifolia</i> , <i>Dodonea viscoa</i> , <i>Saccharum bengalense</i> , <i>Nelumbo nucifera</i>	<i>Cocculus laeba</i> , <i>Rhazya stricta</i> , <i>D. viscoa</i> , <i>S. bengalense</i> , <i>Nelumbo nucifera</i>	<i>Suaeda fruticosa</i> , <i>Rhazya stricta</i> , <i>Gymnosporia royleana</i> , <i>Saccharum bengalense</i> , <i>R. buxifolia</i>
Most dominant aquatic vegetation	<i>Hydrilla verticillata</i> , <i>T. domingensis</i> , <i>Phragmites australis</i> , <i>P. crispus</i> , <i>Nymphoides cristatum</i> , <i>Vallisneria spiralis</i> , <i>Zannichellia palustris</i> , <i>Ranunculus aquatilis</i> , <i>Arundo donax</i> , <i>C. rotundus</i>	<i>T. angustata</i> , <i>Phragmites karka</i> , <i>Hydrilla verticillata</i> , <i>P. pectinatus</i> , <i>Fimbristylis dichotoma</i> , <i>P. pectinatus</i> , <i>A. donax</i> , <i>C. rotundus</i>	<i>Cyperus difformis</i> , <i>Phragmites karka</i> , <i>A. donax</i> , <i>Eleocharis melanocarpa</i> , <i>Schoenoplecton litoralis</i> , <i>Zannichellia palustris</i> , <i>Cyperus rotundus</i> , <i>Sporobolus arabicus</i>	<i>Carex fedia</i> , <i>Hydrilla verticillata</i> , <i>Juncus sp.</i> , <i>Phragmites australis</i> , <i>Potamogeton pectinatus</i> , <i>Ranunculus sceleratus</i> , <i>Typha augusta</i> , <i>Scirpus sp.</i> , <i>Arundo donax</i> , <i>Cyperus rotundus</i> , <i>Sporobolus arabicus</i>	<i>Typha latifolia</i> , <i>Arundo donax</i> , <i>Juncus effuses</i> , <i>Ceratophyllum demersum</i> , <i>Phragmites australis</i> , <i>Echinochloa colona</i> , <i>Lycopus asper</i> , <i>Sagittaria latifolia</i>	<i>Potamogeton spirillus</i> , <i>Myriophyllum spicatum</i> , <i>Ceratophyllum demersum</i> , <i>Vallisneria sp.</i> , <i>Cyperus spp.</i> , <i>Eleocharis palustris</i> , <i>Dulichium spp.</i> , <i>Juncus tenuis</i> , <i>Scirpus flviatilis</i> , <i>Typha angustifolia</i> , <i>Cinna latifolia</i> , <i>Panicum virgatum</i> , <i>Setaria glauca</i> , <i>Phragmites australis</i>

Most common grasses	<i>Chrysopogon serrulatus</i> , <i>Cymbopogon jwarancusa</i> , <i>Digitaria adscendens</i> , <i>Aristida adscensionis</i> , <i>Alopecurus aequalis</i> , <i>C. aucheri</i> , <i>C. setigerus</i> , <i>E. ciliaris</i>	<i>S. spontaneum</i> , <i>C. setigerus</i> , <i>C. pennisetiformis</i> , <i>Sporobolus arabicus</i> , <i>Heteropogon contortus</i> , <i>P. antidotale</i> , <i>C. setigerus</i> , <i>C. dactylon</i> , <i>E. ciliaris</i>	<i>Saccharum spontaneum</i> , <i>Eleusine compressa</i> , <i>Panicum antidotale</i> , <i>Boerhavia diffusa</i> , <i>Fagonia ovalifolia</i> , <i>Imperata cylindrical</i> , <i>E. ciliaris</i> , <i>Rumex sp.</i> , <i>Cenchrus setigerus</i>	<i>Phyla nodiflora</i> , <i>Hydrilla verticillata</i> , <i>Paspalum distichum</i> , <i>Lasiurus hirsutus</i> , <i>Dichanthium annulatum</i> , <i>Aeluropus lagopoides</i> , <i>Zannichellia palustris</i> , <i>Cenchrus setigerus</i> , <i>Eragrostis ciliaris</i>	<i>Digitaria adscendens</i> , <i>Heteropogon contortus</i> , <i>Fagonia ovalifolia</i> , <i>Aeluropus lagopoides</i> , <i>Aeluropus lagopoides</i> , <i>E. ciliaris</i>	<i>C. setigerus</i> , <i>P. antidotale</i> , <i>Fagonia ovalifolia</i> , <i>Imperata cylindrical</i> , <i>Phyla nodiflora</i> , <i>Digitaria adscendens</i> , <i>Saccharum spontaneum</i>
Rainfall	300–500 mm	2–260 mm	200–450 mm	300–800 mm	250–450 mm	148 mm
Relative humidity	22.0–85.0%	20.0–82.0%	25.0–85.0%	22.0–85.0%	37–85.0%	37–85.0%
Temperature	4.5°C–41°C	6°C–46°C	4.5°C–45°C	0.5°C–36°C	2.2°C–48.5°C	7.0°C–44.4°C

Appendix 2. List of the waterbird species in each wetland habitat

Family	Scientific name	Common name	Foraging guild	IUCN status	Wetland habitats						Total
					Chashma	Dhap Chapak	Taunsa	Uchali	Haleji	Raja	
Accipitridae	<i>Haliaeetus leucoryphus</i>	Pallas fish eagle	P	EN	0	0	0	0	0.028	0.010	0.038
Alcedinidae	<i>Alcedo atthis</i>	Common kingfisher	I/P	LC	0	0	0	0	0.020	0	0.020
Alcedinidae	<i>Ceryle rudis</i>	Pied kingfisher	I/P/C	LC	0	0	0	0	0.072	0.082	0.154
Alcedinidae	<i>Halcyon smyrnensis</i>	White-throated kingfisher	I/P/C	LC	0	0	0	0	0.188	0.080	0.268
Anatidae	<i>Anas poecilorhyncha</i>	Spot billed duck	O	LC	0.314	0	0.479	0	0	0	0.794
Anatidae	<i>Anser indicus</i>	Bar-headed goose	O	LC	0.424	0.372	0.430	0.506	0.293	0	2.026
Anatidae	<i>Aythya ferina</i>	Common pochard	O	VU	0.856	0.789	0.914	0	0.322	0.094	2.975
Anatidae	<i>Tadorna tadorna</i>	Common shelduck	O	LC	0.421	0.389	0.469	0.495	0	0	1.775
Anatidae	<i>Anas crecca</i>	Eurasian spoonbill	I/P	LC	0.062	0	0.054	0	0.045	0	0.162
Anatidae	<i>Mareca penelope</i>	Eurasian teal	I/P	LC	0.809	0.751	0.769	0.891	0.446	0.227	3.893
Anatidae	<i>Aythya nyroca</i>	Ferruginous duck	O	NT	0.328	0.344	0.328	0.382	0.276	0	1.658
Anatidae	<i>Mareca strepera</i>	Gadwall	O	LC	1.406	1.044	1.404	1.626	0.319	0.169	5.969
Anatidae	<i>Anas querquedula</i>	Garganey	O	LC	0	0	0	0	0.251	0.126	0.378
Anatidae	<i>Anser anser</i>	Greylag goose	O	LC	0.272	0	0.335	0	0	0	0.606
Anatidae	<i>Anas platyrhynchos</i>	Mallard	O	LC	0.672	0.639	0.621	0.720	0.566	0.179	3.397
Anatidae	<i>Anas acuta</i>	Northern pintail	O	NT	0.976	0.843	0.945	1.062	0.374	0.1476	4.348

Anatidae	<i>Spatula clypeata</i>	Northern shoveler	O	NT	0.393	0.355	0.339	0.436	0.168	0.254	1.947
Anatidae	<i>Netta rufina</i>	Red-crested pochard	O	LC	0.224	0	0.352	0	0	0	0.576
Anatidae	<i>Tadorna ferruginea</i>	Ruddy shelduck	O	LC	0.292	0.273	0.349	0	0	0	0.913
Anatidae	<i>Aythya fuligula</i>	Tufted duck	O	NT	0.199	0	0.310	0	0	0	0.508
Anhingiidae	<i>Anhinga melanogaster</i>	Oriental darter	P	NT	0	0	0	0	0.0889	0.075	0.164
Ardeidae	<i>Bubulcus ibis</i>	Cattle egret	I/P/C	LC	0.922	0.792	0.828	1.028	0.101	0.008	3.678
Ardeidae	<i>Ardea alba</i>	Great egret	I/P/C	LC	1.122	0.954	1.016	1.218	0.035	0.128	4.473
Ardeidae	<i>Ardea cinerea</i>	Grey heron	I/P/C	LC	0.389	0.316	0.376	0.447	0.150	0.081	1.759
Ardeidae	<i>Ardeola grayii</i>	Indian pond heron	I/P/C	LC	0.689	0.601	0.653	0.779	0.118	0.111	2.950
Ardeidae	<i>Ardea intermedia</i>	Intermediate egret	I/P/C	LC	0.801	0.738	0.783	0.885	0.174	0.087	3.467
Ardeidae	<i>Egretta garzetta</i>	Little egret	I/P/C	LC	0.337	0.314	0.341	0.388	0.083	0.061	1.523
Ardeidae	<i>Ardea purpurea</i>	Purple heron	I/P/C	LC	0.271	0.264	0.333	0.316	0.112	0.064	1.359
Charadriidae	<i>Charadrius leschenaultii</i>	Greater sand plover	I/P/C	LC	0	0	0	0	0.015	0	0.015
Charadriidae	<i>Calidris minuta</i>	Little stint	I	LC	0.566	0.481	0.653	0.702	0.208	0.163	2.773
Charadriidae	<i>Charadrius dubius</i>	Little-ringed plover	I/P/C	LC	0.355	0.314	0.416	0.418	0	0	1.504
Charadriidae	<i>Vanellus vanellus</i>	Northern lapwing	I/P/C	NT	0.208	0	0.342	0	0	0	0.551
Charadriidae	<i>Vanellus indicus</i>	Red-wattled lapwing	I/P/C	LC	0.950	0.798	0.898	1.042	0.139	0.093	3.920
Charadriidae	<i>Vanellus leucurus</i>	White-tailed lapwing	I/P/C	LC	0.230	0.238	0.330	0.298	0	0	1.096
Charadriidae	<i>Vanellus malabaricus</i>	Yellow-wattled lapwing	I/P/C	LC	0	0	0	0	0.007	0	0.007
Ciconiidae	<i>Ciconia ciconia</i>	White stork	I/P/C	LC	0.269	0.013	0.348	0	0	0	0.630
Ciconiidae	<i>Ciconia episcopus</i>	Woolly-necked stork	I/P/C	NT	0.050	0.016	0.046	0	0	0	0.111
Gruidae	<i>Grus grus</i>	Common crane	O	LC	0.017	0.012	0	0	0	0	0.0288
Gruidae	<i>Grus virgo</i>	Demoiselle crane	O	LC	0.026	0.015	0	0	0	0	0.042
Jacaniidae	<i>Hydrophasianus chirurgus</i>	Pheasant-tail Jacana	I/P/C	LC	0.139	0	0.349	0	0	0	0.489
Laridae	<i>Sterna acuticauda</i>	Black-bellied tern	I/P	EN	0	0	0	0	0.108	0.084	0.192
Laridae	<i>Chroicocephalus ridibundus</i>	Black-headed gull	I/P/C	LC	0.393	0	0.456	0	0.164	0.100	1.115
Laridae	<i>Chroicocephalus brunnicephalus</i>	Brown-headed gull	I/P/C	LC	0.208	0	0.429	0	0.101	0.047	0.785
Laridae	<i>Sterna hirundo</i>	Common tern	I/P	LC	0	0	0	0	0.011	0.078	0.089
Laridae	<i>Larus argentatus</i>	Herring gull	I/P/C	LC	0.299	0	0.529	0	0	0	0.828

Laridae	<i>Sterna aurantia</i>	Indian river tern	I/P	VU	0.233	0	0.335	0	0.085	0.131	0.783
Laridae	<i>Ichthyaetus ichthyaetus</i>	Pallas's gull	I/P/C	LC	0.115	0	0.346	0	0	0	0.461
Laridae	<i>Chroicocephalus genei</i>	Slender-billed gull	I/P/C	LC	0	0	0	0	0.127	0.006	0.133
Motacillidae	<i>Motacilla alba</i>	White wagtail	I	LC	0	0	0	0	0.156	0.133	0.293
Pelecanidae	<i>Pelecanus crispus</i>	Dalmatian pelican	P	NT	0.011	0	0.021	0	0	0	0.032
Pelecanidae	<i>Pelecanus onocrotalus</i>	Great white Pelican	P	LC	0.009	0	0.076	0	0	0	0.085
Phalacrocoracidae	<i>Phalacrocorax carbo</i>	Great cormorant	I/P/C	LC	1.380	1.069	1.388	1.518	0.094	0.083	5.531
Phalacrocoracidae	<i>Microcarbo niger</i>	Little cormorant	I/P/C	LC	1.446	1.093	1.341	1.557	0.197	0.114	5.747
Phoenicopteridae	<i>Phoenicopterus roseus</i>	Greater flamingo	C	LC	0	0	0	0.163	0	0	0.163
Phoenicopteridae	<i>Phoeniconaias minor</i>	Lesser flamingo	C	NT	0	0	0	0.163	0	0	0.163
Podicipedidae	<i>Podiceps nigricollis</i>	Black-necked grebe	I/P	LC	0.533	0.501	0.624	0.6574	0	0	2.316
Podicipedidae	<i>Podiceps cristatus</i>	Great-crested grebe	I/P/C	LC	0.224	0.233	0.379	0.300	0	0	1.136
Podicipedidae	<i>Tachybaptus ruficollis</i>	Little grebe	I/P/C	LC	0.832	0.775	0.858	0.954	0.189	0.167	3.774
Rallidae	<i>Gallinula chloropus</i>	Common moorhen	O	LC	0.274	0.288	0.349	0.347	0	0	1.258
Rallidae	<i>Fulica atra</i>	Eurasian coot	O	LC	0	0	0	0.178	0.152	0.183	0.513
Rallidae	<i>Porzana parva</i>	Little crane	I	LC	0	0	0	0	0.011	0.003	0.013
Rallidae	<i>Porphyrio porphyrio</i>	Purple swamphen	O	LC	0	0	0	0	0.067	0	0.067
Rallidae	<i>Gallinula cinerea</i>	Watercock	O	LC	0	0	0	0	0.0279	0	0.0279
Rallidae	<i>Amaurornis phoenicurus</i>	White-breasted waterhen	O	LC	0.242	0	0.433	0	0.102	0.104	0.881
Recurvirostridae	<i>Recurvirostra</i>	Avocet	I/C	LC	0.273	0	0.620	0	0	0	0.893
Recurvirostridae	<i>Himantopus himantopus</i>	Black-winged stilt	I/P	LC	0.182	0	0.497	0	0.137	0.131	0.948
Scolopacidae	<i>Tringa nebularia</i>	Common green shank	I/P	LC	0.186	0.164	0.336	0.286	0	0	0.972
Scolopacidae	<i>Tringa totanus</i>	Common red shank	I/P	VU	0.433	0.368	0.565	0.558	0	0	1.924
Scolopacidae	<i>Tadorna tadorna</i>	Common sandpiper	I/P	LC	0.242	0.183	0.345	0.312	0.071	0.156	1.309
Scolopacidae	<i>Actitis hypoleucos</i>	Eurasian wigeon	O	LC	0.948	0.758	0.902	1.053	0.319	0.168	4.148
Scolopacidae	<i>Gallinago media</i>	Greater painted snipe	I/P	LC	0	0	0	0	0.062	0	0.062
Scolopacidae	<i>Limosa limosa</i>	Black-tailed Godwit	I/P	NT	0	0	0	0	0.157	0.171	0.328
Threskiornithidae	<i>Plegadis falcinellus</i>	Glossy ibis	I/P/C	LC	0	0	0	0	0.085	0	0.085

Foraging Guilds: C = Carnivore, I = Insectivore, I/C = Insectivore/Carnivore, I/P = Insectivore/Piscivore, I/P/C = Insectivore/Piscivore/Carnivore, O = Omnivore, and P = Piscivore. IUCN Conservation status; EN = Endangered, LC = Least Concern, NT = Nearly Threatened, and VU = Vulnerable

Appendix 3: Appropriate management plan for wetland ecosystem

Wetland management plans identify the priority areas for enhancing bird populations and improving habitats. It includes the general background, potential threats, biophysical and social environmental issues of the targeted wetland ecosystems.

General background

Pakistan is primarily an arid and semi-arid country. The country is blessed with a wide range of landscapes, such as coastal areas, deserts, semiarid regions, alluvial plains, agriculture fields, forests, salt ranges, mountains, valleys, rangelands, alpine pastures, glaciers, etc. Ramsar International defines wetlands as “natural or artificial areas of marsh, fens, peatland or water, with or without water, flowing or static, fresh, brackish, or salt water, including areas of marine water that are less than 6 m deep at low tide”.

Across the country, there are more than 225 wetlands, which cover 15.0% of the total land area. There are a variety of wetlands in terms of size, floristic structure, and geographical location. The majority of wetlands are permanent, while a few are seasonal. In Pakistan, 20 wetland areas have been designated as Ramsar Sites (Globally Importance). Wetland areas are biodiversity hotspots for migratory waterfowl and waders and are important habitats for endangered bird species. As they serve as kidneys of the earth (improve water quality), habitats for wildlife, and a source of livelihood (fish), they are crucial to the survival of both humans and wildlife. They are also a source of food for the urban and rural population.

There is a lack of scientific data on various aspects of wetlands. In order to prepare an appropriate wetland management plan, it is crucial to improve monitoring activities in order to make informed decisions.

Management activities

Protection of sensitive areas

To enhance the population of threatened wildlife species, nesting and chick rearing sites, wintering areas, spawning grounds, and foraging grounds should be protected.

Installation of signboards

It is imperative to install signs that indicate the ecological status of the targeted species and their conservation requirements, especially in the sensitive areas which have been mentioned above.

Control of illegal activities

A wide variety of illegal activities are detrimental to wildlife species and their habitats, such as hunting, fishing, industrial effluent, domestic sewage, agriculture runoff, and any other form of harvesting. To conserve and protect threatened species and increase their population, all illegal activities should be prohibited. Offenders who violate the rules should be punished severely, including fines and imprisonment.

Control of alien species

To maintain ecological integrity, alien or invasive species should be strictly prohibited. In order to reduce adverse effects on water quality and habitat, thick mats of aquatic vegetation should be removed.

Conservation of flora and fauna of the wetland habitat

Wetlands are crucial to the survival of a wide variety of wildlife species. In order to protect the wide range of threatened species, the conservation of wetland habitat is of utmost importance. Ensure the maintenance of the wetland's function, its value, and its habitat for wildlife. Threatened and endangered species should be given priority. Restoration of degraded wetland habitats can be achieved through planting, increasing food resources, improving water quality, and reducing pollution. In order to enhance wetland productivity, it is important to identify the degraded and less productive areas.

Establishment of zones

It is necessary to develop management plans that match specific requirements according to the ecological characteristics and human activities in different places. The purpose of zoning is to clearly identify boundaries between lands for different management purposes. A wetland area can be divided into three distinct zones (i) transition or public access zone, (ii) buffer zone, and (iii) core or intact zone for proper conservation and management.

1. **Core Zone:** In this zone no activity will be conducted. In this zone, the area is left to nature. Unless a natural disaster occurs, no human activities will be carried out in this zone.
2. **Buffer Zone:** Activities related to conservation and environment safety will take place in the buffer zone. In order to reduce negative impacts on the core zone and to increase food resources and provide safe havens for waterbird species, this zone will be established. It covers shallow water and the edges of wetlands.
3. **Transition or Human Access Zone:** Subsequent to the buffer zone, this area promotes sustainable use. The public is allowed to engage in ecotourism within this zone.

Regular framework

- (a) Local communities can be involved in ecotourism and management activities.
- (b) Any private lands within the core protected zone should be transferred to the government so that regulations can be imposed and observed properly.
- (c) To achieve sustainable use of wetland resources for conservation and wise use, the stakeholders, including those involved in ecotourism and controlled fishing and hunting, must first reach a general agreement. Another management issue is the difficulty in resolving and transferring the land tenure of privately owned lands within the wetlands.
- (d) A general agreement among the stakeholders such as farmers having land adjacent to wetland areas should be done, i.e., they reduce the use of pesticides and fertilizers through Integrated Pest Management (IPM) and promote organic agriculture.

- (e) Environmental impact assessments (EIAs) must be conducted for any development project within this zone to assess potential negative impacts on the wetland. In order to maintain the ecological balance of the wetland in the long run, indirect impacts from all proposed development projects should be analyzed.

Construction of infrastructure

Tourists who visit a particular wetland area should have access to basic facilities. A nature interpretation center, bird watching hides, walking paths, accommodation (chalet), toilets, litter bins, and parking lots are included. Watch towers will be used to survey wildlife and look for signs of illegal activity. The flora and fauna species in wetland habitat should be monitored on a weekly basis as part of a regular monitoring program. The results indicate whether wildlife populations are increasing or decreasing in wetland habitats. A nature interpretation center provides basic information about wetland areas, local cultures, flora and fauna to ecotourists who are interested in preserving and conserving wetlands areas. Furthermore, the Nature interpretation center will be used for research, training, and education. It is important to clearly identify the camping area where ecotourists can enjoy themselves, e.g. camping and walking is a popular activity for ecotourists.

Data collection on various aspects of wetland habitat

Incomplete scientific data exist on these wetlands. It is crucial to gather comprehensive scientific data for the efficient management of wetlands and effective conservation efforts.

Microclimate (temperature, relative humidity and rainfall) monitoring: It is necessary to record temperature, relative humidity, and rainfall data on a monthly basis in order to determine how microclimate variables fluctuate. The parameters above have a significant impact on habitat use, foraging behavior, breeding season, as well as selection of nesting sites. Waterbirds choose habitats that satisfy their needs, i.e., where they can breed and raise chicks. In addition, it can provide protection against harsh weather conditions and predators. Data on microclimate variables will be collected by portable HOBO mini weather stations.

Soil properties assessment: Invertebrates thrive in the soil and are the staple diet of adult waterbirds and their chicks. As soil composition and structure play a key role in floristic characteristics. The soil physical and chemical properties will be examined through collecting the soil sample at heterogeneous location. The physical and chemical properties of soil in shallow waters and at wetland edges will be monitored regularly.

Water quality monitoring: To understand wetland ecology, it is crucial to examine the water quality of the particular wetland habitat at various locations regularly in order to determine whether aquatic flora and fauna can thrive in the water. Furthermore, it will show the concentration of gases, the total dissolve salts, pollutants, and sediments ratio of water. To determine the fluctuation in water quality, the parameters of water quality should be monitored regularly. It provides comprehensive information on wetland habitat from a physical and biological standpoint. The following parameters can be ascertained as given in *Table A1*.

Fauna survey

Wetlands are highly productive communities and provide habitat and food resources to a wide range of species. They provide an ideal habitat for fish, amphibians, shellfish,

insects, and fish because of their high nutritional value. A variety of fauna rely on wetlands for food, water, breeding, and protection.

Table A1. *Water quality parameters can be measure in wetland*

Arsenic	Mercury
Ammonia	Nitrate
An-ionic detergents	Nitrite
Barium	Nickel
Biological oxygen demand (BOD)	Oil and grease
Boron	pH
Cadmium	Phenolic compound
Chloride	Salinity
Chlorine	Selenium
Chromium hexavalent	Silver
Chemical oxygen demand (COD)	Sulphate
Conductivity	Sulphide
Copper	Temperature
Cyanide	Total dissolved solids (TDS)
Dissolved oxygen (DO)	Total suspended solids (TSS)
Fluoride	Total toxic metals
Iron	Turbidity
Lead	Zinc
Manganese	

Large mammal survey

It is imperative that large mammals be surveyed via line transects, spotlights, and direct sightings as well as indirect methods, including footprints, scats, and feeding signs.

Small mammal survey

Mist nets, Sherman traps, and snap traps should also be used to monitor small mammals in particular wetland areas, along with bait (a combination of different grains mixed with fragrant seeds). Food grains like wheat and rice can be used as food while peanut butter, coriander, oats, and onion are utilized for fragrance. The bait is highly effective in luring small mammals. It is mandatory to use freshly prepared bait every day when trapping.

Bird survey

Wetland birds are motile components of wetland habitat and often associated with wetland vegetation and concentrated where food resources are sufficient. A variety of methods can be used to monitor bird fauna, such as direct observation, point counts, line transects, point count line transects, and mist-netting.

Fish fauna survey

Gillnets and hand casts can be used to survey fish fauna.

Amphibian and reptile survey

The amphibians and reptiles are among the most important vertebrates. The amphibians and reptiles should be surveyed by active search and pitfall trapping. As a result of the amphibian and reptile survey, information will be gathered about the food resources of wetlands, the food chain and the food web that exists in wetland habitats.

Vegetation survey

Vegetation is an essential component of wetland productivity and habitat suitability. Vegetation of wetlands can be determined by direct visual estimation, by using a quadrat method, or by using a circular plot method. The vegetation survey will provide information about habitat suitability and productivity for various wildlife fauna species.