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Temporal and Spatial Variation in Avian Diversity at Lake Qaroun, Egypt

Shimaa Y. El Sayed[1], Mohamed A.M. Kadry[1], Basma M. Sheta[2*]
[1]Zoology Department, Faculty of Science, Cairo University, Cairo, Egypt
[2]Zoology Department, Faculty of Science, Damietta University, New Damietta, Egypt
*Corresponding author: basmasheta@du.edu.eg

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ABSTRACT
The lakes of Egypt are the most diverse habitats for breeding and wintering migratory birds. Lakes are classified as wetlands that include both terrestrial and aquatic environments; thus, it is essential to emphasize studying their fauna. The diversity of bird species in the area was evaluated to assess the functionality of several types of habitats around Lake Qaroun. Lake Qaroun is a Ramsar site and is considered an important bird area (IBA). A 15-month fieldwork (five successive seasons) was conducted from December 2020 to February 2022. The study sites were selected and grouped according to habitat types: Open water (OpW), sewage drains (SdR), protected area (PA), and urban villages (UrV). A total of 85 species were recorded belonging to 13 orders and 26 families. The bird community structure was divided into three main groups: resident, migratory, and waterbirds. Waterbirds were the most dominant, representing 68% of the total bird community richness (57 species), followed by residents representing 38% (32 species), and migrants representing 62% (52 species). In addition, the white-headed duck *Oxyura leucocephala* (a scarce endangered species) and graylag goose *Anser anser* were two rare passers that was recorded during the study. Slender-billed gull (*Larus genei*) was the most abundant species in the lake. The spatial and temporal variation was measured using species richness, mean abundance, evenness (equitability), Shanonn-Wiener's, and Simpson's diversity indices. Results showed that spatially, SdR represented the highest habitat in avian diversity of the overall community and resident species, while PA recorded the lowest. Temporally, autumn recorded the highest richness and mean species abundance, while spring experienced the lowest. Species evenness and diversity indices recorded the highest numbers in both winter seasons, with the lowest observed in summer. Indicator species analysis showed that nine indicator species were significantly associated with sewage drain habitat. In contrast, the greater flamingo *(Phoenicopterus roseus)* was identified as an indicator species significantly associated with the habitat of the protected area.

INTRODUCTION

Wetlands play a critical role in protecting ecosystem diversity and provide essential livelihood ecological services for animals and humans. Although they only cover 6% of the earth's terrestrial surface, they are among the most productive habitats since the total values of the wetland ecosystem services are estimated at 47% of the global ecosystem **(Clarkson *et al.*, 2013; Mitsch & Gosselink, 2015; Xu *et al.*, 2019)**. According to the report on Ramsar's fourth strategic plan for 2014 to 2024, a network of wetlands is estimated to consist of 2,208 Ramsar sites, spanning 210.73 million hectares. These wetlands serve as a vital ecological system that benefits the environment and human populations **(Ramsar Convention Secretariat, 2015)**. Despite their significant importance to humans and wildlife, wetlands are under severe threats and risks of degradation and loss for countless reasons including extensive human activities **(Lu *et al.*, 2021; Salimi *et al.*, 2021)**.

The scientific term "biodiversity" refers to the range of living organisms in a particular location or region, including various levels, such as genetic diversity and habitat diversity **(Gaston, 2000)**. Taxonomic diversity is a commonly employed aspect of biodiversity for addressing this issue, which is evaluated through three distinct components: gamma diversity (diversity within a vast region), alpha diversity (diversity of a specific site), and beta diversity (the spatial replacement of species among sites within a given area) **(Whittaker, 1972; Koleff *et al.*, 2003)**. In recent times, extensive ecological research has yielded a comprehensive dataset that enables a more precise comprehension of diversity patterns. This has propelled diversity monitoring to a new level of understanding regarding the factors that drive alterations in these patterns, including those resulting from physical and/or chemical alterations in the water **(Frost *et al.*, 1998; Dudgeon *et al.*, 2006)**, global climate change **(Hannah *et al.*, 2002; Williams & Newbold, 2020)**, and land use **(Foley *et al.*, 2005)**.

Although environmental monitoring does not enable direct inferences about cause-and-effect relationships, it can aid in comprehending complex dynamic patterns and formulating hypotheses regarding ecological relationships **(Franklin, 1989; Bonecker *et al.*, 2013)**. Birds are animals of great value to the ecosystem since they represent a vital part of the food web, and for being a bio-indicator expressing the health and quality of the ecosystem **(Bensizerara *et al.*, 2013)**. Thus, studying avian diversity is essential for understanding ecosystem changes. Birds have been monitored for a very long time worldwide, as they are relatively easy to detect and identify, and survey methods are well-established, making understanding their population dynamics and diversity relatively easy **(Fraixedas *et al.*, 2020)**.

The comprehensive understanding and thorough investigation of the ecological condition of avifauna, particularly waterfowl, in the wetlands of North Africa, remains incomplete. Consequently, it is of major importance to gain a deeper understanding of the selective pressures that are imposed on avian species in the wetlands of North Africa since these regions often constitute the most extreme boundary of their distribution **(Chenchouni, 2015; Sayoud *et al.*, 2017)**.

It is worthy to mention that Egypt is home to a variety of wetlands **(El-Gamal, 2017)**. One of the internationally important wetlands in Egypt is Lake Qaroun. The saline lake occurs in the lowest northern part of the El-Fayoum Governorate **(El-Kady *et al.*,**

2019). It is one of Egypt's most critical wetland habitats due to its value in many aspects. It is a natural protectorate (declared in 1989); Ramsar's convention considered it as one of the internationally important wetlands and, in collaboration with BirdLife International, designates it as an important bird area (IBA), contributing to the total of 34 IBAs in Egypt **(BirdLife International, 2022)**.

Lake Qaroun provides a great habitat for breeding resident birds and wintering ground for migratory birds. Being an ideal wetland, it provides all the essential requirements for the survival of both migratory and resident bird species (**Francesiaz *et al.*, 2017)**. Additionally, this might as well explain Lake Qaroun being a necessary stopover for migratory birds in their journey to refuel with food, water, and seek a proper refuge during winter. Ongoing research on Lake Qaroun focused mainly on the contamination of the lake's water and sediments with high levels of heavy metals in the lake resulting in high levels of pollution, water toxicity, habitat degradation, habitat loss to many populations, and the effect of this pollution on living beings, such as fish, invertebrate, and microbiota without mentioning the avian community, referring to studies of **Goher *et al.* (2018)**, **El-Kady *et al.* (2019)**, **Saleh *et al.* (2021)** and **El-Sayed *et al.* (2022)**. However, fewer studies have been done on bird diversity, creating a huge gap in our knowledge regarding the lake's avian diversity. Consequently, it was imperative to understand the avian community and identify the habitats of avifauna within or surrounding the lake.

The study aimed to provide data about the number and classification of bird species present in the lake, which can be used for subsequent investigations concerning the well-being of the lake and its correlation with the diversity of avian life in the future. The present study also aimed to address the knowledge gap by generating an updated list of avian species that inhabit or migrate to Lake Qaroun and monitoring bird abundance. This information is expected to provide valuable insights for future conservation planning efforts.

MATERIALS AND METHODS

Study area

El Fayoum Governorate is a natural depression in the northern part of the western desert about 90km from Cairo (29.5833, 29.0833 N; 30.3333, 31.1666 E) **(Mohamed & El-Raey, 2019)**. It consists of three protected areas: Wadi El Ryan, Lake Qaroun, and Wadi El Hitan **(EEAA, 2008)**. Lake Qaroun -the studied area- is a closed saline lake with a surface area of 255Km^2 **(El-Shabrawy & Dumont, 2009)**. It holds historical significance since it is the only remaining portion of "the ancient Lake Moreis" **(El-Zeiny *et al.*, 2019)**. It was declared a protected area under Law 102/1983 by Prime Ministerial Decree No. 943/1989 and an important bird area (IBA) in 1989.

It is located northwest of the El Fayoum depression **(EEAA/NCS, 2007)**. The Ramsar Convention and BirdLife International considered Lake Qaroun as an important bird area (IBA), considering that the lake had met several categories, according to the outlines stated by the convention **(Ramsar Convention Secretariat, 2016; BirdLife International, 2022)**.

Bird census and sampling methods

A bird survey was monthly conducted for 15 successive months at 10 sites distributed around the lake under study (Fig. 1). The study sites were selected according to different land use activities and habitat heterogeneity around the lake. Our survey concentrated on the lake's southern and eastern regions since it was observed that most bird populations were located in these areas. Conversely, the northern region was represented by only two points, since we noted that Greater Flamingo primarily dominated this area. Hence, these previously mentioned points represented the entire northern region of the lake. The study started in Winter 2020/ 2021 and ended in Winter 2022, covering migration and breeding seasons. Point count survey method was used during this study **(Sheta, 2019)**. Species were identified either by sight or by identifying the song or the call. Signs of breeding behavior were recorded. Binoculars of 10 x 42 magnification power were used. A Nikon d3500 with a 70-300 non-VR lens was used. A bird identification guidebook by **Mullarney *et al*. (1999)** was utilized.

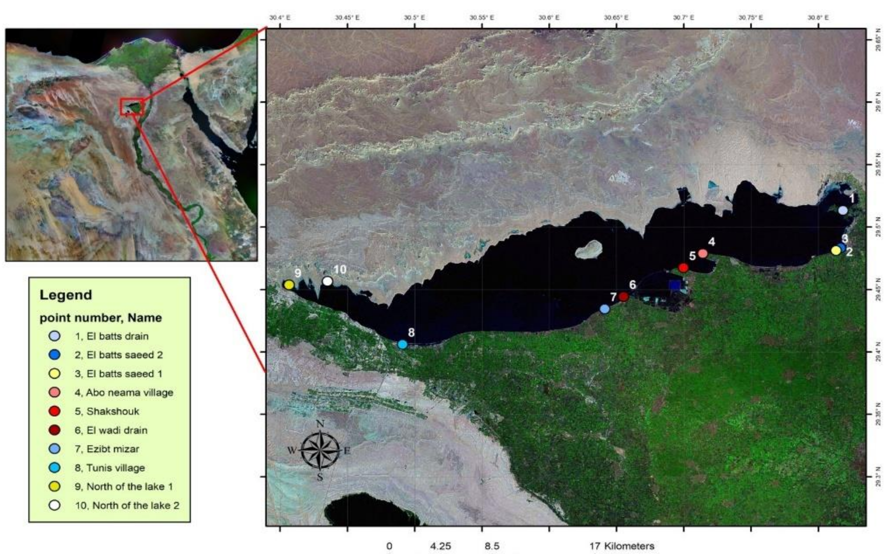

Fig. 1. The study selected locations representing habitats of Lake Qaroun

Statistical analysis

The spatial data have been grouped into four habitat groups: Open water (OpW), sewage drains (SdR), protected area (PA), and urban villages (UrV). Temporal data were divided into five seasons.

The following ecological parameters were used to evaluate the avifaunal diversity:

a) Overall abundance, which was determined by counting the total number of birds.

b) Species richness (S) is the number of bird species observed.

c)To evaluate the study area's species capacity, species area curves were conducted according to the method outlined by **Cain (1938)**.

d) The Simpson diversity index **(Simpson, 1949)**, (D) whose values vary from 0 to 1, with values close to one representing the highest diversity.

$$D' = 1 - \sum_{i=1}^{S} (p_i)^2$$

e) The Shannon-Weiner diversity index (H) **(Shannon & Weaver, 1949)**, widely used, allowing the use of powerful parametric statistics to compare sets of samples **(Magurran, 1988)**. Values of this index usually lie between 1.5 and 3.5, with higher values indicating higher diversity.

$$H' = -\sum_{i=1}^{S} (p_i)^2 \ln p_i$$

f) Species evenness (E), when E is close to one, the observed variety reflects an abundance distribution close to equilibrium.

$$E = H'/H\,max \text{ where } H\,max = \ln S$$

All the indices were calculated using the PC-ORD program version 1.14 **(McCune & Mefford, 1999)**. One-way analysis of variance (One-way ANOVA) was used to determine the variations in spatial and temporal values followed by comparison of means using independent t-test. These analyses were performed using ver.25 of the IBM Statistical Package for the Social Sciences software (SPSS). Unless otherwise stated, all data were represented as Mean ±SE (Tables 2, 3). Site similarity indices were calculated by correlating group distances and plotted using hierarchical cluster analysis by Bray-Curtis's distance linkage on the PC-ORD program version 1.14.

RESULTS

1. Bird community composition and total abundance

A total of 26876 individuals belonging to 85 species, 13 orders, and 26 families were recorded throughout the study period. The total number of species included only 16 species belonging to the Passerine family, while the rest 69 species were non-passerines. Waterbirds were the most dominant, representing 68% of the total bird community richness (23846 individuals belonging to 57 species, 8 orders, and 11 families), followed by resident species representing 38% (32 species) and migratory species representing 62% (52 species). Relative abundance was as follows: Waterbirds recording 89% of the community abundance (23846 individuals), followed by resident species displaying 62% (16774 individuals), and migratory bird species representing 38% (10103 migratory individuals) (Fig. 3A, B). The most abundant species in the lake was slender-billed gull (*Larus geni*) with a relative abundance of 29.5%, followed by greater flamingo (*Phoenicopterus roseus*) with a relative abundance of 15.16%, northern shoveler *(Spatula clypeata)* with a relative abundance of 10.62%, and little egret *(Egretta garzetta)* with a relative abundance of 8.49% (Fig. 4).

Table. (1) shows the spatial and temporal data of the bird community. Spatially, SdR habitat was the highest in all the variants (S= 61, Total abundance= 10644, Mean abundance= 126.726, E= 0.647, H= 2.659, D= 0.8754). While temporally, autumn 2021 was the highest season in the following variants (Richness (S) = 58, Total abundance = 9148, Mean abundance = 108.9). Additionally, both winter 2020/2021 and winter 2022 exhibited the highest species evenness (E= 0.655). Winter 2020/2021 recorded the highest in Simpson's diversity index (D=0.8752), while winter 2022 had the highest in Shannon-Wiener's diversity index (H= 2.601).

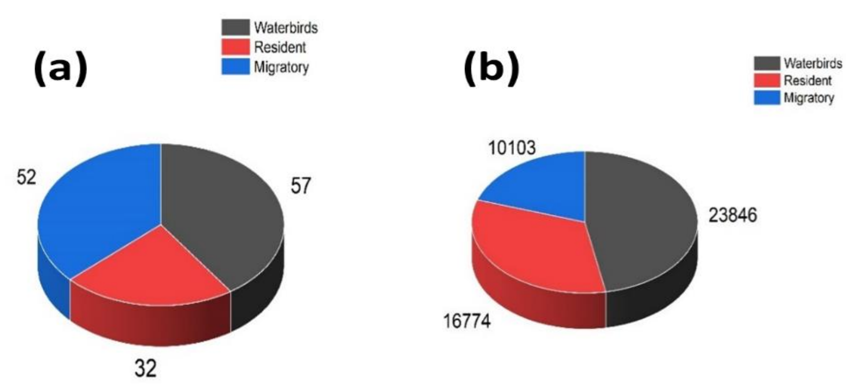

Fig. 3. The three main bird groups showing: **(A)** Species richness and **(B)** Total abundance.

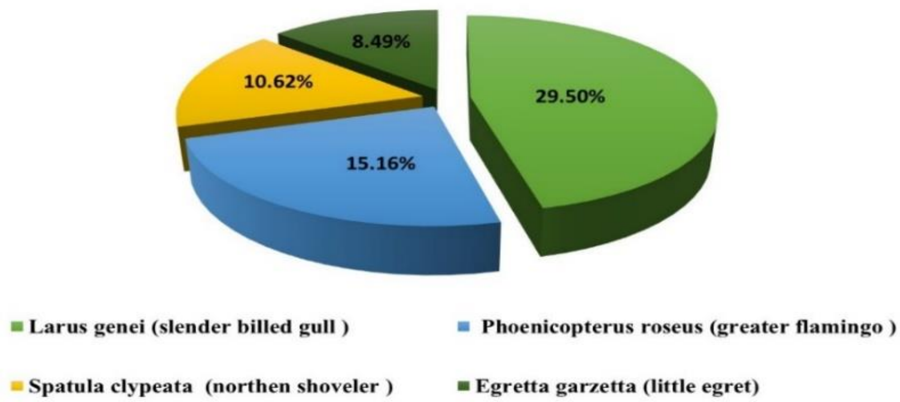

Fig. 4. The % relative abundance of the most abundant bird species

1.1. Species area curve

The number of recorded species was found to be dependent on the sampling effort. The sampling method used during the study period recorded 78.9% of the total estimate of species richness (first-order jackknife estimate= 106.4). The two species-area curves are demonstrated before and after removing rare sightings or the singletons (Fig. 2A, B). The number of recorded species increased gradually with the increasing number of field visits giving an asymptote line from nearly the sixth visit.

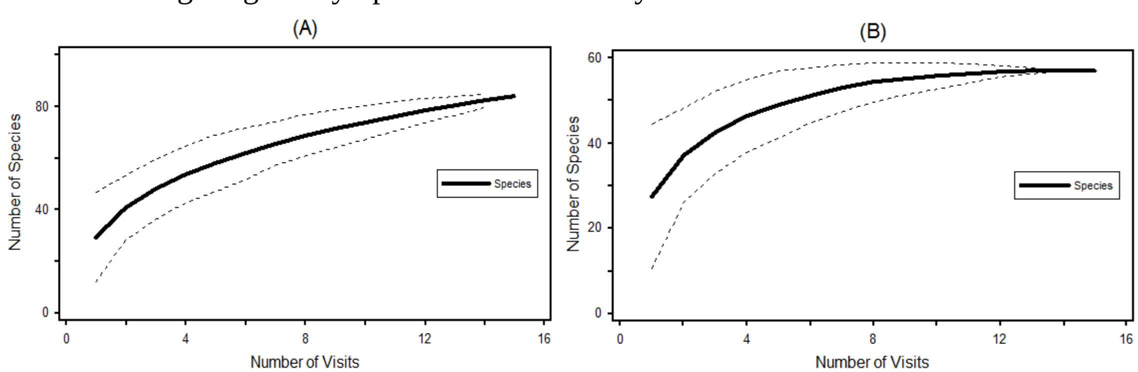

Fig. 2. Species-area curve for all the recorded species during 15 field trips showing: (A): For all recorded bird species and (B): For all species except for the rare ones. The curve is derived from 15 repeated trips during the study period from December 2020 to February 2022. The dotted lines indicate the standard deviation

Table 1. Spatial and temporal data of the bird community

Scientific name (Common name)	Order (family)	IUCN Red list	R/M	Habitat (abundance)				Season (abundance)					
				OPW	**SdR**	**PA**	**UrV**	**Wint. 20/21**	**Spr. 21**	**Sum. 21**	**Atm. 21**	**Wint. 22**	**T.**
Spatula clypeata (northen shoveler)	Anseriformes (Anatidae)	LC	M	2771	42	0	42	163	4	0	2516	172	2855
Aythya fuligula (tufted duck)	Anseriformes (Anatidae)	NT	M	0	15	0	0	15	0	0	0	0	15
Tadorna tadorna (sheld duck)	Anseriformes (Anatidae)	LC	M	0	0	0	10	0	0	0	0	10	10
Oxyura leucocephala (white headed duck)	Anseriformes (Anatidae)	EN	rare passer	0	0	0	1	1	0	0	0	0	1
Anas acuta (pintail)	Anseriformes (Anatidae)	LC	M	0	0	0	103	0	0	0	3	100	103
Anas crecca (Eurasian teal)	Anseriformes (Anatidae)	LC	M	0	0	0	2	0	0	0	0	2	2
Anas platyrhynchos (mallard duck)	Anseriformes (Anatidae)	LC	R	0	0	0	2	0	0	0	2	0	2
Aythya ferina (pochard)	Anseriformes (Anatidae)	VU	M	38	0	0	0	0	0	0	10	28	38
cairina moschata (domesticated Muscovy duck)	Anseriformes (Anatidae)	LC	R	0	25	0	0	0	0	25	0	0	25
Anser anser (graylag goose)	Anseriformes (Anatidae)	LC	rare passer	0	0	0	3	0	0	0	3	0	3

Scientific name (Common name)	Order (family)	IUCN Red list	R/M	Habitat (abundance)				Season (abundance)					
				OPW	SdR	PA	UrV	Wint. 20/21	Spr. 21	Sum. 21	Atm. 21	Wint. 22	T.
***Podiceps nigricollis* (black necked grebe)**	Podicipediformes (Podicipedidae)	LC	M	2	0	5	2	0	0	0	0	9	9
***Podiceps cristatus* (great crested grebe)**	Podicipediformes (Podicipedidae)	LC	M	7	0	0	6	0	0	0	12	1	13
***Tachybaptus ruficollis* (little grebe)**	Podicipediformes (Podicipedidae)	LC	M	0	0	0	2	0	0	0	2	0	2
***Phalacrocorax carbo* (great cormorant)**	Suliformes (phalacrocoracidae)	LC	M	4	0	0	0	4	0	0	0	0	4
***Egretta garzetta* (little egret)**	Pelecaniformes (Ardeidae)	LC	R	613	1585	9	74	529	439	480	624	209	2281
***Adrea alba* (great white egret)**	Pelecaniformes (Ardeidae)	LC	M	4	0	0	1	1	0	0	4	0	5
***Ardeola ralloides* (squacco heron)**	Pelecaniformes (Ardeidae)	LC	R	13	507	0	2	457	7	15	33	10	522
***Bubulcus ibis* (Cattel egret)**	Pelecaniformes (Ardeidae)	LC	R	5	248	0	0	216	14	2	10	11	253
***Ardea cinerea* (grey heron)**	Pelecaniformes (Ardeidae)	LC	M	2	1	0	2	0	0	0	5	0	5
***Butorides striata* (striated heron)**	Pelecaniformes (Ardeidae)	LC	R	0	0	0	1	0	0	1	0	0	1
***Nycticorax nycticorax* (Black crowned night heron)**	Pelecaniformes (Ardeidae)	LC	R	0	34	0	1	0	0	28	3	4	35

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				OPW	SdR	PA	UrV	Wint. 20/21	Spr. 21	Sum. 21	Atm. 21	Wint. 22	T.
Phoenicopterus roseus (Greater flamingo)	Phoenicopteriformes (Phoenicopteridae)	LC	M	0	153	3922	0	829	1123	568	722	833	4075
Milvus migrans (black kite)	Accipitriformes (Accipitridae)	LC	M	0	391	0	0	301	2	0	0	88	391
Elanus caeruleus (black winged kite)	Accipitriformes (Accipitridae)	LC	M	0	0	0	1	0	0	0	1	0	1
Circus aeruginosus (marsh harrier)	Accipitriformes (Accipitridae)	LC	M	0	1	0	0	1	0	0	0	0	1
Porphyrio martinica (purple gallinule)	Gruiformes (Rallidae)	LC	R	0	1	0	2	2	0	0	0	1	3
Fulica atra (Eurasian coot)	Gruiformes (Rallidae)	LC	M	430	165	5	381	544	54	0	22	361	981
Gallinula chloropus (moorhen)	Gruiformes (Rallidae)	LC	R	2	104	0	3	10	17	9	11	62	109
Recurvirostra avosetta (avocet)	Charadriiformes (Charadriidae)	LC	M	3	12	0	0	0	0	0	9	6	15
Himantopus himantopus (black winged stilt)	Charadriiformes (Charadriidae)	LC	R	164	493	120	201	97	54	398	345	84	978
Burhinus senegalensis (Senegal thick knee)	Charadriiformes (Charadriidae)	LC	M	0	1	0	0	0	0	1	0	0	1

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				OPW	**SdR**	**PA**	**UrV**	**Wint. 20/21**	**Spr. 21**	**Sum. 21**	**Atm. 21**	**Wint. 22**	**T.**
Charadrius hiaticula (ringed plover)	Charadriiformes (Charadriidae)	LC	M	44	116	33	53	101	53	25	53	14	246
Charadrius dubius (little ringed plover)	Charadriiformes (Charadriidae)	LC	M	11	14	0	21	0	0	28	18	0	46
Charadrius alexandrinus (Kentish plover)	Charadriiformes (Charadriidae)	LC	R	5	2	13	0	0	0	10	9	1	20
Pluvialis squatarola (grey plover)	Charadriiformes (Charadriidae)	LC	M	14	0	162	5	41	116	0	4	20	181
Vanellus spinosus (spur winged lapwing)	Charadriiformes (Charadriidae)	LC	R	63	413	1	64	55	202	81	169	34	541
vanellus leucurus (white tailed lapwing)	Charadriiformes (Charadriidae)	LC	M	0	3	0	0	0	0	0	0	3	3
Arenaria interpres (ruddy turnstone)	Charadriiformes (Scolopacidae)	LC	M	10	6	0	10	0	0	21	5	0	26
Calidris ferruginea (curlew sandpiper)	Charadriiformes (Scolopacidae)	NT	M	9	2	24	0	0	0	1	2	32	35
Calidris alpina (dunlin)	Charadriiformes (Scolopacidae)	LC	M	31	78	66	29	5	17	1	111	70	204
Calidris alba (sanderling)	Charadriiformes (Scolopacidae)	LC	M	42	116	8	126	0	0	29	262	1	292
Calidris minuta (little stint)	Charadriiformes (Scolopacidae)	LC	M	4	17	25	8	2	0	0	9	43	54

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				OPW	SdR	PA	UrV	Wint. 20/21	Spr. 21	Sum. 21	Atm. 21	Wint. 22	T.
Numenius arquata (curlew)	Charadriiformes (Scolopacidae)	NT	M	5	0	0	9	9	0	0	3	2	14
Limosa limosa (black tailed god wit)	Charadriiformes (Scolopacidae)	NT	M	18	0	0	0	0	0	15	3	0	18
Actitis hypoleucos (common sandpiper)	Charadriiformes (Scolopacidae)	LC	M	2	54	19	9	28	31	1	5	19	84
Tringa ochropus (green sandpiper)	Charadriiformes (Scolopacidae)	LC	M	1	1	0	2	0	0	0	4	0	4
Tringa nebularia (green shank)	Charadriiformes (Scolopacidae)	LC	M	0	1	0	1	0	0	0	2	0	2
Tringa stagnatilis (marsh sandpiper)	Charadriiformes (Scolopacidae)	LC	R	25	45	30	6	0	9	4	65	28	106
Tringa totanus (red shank)	Charadriiformes (Scolopacidae)	LC	M	32	30	43	9	5	12	0	48	49	114
Tringa erythropus (spotted red shank)	Charadriiformes (Scolopacidae)	LC	M	4	2	0	2	0	0	2	6	0	8
Calidris pugnax (ruff)	Charadriiformes (Scolopacidae)	LC	M	0	31	0	1	0	0	0	30	2	32
Larus fuscus (lesser black backed gull)	Charadriiformes (Laridae)	LC	M	1	2	0	0	0	0	0	2	1	3
Larus genei (slender billed gull)	Charadriiformes (Laridae)	LC	R	1734	2759	1695	1740	1566	807	2084	2569	902	7928

Scientific name (Common name)	Order (family)	IUCN Red list	R/M	Habitat (abundance)				Season (abundance)					
				OPW	SdR	PA	UrV	Wint. 20/21	Spr. 21	Sum. 21	Atm. 21	Wint. 22	T.
***Larus ridibundus* (black headed gull)**	Charadriiformes (Laridae)	LC	M	3	10	0	0	10	1	2	0	0	13
***Chlidonias hybrida* (whiskered tern)**	Charadriiformes (Laridae)	LC	R	54	117	7	95	0	16	4	127	126	273
***Gelochelidon nilotica* (gull billed tern)**	Charadriiformes (Laridae)	LC	R	180	452	5	161	311	188	24	259	16	798
(Mixed terns)	Charadriiforme (Laridae)	LC	R	0	250	0	120	0	0	0	370	0	370
***Sterna albifrons* (little tern)**	Charadriiformes (Laridae)	LC	R	0	20	0	1	0	1	20	0	0	21
***Columba livia* (rock pigeon)**	Columbiformes (Columbidae)	LC	R	0	23	0	2	2	1	10	10	2	25
***Columba livia* (domesticated pigeon)**	Columbiformes (Columbidae)	LC	R	0	12	0	0	3	3	0	1	5	12
***Streptopelia decaocto* (collard dove)**	Columbiformes (Columbidae)	LC	M	0	0	0	2	0	0	0	2	0	2
***Streptopelia turtur* (European turtle dove)**	Columbiformes (Columbidae)	VU	M	0	0	0	2	1	1	0	0	0	2
***Streptopelia senegalensis* (laughing dove)**	Columbiformes (Columbidae)	LC	R	9	26	0	5	10	13	4	9	4	40
***Ceryle rudis* (pied kingfisher)**	Coraciiformes (Alcedinidae)	LC	R	10	41	1	8	9	10	9	14	18	60

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				OPW	SdR	PA	UrV	Wint. 20/21	Spr. 21	Sum. 21	Atm. 21	Wint. 22	T.
Halcyon smyrnensis (white throated kingfisher)	Coraciiformes (Alcedinidae)	LC	R	1	3	0	0	1	0	0	2	1	4
Merops orientalis (green bee eater)	Coraciiformes (Meropidae)	LC	M	0	1	0	0	0	0	1	0	0	1
Upupa epops (hoopoe)	Bucerotiformes (Upupidae)	LC	R	1	19	0	1	3	6	3	7	2	21
Galerida cristata (crested lark)	Passeriformes (Alaudidae)	LC	R	5	33	0	1	13	7	1	11	7	39
Hirundo rustica savinii (Egyptian swallow)	Passeriformes (Hirundinidae)	-	R	75	1630	3	29	419	194	443	462	219	1737
Hirundo rustica rustica (barn swallow)	Passeriformes (Hirundinidae)	LC	M	2	72	0	2	2	8	0	66	0	76
Riparia diluta (sand martin)	Passeriformes (Hirundinidae)	LC	M	0	2	5	0	0	0	0	2	5	7
Motacilla alba (white wagtail)	Passeriformes (Motacillidae)	LC	M	6	46	2	6	16	9	1	12	22	60
Acrocephalus stentoreus (clamorous reed warbler)	Passeriformes (Acrocephalida)	LC	R	1	8	0	1	0	1	8	0	1	10
Acrocephalus scirpaceus (Eurasian reed warbler)	Passeriformes (Acrocephalida)	LC	M	0	25	0	0	6	12	6	0	1	25

Scientific name (Common name)	Order (family)	IUCN Red list	R/M	Habitat (abundance)				Season (abundance)					T.
				OPW	SdR	PA	UrV	Wint. 20/21	Spr. 21	Sum. 21	Atm. 21	Wint. 22	
Hippolais icterina (icterine warbler)	Passeriformes (Acrocephalida)	LC	M	0	15	0	0	13	0	2	0	0	15
Prinia gracilis (graceful perinea)	Passeriformes (Cisticolidae)	LC	R	3	39	0	2	23	10	4	0	7	44
phylloscopus collybita (common chiffchaff)	Passeriformes (Phylloscopidae)	LC	M	1	2	0	0	0	0	0	0	3	3
Euodice malabarica (Indian silver bill)	Passeriformes (Estrildidae)	LC	M	0	0	0	1	1	0	0	0	0	1
Amandava amandava (Red avadavat)	Passeriformes (Estrildidae)	LC	M	0	0	0	1	0	0	0	1	0	1
Luscinia megarhynchos (common nightingale)	Passeriformes (Muscicapidae)	LC	M	0	1	0	0	1	0	0	0	0	1
luscinia svecica (bluethroat)	Passeriformes (Muscicapidae)	LC	M	0	0	0	1	0	0	0	0	1	1
Passer domesticus (house sparrow)	Passeriformes (Passeridae)	LC	R	12	128	0	63	40	69	55	27	12	203
Corvus cornix (hooded crow)	Passeriformes (Corvidae)	-	R	29	199	0	82	68	57	53	50	82	310
Centropus senegalensis (Senegal coucal)	Cuculiformes (Cuculidae)	LC	R	0	0	0	1	0	1	0	0	0	1

Scientific name (Common name)	Order (family)	IUCN Red list	R/M	Habitat (abundance)				Season (abundance)					
				OPW	**SdR**	**PA**	**UrV**	**Wint. 20/21**	**Spr. 21**	**Sum. 21**	**Atm. 21**	**Wint. 22**	**T.**
	Total abundance			6505	10644	6203	3524	5934	3569	4479	9148	3746	26876
	Species richness			49	61	23	60	44	37	41	58	53	
	Simpson (D')			0.73	0.875	0.524	0.733	0.87	0.82	0.73	0.82	0.87	
	Shannon (H)			1.828	2.659	1.084	2.131	2.47	2.21	1.88	2.28	2.60	
	Evenness_e^H/S			0.47	0.647	0.346	0.52	0.65	0.61	0.50	0.56	0.65	

1.2. Total species abundance

Fig. (5a, b, c, d) shows the spatial and temporal variation in species abundance. Total abundance showed a notable increasing trend between study sites. It was observed that bird species have shown a preference for sewage drain habitats, as displayed by higher population numbers in all groups, except for migratory birds. In the case of migratory birds, the protected area exhibited greater abundance, mostly due to the dominance of the Greater flamingo species. Urban villages were found to have the lowest values. Temporally, Autumn 2021 had the highest numbers of birds in all groups, while Spring 2021 had the lowest in all groups except for migratory birds, where Summer 2021 recorded the lowest numbers. ANOVA showed no significant difference in bird species abundance spatially and temporally in all groups except waterbirds (Tables 2, 3)

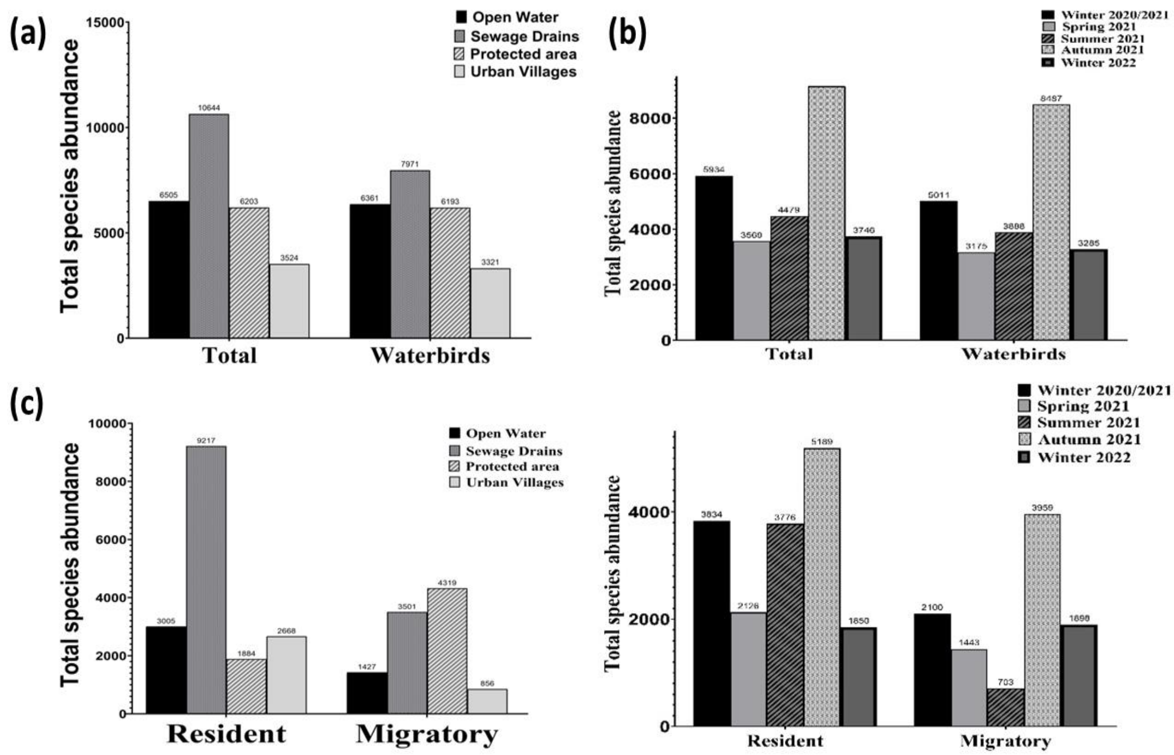

Fig. 5. The variation pattern in bird's species abundance where; **(a)** and **(c)** abundance varied spatially, while **(b)** and **(d)** abundance varied seasonally

Table 2. Spatial variation in bird species diversity of the four habitats representing the study area.

Diversity indices	Bird group	ANOVA *P*-value	Habitat type (Mean ±SE)			
			OpW	SdR	PA	UrV
Species richness (S)	All	0.086	30.667±7.125	42±3.2145	16±3	12±8.5
	Resident	0.024	15.67±2.848	23.67±1.7638[#]	7±1	18±4
	migratory	0.184	15±4.358	18.66667±1.7638	9±2	22±4
	waterbirds	0.11	23.6667±5.0442	28±1	14.5±1.5	28.5±2.5
Species mean abundance	All	0.793	25.817±16.625	42.238±20.3787	36.922±0.14849	20.976±0.58349
	Resident	0.439	31.302±16.1611	96.013±48.242	29.4375±9.1565	41.6875±11.5625
	migratory	0.283	22.44233±17.0987	9.14733±3.30087	41.529±5.394	8.231±6.173
	waterbirds	0.853	37.1987±24.2907	46.6137±20.02247	54.325±0.3069	29.132±0.272
Species evenness (E)	All	0.113	0.58767±0.08694	0.65267±0.0521227	0.368±0.007	0.523±0.042
	Resident	0.082	0.52433±0.0673	0.63533±0.0518	0.2385±0.1695	0.476±0.048
	Migratory	0.061	0.43067±0.1348	0.70533±0.066	0.196±0.022	0.689±0.152
	Waterbirds	0.22	0.57167±0.0844	0.63067±0.07	0.376±0.015	0.5135±0.075

Diversity indices	Bird group	ANOVA *P*-value	Habitat type (Mean ±SE)			
			OpW	SdR	PA	UrV
Shannon-Weiner's diversity index (H)	All	0.026	1.8733±0.2364	2.44±0.21046*	1.015±0.09	1.932±0.264
	Resident	0.011	1.402±0.1415	2.011±0.188*	0.4855±0.3625	1.353±0.0289
	Migratory	0.02	1.078±0.35736	2.054±0.18048#	0.4305±0.0915	2.09±0.34*
	Waterbirds	0.09	1.75±0.2116	2.105±0.2529	1.004±0.079	1.7265±0.29749
Simpson's diversity index (D)	All	0.038	0.7553±0.0558*	0.838±0.051*	0.5036±0.03735	0.7076±0.08345
	Resident	0.021	0.63607±0.048	0.7854±0.064*	0.22585±0.18595	0.5471±0.0289
	Migratory	0.021	0.48053±0.1485	0.7857±0.05125#	0.1702±0.0161	0.79415±0.088*
	Waterbirds	0.134	0.7399±0.05339	0.77837±0.07318	0.50195±0.03905	0.6688±0.10489

Where, OpW (Open water habitat), SdR (sewage drains), PA (protected area), UrV (urban villages), and the asterisk * and # indicate that this group varied significantly when compared to another group using independent T-test. Symbol asterisk * indicates significance at $P< 0.05$, and symbol hashtag **#** indicates significance at $P< 0.01$.

Table 3. Temporal variation in bird species diversity of the five seasons of the study.

Diversity indices	Bird group	ANOVA *P*-value	Season (Mean ±SE)				
			Wint. 2020/2021	Spr. 2021	Sum. 2021	Atmn. 2021	Wint. 2022
Species richness (S)	All	0.0027	30.66±0.3[#]	27.3±1.76	24.3±2.03	39±1.1547[#]	36±3.51*
	Resident	0.831	16.66±0.67	18.67±1.2	18±2.517	19±0.57735	18.67±1.85
	Migratory	0.001323	14±1[#]	8.67±2.85	6.3±0.882	20±1.732 [*#]	17.33±1.67[#]
	Waterbirds	0.001641	18.67±0.881	16.33±2.3	17±2	30±1[#]	26.67±2.84*
Species mean abundance	All	0.064	23.54±6.808	14.163±3.4	17.75±4.16	36.3±7.525	14.873±0.76
	Resident	0.215	39.93±9.64	22.14±3.78	39.271±8.8	54.052±19.75	19.27±2.79
	Migratory	0.078	13.46±7.43	4.50±1.31	4.50±1.31	25.37±5.8	12.16±1.12
	Waterbirds	0.032	29.30±6.90	18.56±5.30	22.73±5.31	49.63±9.87*	19.21±0.7055
Species evenness (E)	All	0.036	0.615±0.006	0.63±0.03	0.53±0.03	0.58±0.02	0.67±0.01*
	Resident	0.1	0.56±0.046	0.62±0.037	0.48±0.03	0.58±0.01	0.60±0.02
	Migratory	0.169	0.55±0.07	0.31±0.13	0.34±0.12	0.434±0.06	0.61±0.04
	Waterbirds	0.02	0.610±0.02	0.64±0.03	0.49±0.04	0.57±0.02	0.66±0.01*

Diversity indices	Bird group	ANOVA *P*-value	Season (Mean ±SE)				
			Wint. 2020/2021	Spr. 2021	Sum. 2021	Atmn. 2021	Wint. 2022
Shannon-Weiner's diversity index (H)	All	0.017	2.10±0.01*	2.08±0.15	1.71±0.13	2.14±0.10	2.42±0.092*
	Resident	0.091	1.57±0.11	1.81±0.11	1.40±0.14	1.72±0.0285	1.76±0.02
	Migratory	0.048	1.46±0.18	0.72±0.36	0.66±0.27	1.30±0.22	1.75±0.15*
	Waterbirds	0.022	1.78±0.07	1.78±0.18	1.39±0.17	1.95±0.10*	2.16±0.07*
Simpson's diversity index (D)	All	0.55	0.81±0.01	0.80±0.02	0.69±0.05	0.80±0.022	0.7109±0.12812
	Resident	0.211	0.69±0.14	0.75±0.105	0.60±0.19	0.708±0.019	0.711±0.0387
	Migratory	0.075	0.64±0.1004	0.30±0.16	0.29±0.13	0.56±0.097	0.7221±0.04976
	Waterbirds	0.045	0.76±0.023	0.76±0.034	0.61±0.07	0.77±0.02	0.81±0.0072*

Where, Wint. (winter), Spr. (Spring), Sum. (summer), Atmn. (Autumn), and the asterisk * and # indicate that this group varied significantly when compared to another group using independent T-test. Symbol asterisk * indicates significance at $P < 0.05$, and symbol hashtag # indicates significance at $P < 0.01$.

2. Spatial and temporal variations in bird species richness and diversity

The following results are represented graphically as absolute values, meanwhile, analysis of variants and student's t-test were preformed between means which are represented in Tables (2, 3) as Mean ±SE. Fig. (6a, b, c, d) shows the spatial and temporal variation in species richness. Spatially, the Sewage drains (SdR) was the highest in species richness in resident species (S= 29), Urban villages (UrV) was the highest in migratory species richness (S= 34), and Protected area (PA) was the lowest in both resident and migratory (S= 10, 13, respectively). Meanwhile in waterbirds, Urban villages (UrV) was also the highest in species richness (S= 42), and the Protected area (PA) was the lowest (S= 20). Temporally, autumn 2021 was the highest in migratory species richness (S= 34), while summer 2021 was the highest in resident species (S=26). Spring 2021 was the lowest in the migratory species richness (S= 14), while winter 2020/2021 was the lowest in resident species richness (S= 20). While in waterbirds, autumn 2021 was the highest in species richness (S= 44), and spring 2021 was the lowest (S= 21). The analysis of variants (ANOVA) showed significant differences between study sites in resident birds, no significant differences in migratory birds, and no significant differences in water birds. Meanwhile, temporally, ANOVA showed a significant difference between seasons in migratory birds, no significant differences in resident birds, and a significant difference between seasons in waterbirds (Tables 2, 3)

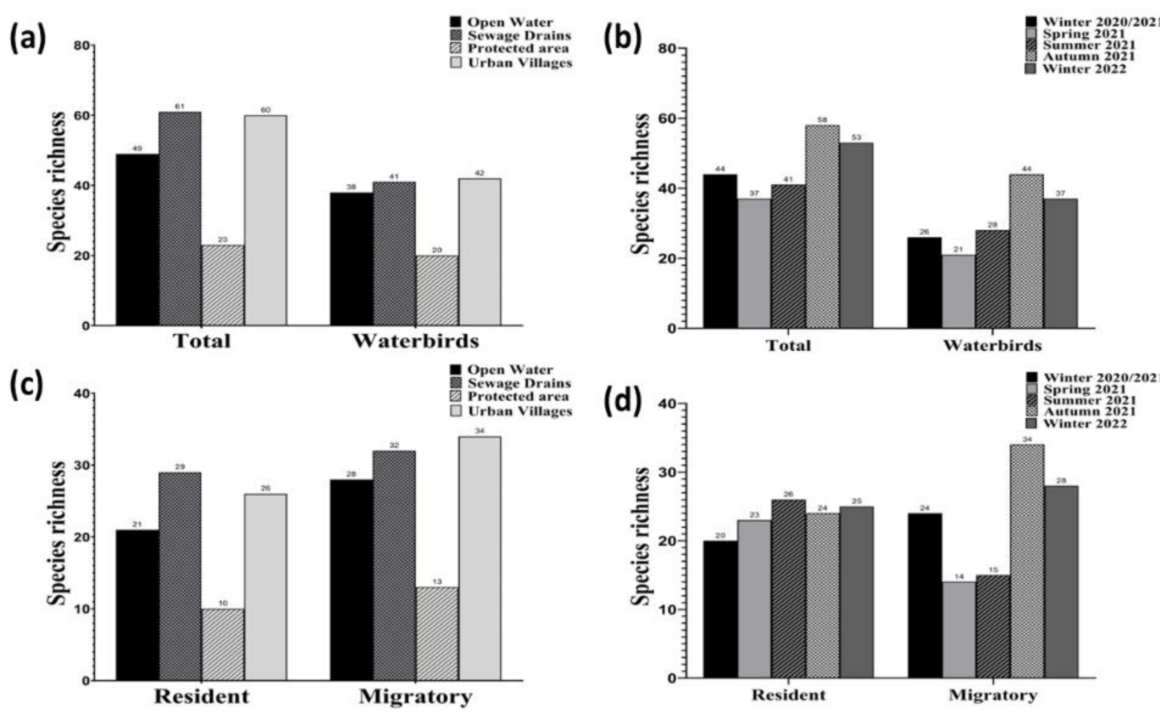

Fig. 6. The variation pattern in bird's species richness where; **(a)** and **(c)** richness varied spatially, while **(b)** and **(d)** richness varied seasonally.

2.3. Species diversity

Species diversity was represented via species evenness and the two most popular diversity indices (Shannon-Wiener's and Simpson's) where evenness relied on Shannon-Wiener's index and Simpson's index indicated dominance.

2.3.1. Species evenness

Fig. (7a, b, c, and d) shows the spatial and temporal variations in species evenness among the studied groups. Values closer to one indicate higher diversity and those closer to zero indicate lowered diversity or that this site was dominated by a single species. Spatially, SdR habitat was the highest in species evenness in both resident and migratory species (E = 0.661, 0.688, respectively), while PA habitat was the lowest in all bird species (E= 0.196, 0.187, 0.358, respectively). In waterbirds, SdR habitat was the highest in species evenness (E = 0.621), while PA habitat was the lowest (E= 0.358). Temporally, winter 2022 was the highest season in species evenness in resident species (E= 0.716), while winter 2022 was also the highest in migratory species (E= 0.587). Summer 2021 was the lowest in both (E=0.606, 0.323, respectively). In waterbirds, winter 2020/ 2021 was the highest season in species evenness (E= 0.659), while summer 2021 was the lowest (E=0.47). The analysis of variants (ANOVA) showed no significant difference between habitats spatially and seasons temporally (Tables 2, 3).

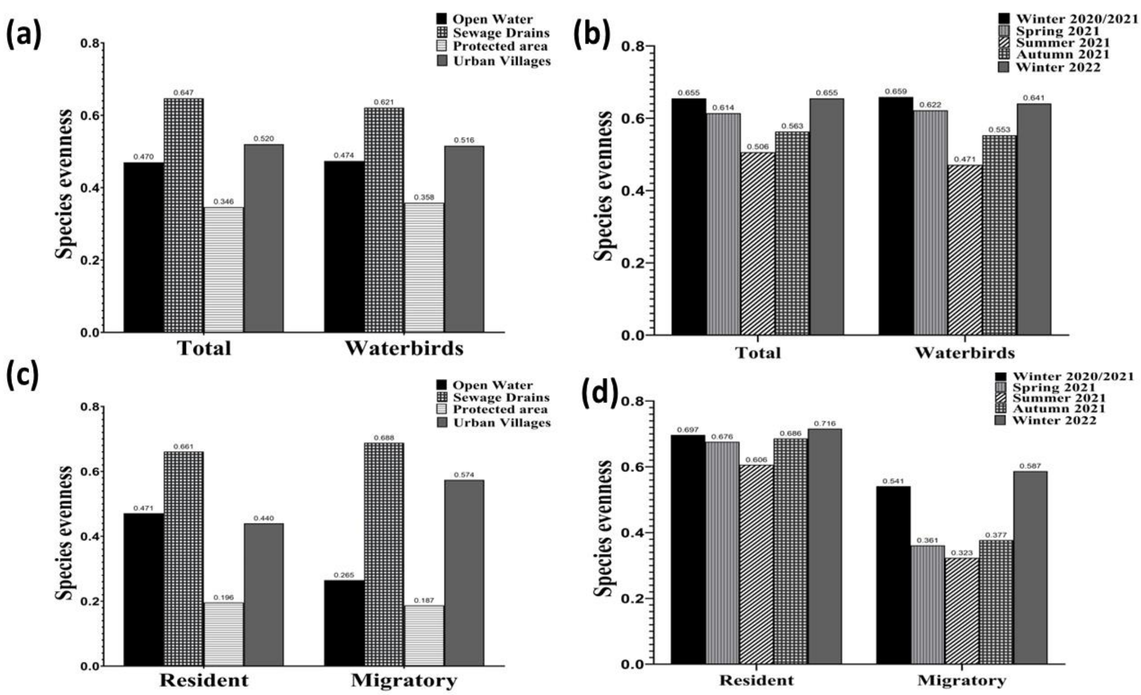

Fig. 7. The variation pattern in species evenness where; **(a)** and **(c)** evenness varied spatially, while **(b)** and **(d)** evenness varied seasonally

2.3.2. Shannon-Wiener's and Simpson's diversity indices

Fig. (8a, b, c, and d) shows the spatial and temporal variations in Shannon-Wiener's index, while Fig. (9a, b, c, and d) shows the spatial and temporal variations in Simpson's index among the studied groups. Spatially, the SdR habitat was the highest in Shannon-Wiener's diversity index for resident and migratory species (H= 2.226, 2.384). In contrast, PA habitat was the lowest (H= 0.451, 0.479), while SdR habitat was also the highest in Simpson's diversity index in both resident and migratory (D = 0.8367, 0.8547, respectively), while PA habitat was also the lowest in resident and migratory bird species (D= 0.1862, 0.1735, respectively). In waterbirds, SdR habitat was the highest in Shannon Weiner's and Simpson's diversity indices (H= 2.308, D=0.823), while PA habitat was the lowest in Shannon Weiner's and Simpson's diversity indices (H= 1.073, D= 0.5227). The analysis of variants (ANOVA) showed a significant difference between habitats in resident and migratory groups, while it showed no significant difference between habitats in waterbirds (Table 2).

Temporally, Shannon-Wiener's diversity index varied among seasons. Winter 2022 recorded the highest season in migratory species (H= 1.956), while spring 2021 had the highest in resident species (H= 1.943). On the other hand, summer 2021 had the lowest in both resident and migratory species (H= 1.544, 0.875). Meanwhile, Simpson's diversity index also varied among seasons, where resident species recorded the highest values in spring 2021 (D= 0.7854), while winter 2022 was the highest in migratory species (D= 0.7545). The lowest values were recorded in the summer season for resident and migratory bird species (D= 0.6522, 0.3412). In waterbirds, winter 2022 was the highest season in Shannon Weiner's and Simpson's diversity indices (H= 2.314, D=0.8366). On the other hand, summer 2021 was the lowest in Shannon Weiner's and Simpson's diversity indices (H= 1.569, D=0.6674). The analysis of variants (ANOVA) showed significant difference between seasons in migratory and waterbirds, however no significant difference between seasons in resident birds (Table 3).

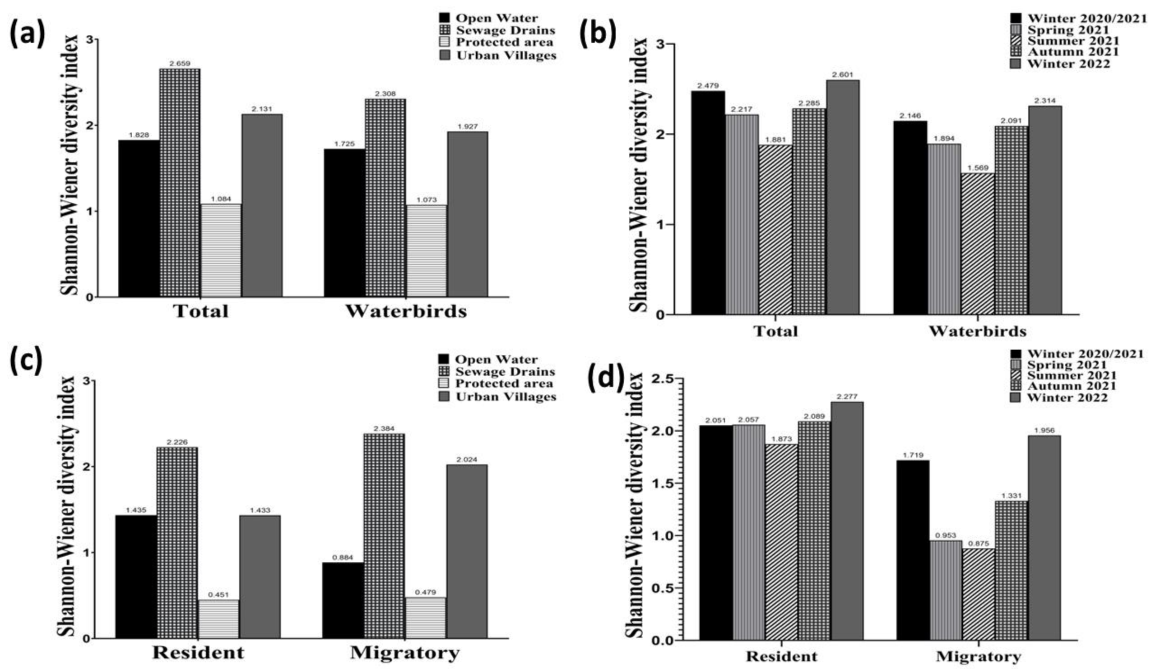

Fig. 8. The variation pattern in Shannon-Wiener's diversity index where; **(a)** and **(c)** show the spatial variation, while **(b)** and **(d)** show the seasonal variation.

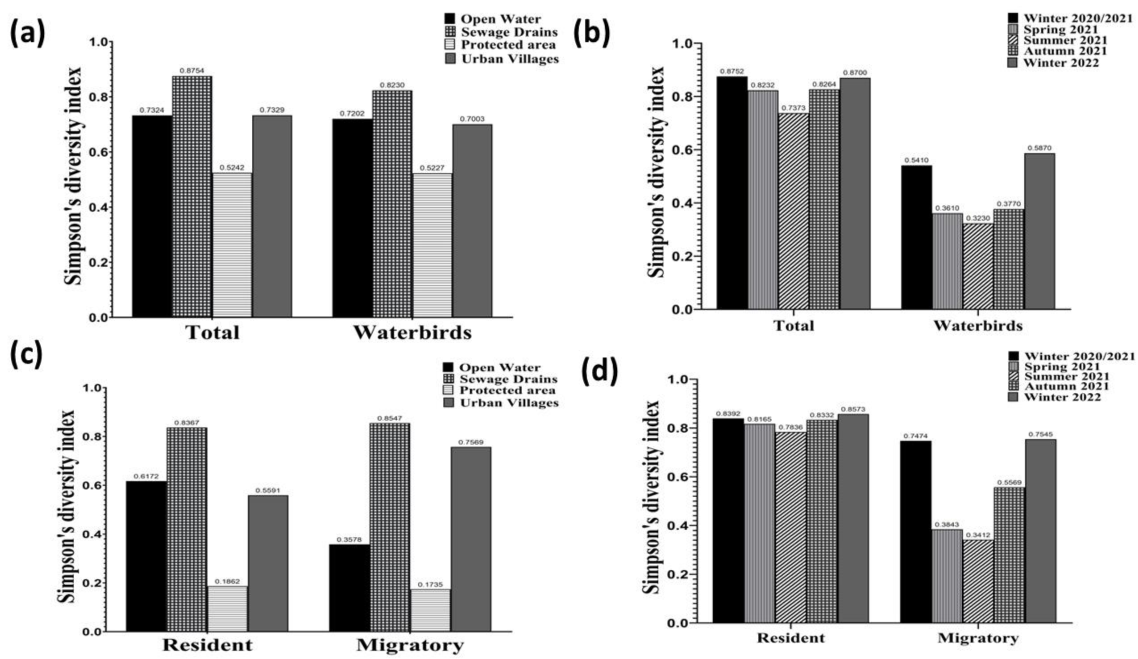

Fig. 9. The variation pattern in Simpson's diversity index where; **(a)** and **(c)** show the spatial variation, while **(b)** and **(d)** show the seasonal variation.

3. Assemblage trends: Hierarchical cluster analysis

A cluster analysis was employed to characterize the relationship between the assemblage of bird communities and habitat types of the studied locations. The classification of the habitat types was based on bird abundance. The resultant cluster delineated the avian communities associated with each habitat type within the lake. On the first level, PA was separated from the rest of the habitat types. While on the second level, SdR was separated from OpW and UrV, however the later habitats were almost identical to each other (Fig. 10).

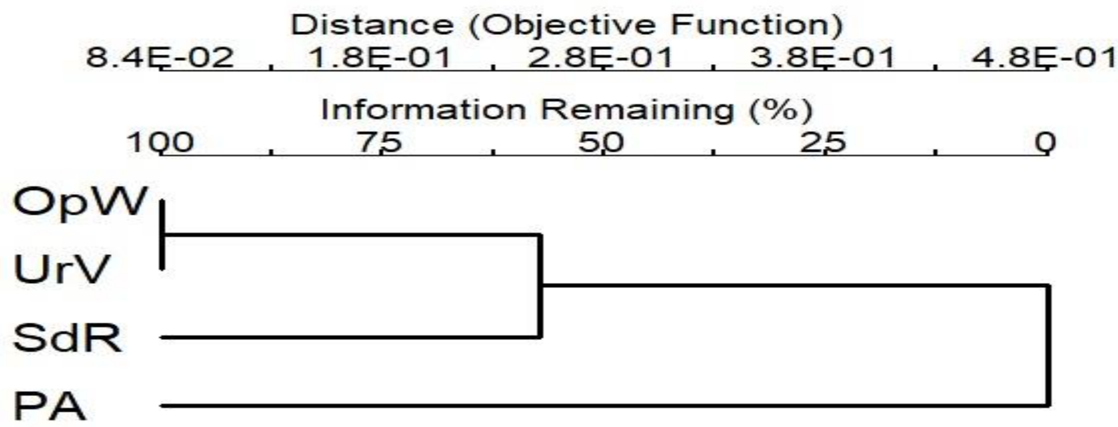

Fig. 10. A dendrogram showing the classification of the habitat types based on their avifauna, interpreted from the hierarchical cluster analysis. The scale represents dissimilarity (Bray-curtis). (OpW) Open water habitat, (UrV) Urban villages habitat, (SdR) Sewage drains habitat, and (PA) Protected area habitat.

4. Indicator species

Ten species were found to be indicator species to the entire sites of the study area (Table 4). SdR habitat obligated the abundance and occurrence of the following bird species: *Bubulcus ibis* (Pelecaniformes: Ardeidae) (Indicator value IV= 98, *P*-value= 0.003), *Streptopelia senegalensis* (Columbiformes: Columbidae) (Indicator value IV= 61.2, *P*-value= 0.003), *Hirundo rustica savinii* (Passeriformes: Hirundinidae) (Indicator value IV=83.5, *P*-value= 0.003), *Hirundo rustica rustica* (Passeriformes: Hirundinidae) (Indicator value IV= 93, *P*-value= 0.002), *Acrocephalus stentoreus* (Passeriformes: Motacillidae) (Indicator value IV= 71.9, *P*-value= 0.047), *Prinia gracilis* (Passeriformes: Cisticolidae) (Indicator value= 84.4, *P*-value= 0.003), *Sterna albifrons* (Charadriiformes; Laridae) (Indicator value= 93, *P*-value= 0.024), *Himantopus himantopus* (Charadriiformes : Charadriidae) (Indicator value= 43, *P*-value= 0.05), *Upupa epops* (Bucerotiformes : Upupidae) (Indicator value= 88.4, *P*-value= 0.015) that were significant associated with sewage drains habitat. In comparison, *Phoenicopterus roseus* (Phoenicopteriformes: Phoenicopteridae) (Indicator value IV= 97.5, *P*-value= 0.048) was significantly associated with Protected area habitat, whereas no indicator species were found associated with Open water and Urban villages habitats.

Table 4. Indicator bird species recorded in the habitats of the study area. SdR; sewage drains habitat, PA; Protected area

Bird species (Latin name)	Bird common English name	Habitat group	Indictor value	*P-value*
Bubulcus ibis	Cattle egret	SdR	98	0.003
Phoenicopterus roseus	Greater flamingo	PA	97.5	0.048
Streptopelia senegalensis	Laughing dove	SdR	61.2	0.003
Hirundo rustica savinii	Egyptian barn swallow	SdR	83.5	0.003
Hirundo rustica	Barn swallow	SdR	93	0.002
Acrocephalus stentoreus	Clamorous reed warbler	SdR	71.9	0.05
Priniagracilis	Graceful perinea	SdR	84.4	0.003
Sterna albifrons	Little tern	SdR	93	0.024
Himantopus Himantopus	Black winged stilt	SdR	43	0.05
Upupa epops	Common hoopoe	SdR	88.4	0.015

Ethical clearance

This work was ethically approved by the institutional animal care and use committee in Cairo university (CU-IACUC) and was given the following number: CU I F 86 19.

DISCUSSION

Ecological interactions between species and ecological and evolutionary mechanisms contributing to ecosystem diversification worldwide are frequent drivers of population dynamics and community stability **(Rocha, 2023)**. Growing demand for natural resources as a consequence of increasing human population, rapidly increasing per capita consumption, and changing consumption patterns has resulted in the use of ever more natural habitats for agriculture, mining, industrial infrastructure, and urban areas, resulting in habitat loss which has a significant impact on the populations of plants and animals living within **(Prakash & Verma, 2022)**. Thus, monitoring biodiversity in habitats is crucial for maintaining biodiversity. Specifically, the Ramsar site's biodiversity monitoring offers important information on biodiversity, wetland condition, and economic relevance **(Haider *et al.*, 2022)**, thus, knowing the conservation actions needed to be taken.

Lake Qaroun is an internationally important wetland (Ramsar site) and an Important bird area (IBA) that is under major stress due to excessive urban activity and elevated levels of pollution, since the following references confirmed with various types of studies on the lake's water and sediments, that it is exceedingly polluted and is considered an extreme danger facing the aquatic biota and other creatures that are intact with the lake's water body **(Redwan & Elhaddad, 2017; Mahmoud *et al.*, 2018; Moussa *et al*., 2022)**, which was an inducement for us to conduct this study for better understanding the avifauna and its diversity and identifying the habitats of the lake and their suitability to the existing bird community. In this work, several biodiversity indices were proposed to measure avian diversity and provide accurate data about the structure of the bird community within the lake.

The species-area curve is usually used to measure an area's species capacity **(Cain, 1938)**. Species area curve became an old term; instead, carrying capacity is now frequently used. Carrying capacity for species richness can be just as beneficial as its counterpart in population biology. Numerous empirical lines of evidence suggest the existence of species richness limits, at least at vast spatial and phylogenetic scales **(Storch & Okie, 2019)**. The present data for the species-area curve was represented in the number of species recorded in a certain number of visits within the given area. The curve showed that most of the common species for all 13 orders were obtained, especially after removing the rare recordings and extreme numbers from the analysis; 100% of common bird species occurring in the study area were found to be surveyed after the sixth trip (May 2021). It can be concluded that the sampling efforts were enough to record all the species available in our study area and that the data accurately reflected the species diversity of the sampling sites. The study revealed that 85 species belong to 13 orders and 26 families. **Hussein *et al.* (2008)** and **Fouda and Fishar (2012)** mentioned that 88 bird species were recorded in the lake.

Compared to global wetland habitats, **Gherib *et al.* (2021)** recorded 61 species belonging to 17 families in a Ramsar site and IBA in Algeria. This can indicate that the habitat nature of Lake Qaroun is more suitable for several species of birds. Countless factors influence bird species distribution and abundance, including the architecture of specific habitats and the availability of important requirements for them, such as a diverse food supply, access to a dry or muddy environment, and nest materials **(Chenchouni, 2010; Sheta *et al.*, 2023)**.

Since the lake serves as a refueling and resting area for migrating water birds, migrants were higher in species richness. Still, they were less represented in numbers of individuals than resident species. Migratory species richness is higher due to the significance of a Ramsar site, which provides the support to a vast number of waterfowl, especially the migratory ones that use the lake as its wintering ground **(Hussein *et al.*, 2008; Ramsar Convention Secretariat, 2016)**, and the fact that many species were only recorded one time throughout the study period. *Larus genei* (Slender-billed gull) was found to be the dominating species with the highest relative abundance. This is attributed to the breeding population first recorded by the work of **Meininger and Atta (1994)** in the winter of 1989 on El Qarn island in the middle of the lake **(Baha El Din, 1999)**.

The lake collects drainage water (agricultural, industrial, and sewage) from different parts of El-Fayoum through many drains; among these drains EL-Batts (S1) and EL-Wadi (S6) are the most important since they are considered the main drains of the lake. EL-Batts drain collects drainage water from the eastern and northeastern parts of EL-Fayoum governorate and drains in the eastern part of the lake. In contrast, the EL-Wadi drain collects drainage water from the middle part of EL-Fayoum and drains it into the lake near its southern shore **(El-Sayed *et al.*, 2022)**. An additional agricultural drain (Shakshuk S5) was added to these main drains and grouped as sewage drains habitat or SdR. The avian community in this habitat exhibited the highest ecological values across measured variants, including those for resident and migratory species and waterbirds. Even though this habitat is highly exposed to pollution, it appears to have optimum conditions for waterbirds, hence having high diversity.

This can be attributed to the microhabitat heterogeneity of this habitat type and that it was at distant locations isolated from anthropogenic activities. Many studies mentioned that habitats isolated from anthropogenic activity had more species richness, abundance, and overall diversity than highly human-populated areas. The study of **Mercker *et al.* (2021)** mentioned that habitat disturbance by urbanization might severely impact bird populations as human activities can impact birds' food supply. For instance, the benthic fauna may suffer damage due to bottom-trawling fisheries.

de Camargo Barbosa *et al.* (2020) suggested another approach in which the species richness of resident and migratory avian species decreased since the noise level and distance from water increased. Additionally, they mentioned that the greatest predictors of bird presence were noise level for migratory species and water distance for resident species.

Bonnet-Lebrun *et al.*, (2020) suggested that urbanization increases the possibility of migrating birds staying year-round in their original habitats. Micro habitats within SdR habitat were represented by densely vegetated areas, mudflats, and open water areas. We may comprehend the spatial and temporal variation in the diversity and composition of waterbirds by identifying the mechanisms that regulate multi-species assemblages. These mechanisms may rely on a set of habitat filters that operate locally to exclude certain species, thereby determining the group of species likely to inhabit a given patch. These characteristics are frequently associated with vegetation structure for birds, specified interactions, and human disruption **(Lindenmayer *et al.*, 2012; Cornell and Harrison, 2014; Klingbeil and Willig, 2016; Martin and Proulx, 2016; Salgueiro *et al.*, 2018; Panda *et al.*, 2021)**, and the habitat selection factors.

Additionally, studies showed that the impact of terrain variables on spatial variation in vegetation had been observed to be significant, since they influence factors, such as water availability, temperature, radiation, and availability of nutrients **(Dong *et al.*, 2014; Riihimäki *et al.*, 2017)**, thus, affecting the distribution of birds.

Furthermore, **Nsor *et al.* (2018)** mentioned that the structure of vegetation affects the composition and structure of avian communities. While **Sol *et al.* (2020)** found that the reduction in functional diversity within heavily urbanized regions was primarily attributed to changes in species abundance and that compared to highly and moderately urbanized regions, functional diversity is highly conserved in rural areas and natural vegetation. In a study carried out by **Yuan *et al.* (2014)**, they found that sedge, water, reed areas, patch density, and distance to residents were identified as significant factors influencing the abundance of bird species.

Shannon-Weiner and Simpson’s diversity indices along with species evenness are important functions of bird diversity. Spatially, SdR was the highest in diversity, while PA was the lowest. Species evenness, also known as equitability, indicates the relative abundances of the various species present within a given sample. Species evenness is directly proportional to the degree of uniformity in species distribution within a given sample. It has been observed that the highest level of evenness is achieved when all species exhibit equal levels of abundance **(Pielou, 1969; Kricher, 1972; DeJong, 1975)**. Hence, it can be inferred that in ecosystems where certain species exhibit greater functional dominance, an increase in evenness would adversely impact the overall functioning of the ecosystem **(Omidipour *et al.*, 2021)**.

The biological equivalence between greater evenness and higher species richness may exist, since species with low abundance or small individuals are unlikely to significantly contribute to biomass directly or through species interactions **(Grime, 1998)**.

Studies like **Tu *et al.* (2020)** found that grasslands had a greater impact on species evenness of bird species in natural habitats. It may be linked to the availability of a wide variety of food, water, and shelter, all of which contributed to the elevation of species evenness **(Tsegay *et al.*, 2019; Asmare *et al.*, 2023)**. The diversity index proposed by **Simpson (1949)** serves as a metric for assessing the degree of species concentration within a given ecosystem. A frequently used modification of Simpson's index produces outcomes on a probability continuity ranging from 0.0 to 1.0, arranged in ascending order as diversity increases **(DeJong, 1975)**. In comparison, Shannon-Weiner is the predominant metric for quantifying species diversity. It is the modified version of Shannon's Information Theory of Communication **(Shannon & Weaver 1949)**. The Shannon-Weiner Diversity Index typically ranges from 1.5 to 3.5, with rare instances exceeding 4.5 **(Bibi & Ali, 2013)**.

According to **Mengesha and Bekele (2008)** findings, the diversity of avian species can serve as a reliable indicator of habitat heterogeneity. The study of **Kiros *et al*. (2018)** noted that vegetation composition is strongly related to bird species diversity, richness, and abundance, and any changes in vegetation may result in changes in diversity. Additionally, they noted that vegetation is related to food sources and nesting locations, all of which are influenced by the birds' preferred habitats and feeding behaviors. Habitat selection is another significant factor of bird diversity. Correlation between the prevalence of avian species within a given region is typically dependent upon the accessibility of fundamental necessities for sustaining life (i.e., food, hydration, and refuge) in conjunction with favorable weather conditions **(Issa, 2019)**. Moreover, birds' habitat selection can be influenced by food availability, nesting sites, and predator avoidance **(Cody, 1985; Maurer, 2009)**.

Many studies, including those by **Svärdson (1949)**, **Hildén (1965)**, **Klopfer and Hailman (1965)**, **Cody (1981, 1985)**, **Jones (2001)**, **Kristan III *et al.* (2007)**, **Maurer (2009)**, **Hsu *et al.* (2019)** and **Buxton *et al.* (2020)**, have mentioned the mechanism of habitat selection in birds and its role in determining their distribution. The previous evidence supported our results about SdR being the most diverse habitat and PA being the least favorable habitat for all bird groups. PA habitat is located at the desert margin of the lake with extreme conditions to adapt to. The results of the cluster analysis also showed that PA is a unique habitat. Meanwhile, OpW and UrV were slightly related. This is related to the similarity of the distribution of bird species that inhabit these habitats based on their habitat preferences and selection. It can also be related to the resemblance in topography and the dominance of a certain order, since OpW and UrV seemed to share the same habitat topography consisting of open water body of the lake. It was also noticed that order Anseriformes -represented in ducks- dominated both habitats. This comes in consistency with the previous justification. However, the abundance of migratory species was the only case in which PA reported the greatest numbers. This is explained by the dominance of Greater flamingos in this area, with a massive population reaching up to +3000 individuals.

In contrast, and contrary to our predictions, UrV had the highest species richness yet the least mean abundance of migratory species. Additionally, microhabitat plays a major role in this habitat, resembling the SdR habitat. Both villages were semi-urban points. **Xu *et al*. (2018)** suggest that diversity depends on the degree of urbanization of the area, while **(Panda *et al.*, 2021)** also agreed with their findings that wetlands of semi-urban areas with agricultural lands were more diverse than highly populated areas.

The study of **Mukhopadhyay and Mazumdar (2019)** mentioned that according to several studies conducted along the urban-rural gradient and by following the intermediate disturbance hypothesis, the number of bird species tends to be higher and frequently reaches a maximum in suburban areas. The previous explanation of the elevated richness is opposite to that explaining the decreased abundance. Based on the field work, this habitat contained many single observations of migrating species which might lead to these results.

Temporally, autumn 2021 had the highest richness and mean abundance, while spring 2021 had the lowest for all bird groups (except for resident species richness and migratory mean species abundance).Since the autumn migration of birds reaches its peak, many individuals of the migrant species start to arrive at the lake. Birds are believed to migrate in winter to their wintering grounds to avoid harsh winters in their homeland. Studies conducted on the wintering ecology of migratory avifauna indicate that the adherence of individual birds to specific wintering locations is a crucial aspect of migration for certain species. This fidelity to wintering sites has been shown to enhance birds' survival and physical well-being during the winter season.

It is also believed that individuals who engage in migration are subject to significant pressure to promptly return to familiar breeding areas and re-establish their territories, leading to faster migration in spring to fly back to the suitable breeding grounds, while sedentary species tend to engage in territory preparing and parenting behavior **(*Holmes et al.*, 1989; Holmes & Sherry, 1992; Kokko, 1999; Cresswell, 2014; Shizuka *et al.*, 2014; Blackburn & Cresswell, 2016; Horton *et al.*, 2016; Sheta,**

2019; Bonnet-Lebrun *et al.*, 2020), since birds migrate in response to biological needs, such as feeding and finding suitable locations for breeding and raising the offspring **(Van Vessem *et al.*, 1997; Wondefrash *et al.*, 2003)**.

Thus, migration is considered an adaptive strategy that facilitates endurance and sustained reproduction in seasonal habitats **(Winger *et al.*, 2019)**. Migration behavior is still poorly understood, yet many studies, including those by **Zimmerman *et al.* (1998)**, **Berthold (2001)** and **Newton (2010)**, tend to explain migration timing, routes, mechanism, and physiology. Meanwhile, in spring, most migrant species return to their original habitat or start collecting nest material, and parenting behavior is well noticed, explaining the increase in diversity of resident species in spring. We observed a notable decline in the migratory species abundance and an increase in resident species richness. During the summer, the abundance of migratory species is expected to reach its minimum levels in the lake (except for summer migrants), and only habitat generalists and resident species are active explaining the increase in resident species richness in summer. Winter seasons (2020/ 2021 and 2022) either equally or each one was the highest in species evenness and diversity, while summer 2021 was the lowest.

The work of **Sheta (2019)**, **Asmare *et al.* (2023)** and **Jha and Devkota (2023)** agreed with our results and justification, since they also found an increase in species evenness during winter, explaining why one of the winter seasons varied significantly compared to other seasons.

Indicator species analysis showed that nine species, such as *Bubulcus ibis* (Cattle egret), *Streptopelia senegalensis* (Laughing dove), *Hirundo rustica savinii* (Egyptian Barn swallow), *Hirundo rustica rustica* (Barn swallow), *Acrocephalus stentoreus* (Clamorous reed warbler), *Prinia gracilis* (Graceful perinea), *Sterna albifrons* (Little tern), *Himantopus himantopus* (Black winged stilt), *Upupa epops* (Eurasian hoopoe) that were significantly associated with SdR habitat. Once more, it is related to the microhabitat structure of this habitat, which satisfies the requirements of each of these species. *Phoenicopterus roseus* (Greater flamingo) was significantly associated with Protected area habitat. No previous studies have recorded Greater flamingos in Lake Qaroun before. Only **Johnson (1989)** mentioned that eight ringed individuals were recovered from Egypt, however no other information about its population status. Greater flamingos inhabit suitable wetland habitats in southern Europe, southwest Asia, and much of Africa **(Kahl, 1975; Cramp & Simmons, 1977**). Unlike birds with a distinct seasonal migration pattern, Greater flamingos have a complex movement pattern in the western Palearctic, where they are described as migratory, partially migratory, dispersal, and erratic **(Cramp & Simmons, 1977)**.

CONCLUSION

Following the previous research and confirmed by the results obtained, it can be concluded that Lake Qaroun is a highly productive and supportive habitat for the avian community. This research contributes to comprehending the ecological niches occupied by avian species that inhabit diverse habitat types and their adjacent surroundings. Moreover, this survey attempts to offer insights into the ecology of avian species in the lake. The observations of this study also pointed out the importance of the arid borders of the lake as it formed a viable ecological niche for the Greater flamingo, providing both a good foraging area and a secure sanctuary for these birds. Here we point out the importance of further studies on the status of the Greater flamingo in the lake. The lack of literature on the avian community structure after the report by **Fouad and Fishar (2012)** highlights the significance of our study in addressing this research gap. Thus, this study recommends continuous, systematic bird surveys for further updates to this list and for keeping Lake Qaroun on track in avifaunal biodiversity, which is under studied.

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