Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 12, 513-529
2025
Publisher: Learning Gate
DOI: 10.55214/2576-8484.v9i12.11381

Ecological impact of Oued Fez canalisation Morocco on waterbirds biodiversity

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Abstract: The Oued Fez River crosses northern Fez and historically maintained a permanent marsh that supported both resident and migratory waterbird communities. In 2024, the Sebou Water Basin Agency implemented river-channeling operations to control Pistia stratiotes, an invasive aquatic plant. These interventions altered the hydrological regime and resulted in the complete drying of the wetland area. To assess the ecological consequences of these developments, monthly waterbird surveys were conducted over a three-year period (2022–2024), covering conditions before and after the works. Results indicate a marked decline in avifaunal diversity, with total numbers decreasing from 2,910 individuals in 2022 to 756 in 2024, and species richness falling from 66 to 28, mainly affecting migratory species. A Student's t-test confirmed a statistically significant difference between the two periods, suggesting that the observed changes are attributable to habitat degradation rather than random variation. The loss of wetland habitat, disruption of hydrological dynamics, and reduction of suitable wintering and feeding areas appear to be the primary drivers of this decline. The study underscores the need for integrated ecological management to balance hydraulic development objectives with the conservation of avian biodiversity.

Keywords: *Habitat loss, Waterbird diversity, Oued Fez, Pistia stratiotes, Morocco, Urban wetlands.*

1. Introduction

Among the ecosystems most vulnerable to anthropogenic pressure are urban wetlands [1]. Subjected to drainage and filling operations intended to free up land for construction, they undergo profound and often irreversible alterations to their hydrological dynamics [2, 3]. These transformations disrupt water circulation and retention, reduce soil stabilization, and compromise flood mitigation and groundwater recharge [4]. Ecologically, the degradation of these environments results in the loss of essential habitats for many aquatic, fish, and bird species, leading to a marked decline in biodiversity [5-7].

In Morocco, wetlands are characterized by significant biodiversity, despite their relatively small surface area of approximately 4,000 km², and include nearly 300 natural and artificial sites [8-12], 38 of which are classified as Ramsar sites. Morocco's avifauna comprises 421 recorded species, 240 of which breed in the country [9]. Among these, 95 breeding species are of significant conservation value according to IUCN criteria [9, 13].

The Oued Fez, a tributary of the Oued Sebou, is a natural urban wetland of great ecological importance, particularly for aquatic birdlife. Flowing through the city of Fez, this watercourse plays an essential role in maintaining biodiversity [14]. However, it is now severely degraded by urban developments that channel its flow.

Various interventions to combat *Pistia stratiotes* have profoundly altered the hydrological regime of the Oued Fez [15, 16], leading in particular to the disappearance of the marshland area that provided a habitat for many species of aquatic birds. It is in this context that our study is being conducted, with the

History: Received: 3 October 2025; Revised: 17 November 2025; Accepted: 21 November 2025; Published: 9 December 2025
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aim of studying the phenological status of the site's aquatic bird population through monthly monitoring from January 2022 to December 2024, as well as assessing the impact of developments on its biodiversity.

2. Materials and Methods

2.1. Presentation of the Site

The Oued Fez is a watercourse that flows through the city of Fez between parallels 33°30' and 34°08' N, and meridians 4°54' and 5°09' W, fed by karstic resurgence springs at Ras El Ma (Fig. 1). This watercourse plays a fundamental hydrological role, collecting water from the Fez catchment area before joining the Oued Sebou. This is a subsidence region filled with Neogene deposits, bordered to the south by the Jurassic limestones and dolomites of the Middle Atlas, and to the north by the Prerif formations [17, 18].

The climate is semi-arid, characterized by cold, wet winters and hot, dry summers. The average annual rainfall is 494 mm, while the average temperature is around 17.5°C [19]. The hydrological regime of the Oued is characterized by irregular flow that varies according to the seasons and years, depending on the weather conditions in the region.

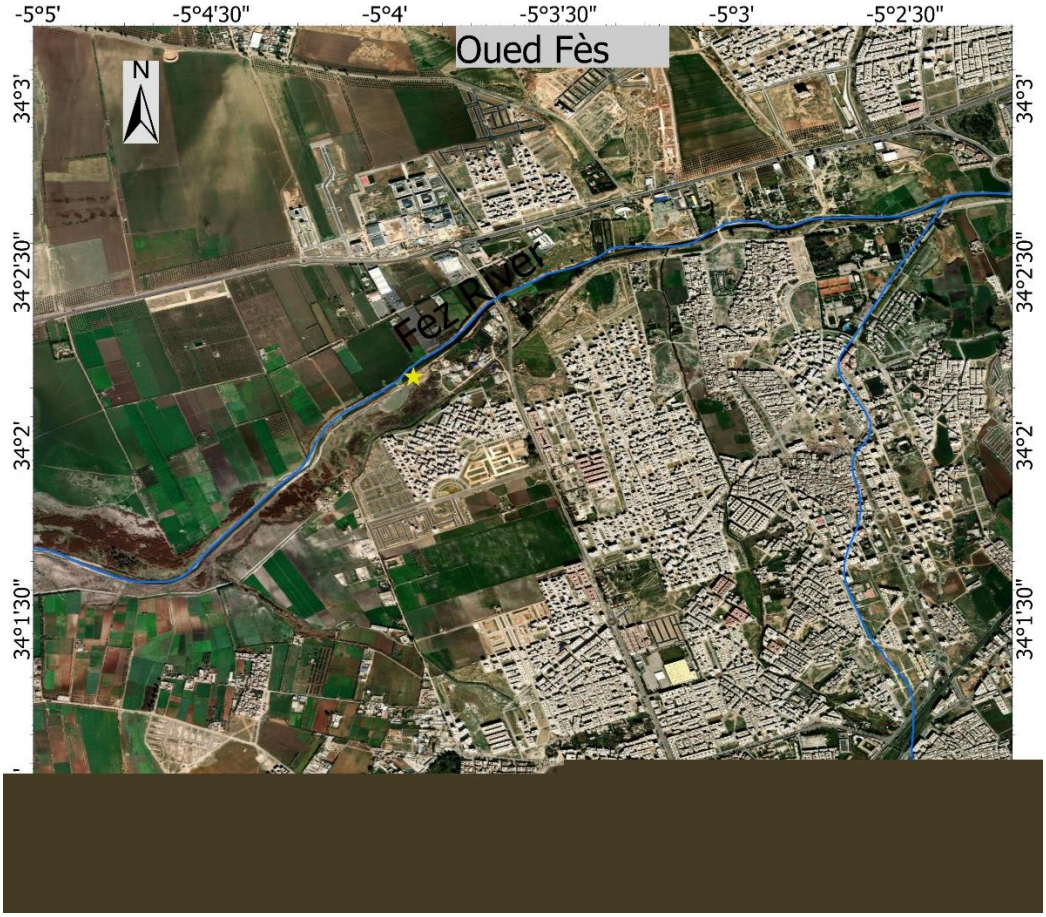

Figure 1.
Location of the study area.

Our study area is a marshy depression that receives water from adjacent springs located mainly on the right bank, as well as from rainfall.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 12: 513-529, 2025
DOI: 10.55214/2576-8484.v9i12.11381

2.2. Bird Census

To study the phenology of the avifauna of Oued Fez, census campaigns were conducted from January 2022 to December 2024 on a bi-monthly to monthly basis, depending on the nesting, migration, and/or wintering periods across the entire study site (Fig. 1).

The direct counting method adopted was that of Lamotte and Bourlière [20], which involves counting individuals when the group does not exceed 200 individuals. The census was carried out by two observers using binoculars (12×50) and a high-magnification camera (Nikon Coolpix P1000). Species identification was carried out using ornithological guides [21-23].

2.3. Avifauna Population Structure

The structure of populations in the study area was examined using various ecological indices that reflect population balance: total abundance, species richness, Shannon and Weaver diversity index [24], equitability index, Student's t-test, and factor analysis of correspondences.

Shannon and equity index:

The Shannon index was calculated using the following formula:

$H' = -\sum (ni/N) \times Log_2 (ni/N)$

Where:

N = Sum of the numbers of all species

ni = Population size of species i

The results are expressed in bits/individual.

Equity index is determined using the following formula: E = H' / H'max, where H'max represents the theoretical maximum diversity of the population. This value corresponds to a situation in which individuals are distributed perfectly equally among all species and is calculated according to the relationship $H'max = Log_2(S)$, where S denotes the total species richness, i.e., the number of species present in the environment.

2.4. Student's T-Test for Paired Samples

This test compares the means of two measurements taken on the same individuals or experimental units. It determines whether the mean difference between these two series of measurements is statistically significant [25].

It is represented by the following equation:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{{s_1}^2}{n_2} + \frac{{s_2}^2}{n_2}}}$$

Where:

$\bar{x}_1$: Mean value of the first group

$\bar{x}_2$: Mean value of the second group

n_1: Size of the first group

n_2: Size of the second group

s_1: Standard deviation of the first group

s_2: Standard deviation of the second group

2.5. Factor Analysis of Correspondences

Census correlation, the multivariate statistical method PCA was used to analyze annual variations in aquatic bird species at the study site and to establish a correlation between the presence of bird species (observed variables) and observations (census dates).

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3. Results

3.1. Specific Composition of the Bird Population

In 2022, there was a significant number of birds, reaching 2,887. This number decreased by half to 1,551 individuals in 2023, then fell sharply to 758 individuals in 2024 (Table 1).

Monthly monitoring of birdlife in the Oued Fez area from January 2022 to December 2024 identified 67 species of water birds, divided into 18 families. The Scolopacidae and Anatidae families are the most abundant, with 23% and 16% of species, respectively, followed by Ardeidae at 11% and Laridae at 7.4%. The species richness within these families represented a significant proportion of the species counts reported at the national level: 80% for Ardeidae, 69% for Scolopacidae, 52% for Anatidae, and 44% for Rallidae. The observations also recorded the presence of species of international importance such as the coot, a species found mainly in Morocco and Spain; the white-headed duck (endangered); the tufted duck (vulnerable); as well as the ferruginous duck, the marbled teal, the bar-tailed godwit, the black-tailed godwit, the red knot, and the dunlin (near threatened). Coastal species such as the sanderling and the ringed plover were also observed (Table 1).

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Table 1.
List of bird species with their phenological status and conservation status at the study site during the three-year monitoring period (2022 to 2024).

Orders	Families	Scientific names	Phenological status	Conservation status	2022	2023	2024	Total	Percentage
Anseriformes	Anatidae	*Oxyura leucocephala* Scopoli, 1769	WV; RB; PM?	EN	5	1	0	6	0.09%
		Spatula clypeata Linnaeus, 1758	WV; PM; OB	LC	68	13	0	145	2.22%
		Anas crecca Linnaeus, 1758	WV; PM	LC	85	27	0	195	2.99%
		Anas platyrhynchos Linnaeus, 1758	RB; WV	LC	174	72	28	358	5.48%
		Spatula querquedula Linnaeus, 1758	PM; OW	LC	7	4	0	11	0.17%
		Mareca strepera Linnaeus, 1758	WV; PM; OB	LC	66	8	0	102	1.56%
		Aythya ferina Linnaeus, 1758	WV; PM; OB	VU	75	22	0	97	1.49%
		Aythya nyroca Güldenstädt 1770	RB		13	0	0	16	0.25%
		Tadorna ferruginea Pallas, 1764	RB	LC	1	0	0	1	0.02%
		Netta rufina Pallas, 1773	RB		4	0	0	4	0.06%
		Marmaronetta angustirostris Ménétries, 1832	RB; WV; PM	NT	2	2	0	5	0.08%
					500	149	28	940	14.40%
Ciconiiformes	Ardeidae	Ardea alba Linnaeus, 1758	WV; PM	*LC*	2	0	0	3	0.05%
		Ardea cinerea Linnaeus, 1758	PM; WV; OB	*LC*	17	22	8	62	0.95%
		Ardea purpurea Linnaeus, 1766	PM; BM; OW	*LC*	2	2	0	5	0.08%
		Nycticorax nycticorax Linnaeus, 1758	PM; BM; WV	*LC*	17	20	37	84	1.29%
		Bubulcus ibis Linnaeus, 1758	RB; PM; WV	*LC*	219	193	198	627	9.61%
		Egretta garzetta Linnaeus, 1766	RB; PM; WV	*LC*	145	79	100	370	5.67%
		Ardeola ralloides Scopoli, 1769	BM; RB? PM; W	*LC*	63	71	51	199	3.05%
		Botaurus minutus Linnaeus, 1766	BM; RB? PM		9	5	2	18	0.28%
					474	392	396	1368	20.96%
	Ciconiidae	Ciconia ciconia Linnaeus, 1758	PM; BM; WV	*LC*	47	121	46	224	3.43%
					47	121	46	224	3.43%
	Phoenicopteridae	Phoenicopterus roseus Pallas, 1811	PM; WV; RB	*LC*	1	0	0	1	0.02%
					1	0	0	1	0.02%
	Threskiornithidae	Platalea leucorodia Linnaeus, 1758	PM; WV; RB	*LC*	1	0	0	1	0.02%
		Plegadis falcinellus Linnaeus, 1766	PM; WV; OB	*LC*	70	55	41	181	2.77%
					71	55	41	182	2.79%
	Rallidae	Fulica spp			28	0	0	40	0.61%
		Fulica atra Linnaeus, 1758	RB; WV	*LC*	396	78	5	771	11.81%
		Fulica cristata Gmelin, 1789	RB	*LC*	406	93	58	874	13.39%
		Gallinula chloropus Linnaeus, 1758	RB; WV	*LC*	124	157	54	393	6.02%
		Porphyrio porphyrio Linnaeus, 1758	WV; PM; OB	*LC*	5	99	27	147	2.25%

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					959	427	144	2225	34.09%
	Laridae	Chlidonias niger Linnaeus, 1758	PM	*LC*	2	0	0	2	0.03%
Charadriiformes		Chlidonias hybrida Pallas, 1811	PM; WV; OB	*LC*	5	0	0	5	0.08%
		Gelochelidon nilotica Gmelin, 1789	PM	*LC*	12	1	0	13	0.20%
		Chroicocephalus ridibundus Linnaeus, 1766	WV; PM; RB	*LC*	3	0	0	12	0.18%
		Sternula albifrons Pallas, 1764	BM; PM; OW	*LC*	9	4	0	13	0.20%
					31	5	0	45	0.69%
	Scolopacidae	Calidris spp			0	0	0	4	0.06%
		Calidris alba Pallas, 1764	PM; WV	*LC*	1	1	0	2	0.03%
		Calidris alpina Linnaeus, 1758	PM; WV	*LC*	2	3	0	5	0.08%
		Calidris canutus Linnaeus, 1758	PM; WV	*NT*	2	0	0	2	0.03%
		Calidris ferruginea Pontoppidan, 1763	PM, WV	*NT*	4	0	0	4	0.06%
		Calidris minuta Leisler, 1812	PM; WV	*LC*	6	0	0	6	0.09%
		Calidris temminckii Leisler, 1812	PM; WV	*LC*	4	0	0	4	0.06%
		Tringa spp			2	0	0	4	0.06%
		Tringa erythropus Pallas, 1764	PM; WV	*LC*	5	4	0	11	0.17%
		Tringa glareola Linnaeus, 1758	PM; WV	*LC*	10	14	3	29	0.44%
		Tringa nebularia Gunnerus, 1767	PM; WV	*LC*	22	14	3	60	0.92%
		Tringa ochropus Linnaeus, 1758	PM; WV	*LC*	5	4	1	10	0.15%
		Tringa tetanus Linnaeus, 1758	PM; WV; OB	*LC*	7	2	0	14	0.21%
		Actitis hypoleucos Linnaeus, 1758	PM; WV	*LC*	25	17	9	61	0.93%
		Gallinago Gallinago Linnaeus, 1758	PM; WV	*LC*	23	3	0	41	0.63%
		Calidris pugnax Linnaeus, 1758	PM	*LC*	55	32	0	99	1.52%
		Limosa lapponica Linnaeus, 1758	PM; WV	*NT*	2	1	0	3	0.05%
		Limosa limosa Linnaeus, 1758	PM; WV	*NT*	0	0	4	6	0.09%
					175	95	20	365	5.59%
	Charadriidae	Charadrius alexandrines Linnaeus, 1758	RB; PM; WV	*LC*	5	2	6	19	0.29%
		Charadrius dubius Scopoli, 1786	RB; PM; WV	*LC*	68	48	16	142	2.18%
		Charadrius hiaticula Linnaeus, 1758	PM; WV	*LC*	0	0	0	2	0.03%
					73	50	22	163	2.50%
Charadriiformes	Glareolidae	Glareola pratincola Linnaeus, 1758	PM; BM; OW	*LC*	142	8	0	155	2.37%
					142	8	0	155	2.37%
	Recurvirostridae	Himantopus Himantopus	BM/RB; PM; WV	*LC*	106	70	37	271	4.15%
		Linnaeus, 1758							
					106	70	37	271	4.15%
Pelecaniformes	Phalacrocoracidae	Phalacrocorax carbo Linnaeus, 1758	WV	*LC*	132	25	0	186	2.85%
					132	25	0	186	2.85%

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Podicipediformes	Podicipedidae	Podiceps cristatus Linnaeus, 1758	RB; WV	*LC*	19	4	1	27	0.41%
		Tachybaptus ruficollis Pallas, 1764	RB	*LC*	54	57	0	137	2.10%
					73	61	1	164	2.51%
Pandioniformes	Pandionidae	Pandion haliaetus Linnaeus, 1758	PM; WV; RB	*LC*	4	3	0	7	0.11%
					4	3	0	7	0.11%
Falconiformes	Accipitridae	Elanus caeruleus Desfontaines, 1789	RB, BM	*LC*	2	1	0	5	0.08%
		Circus aeruginosus Linnaeus, 1758	RB; WV; PM	*LC*	11	2	0	15	0.23%
		Hieraaetus pennatus Gmelin, 1788	RB	*LC*	2	1	0	3	0.05%
					15	4	0	23	0.35%
	Falconidae	Falco peregrinus Tunstall, 1771	RB	*LC*	2	0	0	2	0.03%
		Falco tinnunculus Linnaeus, 1758	RB	*LC*	10	2	2	16	0.25%
					12	2	2	18	0.28%
Burhiniformes	Burhinidae	Burhinus oedicnemus Linnaeus, 1758	RB; WV; PM	*LC*	5	18	3	27	0.41%
					5	18	3	27	0.41%
Passeriformes	Motacillidae	Motacilla alba Linnaeus, 1758	WV; RB; PM	*LC*	47	22	9	83	1.27%
		Motacilla alba subpersonata Meade-Waldo, 1901	RB	*LC*	2	1	1	5	0.08%
		Motacilla cinerea Tunstall, 177	PM; RB; WV	*LC*	6	4	7	20	0.31%
		Motacilla flava Linnaeus, 1758	PM; BM/RB; WV	*LC*	12	39	1	55	0.84%
					67	66	18	163	2.50%
					2887	1551	758	6527	100%

Note: (*) Species with significant conservation status; (**) Species of coastal origin. Phenological status: (RB: Resident breeder, WV: Winter visitor, PM: Passage migrant, BM: Breeding migrant, OB: Occasional breeder; PAV: Palearctic vagrant) and conservation status according to the IUCN (EN: Endangered, LC: Least concern, NT: Near threatened).

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From 66 in 2022 to 52 in 2023, then dropping sharply to 28 in 2024. The Shannon index fell from 3.28 in 2022 to 3.16 in 2023 and 2.55 in 2024, indicating a significant loss of species diversity, both in terms of richness and distribution of individuals. These results show that 2022 was the most favorable year for biodiversity, while 2024 saw a significant decline in biological diversity (Table 2).

The equity index remains relatively stable (0.78 in 2022, 0.79 in 2023, and 0.76 in 2024), despite the sharp decline in the number of species in 2024, as those that remain are distributed evenly.

Table 2.
Species richness, Shannon biodiversity index, and equity index in 2022, 2023, and 2024.

Year	2022	2023	2024	Total
Specific richness	66	52	28	67
Shannon index	3.28	3.16	2.55	3.17
Equity index	0.78	0.79	0.76	0.75

The species recorded belong to different phenological categories, namely: winter visitors, summer visitors, migrants, breeders, and non-breeders, which can be described as follows:

1. Migrants, winter visitors, and summer visitors: these are species that are present all year round but do not breed locally, such as the grey heron and the little ringed plover.
2. Migrants and winter visitors: these are species that are absent in summer and present in autumn, winter, and spring, such as the common teal and the northern shoveler.
3. Strict winter visitors: these are species observed exclusively during winter, such as the great cormorant and the great egret.
4. Migratory breeders: these are summer breeders observed in summer, such as the collared pratincole.
5. Non-breeding summer visitors: these arrive during the summer without breeding, such as the Sandwich Tern and the Whiskered Tern.
6. Sedentary breeders: localised breeders, found throughout the year. This is the case for the coot.
7. Sedentary, migratory, and wintering breeders: these are sedentary birds that breed on the site, joined by passing migrants and wintering birds, such as the common coot, mallard, moorhen, purple swamphen, and black-winged stilt.
8. Strict migrants: these are species that have been observed during postnuptial migration from July to October and prenuptial migration from March to May; Temminck's stint, red knot, and green sandpiper.

3.2. Interannual Variation in Bird Numbers

Ornithological monitoring showed a very significant interannual variation in the number of each species observed during the study period. The highest percentages of the population are attributed to the crested coot (13.39%), the common coot (11.81%), cattle egret (9.61%), moorhen (6.02%), little egret (5.67%), mallard (5.48%), and black-winged stilt (4.15%). These seven species alone account for 56.13% of the total bird population (Table 2).

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Figure 2.
Temporal variation of representative species at the site.

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3.3. Paired Samples Student's T-Test

The biodiversity averages show a significant decrease from 2022 to 2024, with average values falling from 188.33 in 2022 to 101.8 in 2023, then to 50.2 in 2024. This decrease is confirmed by the Student's t-test ($t = 2.233$; $p = 0.042$ between 2022 and 2023, $t = 2.735$; $p = 0.016$ between 2023 and 2024, and $t = 2.502$; $p = 0.025$ between 2022 and 2024), indicating that these differences are statistically significant. The high correlations between the series ($r = 0.889$, 0.836, and 0.572) show a consistent trend (Table 3).

Table 3.
Results of Student's t-tests comparing biodiversity between the years 2022, 2023, and 2024 (means, variances, correlations, t-values and p-values).

Comparison	Mean 1	Mean 2	Variance 1	Variance 2	Observations	Correlation (r)	T-statistic	p (bilateral)
2022 – 2023	188.33	101.8	65 108.81	17 545.46	15	0.889	2.233	0.042
2023 – 2024	101.8	50.2	17 545.46	10 493.6	15	0.836	2.735	0.016
2022 – 2024	188.33	50.2	65 108.81	10 493.6	15	0.572	2.502	0.025

3.4. Principal Component Analysis

1. In 2022, principal component analysis shows that axes 1 and 2 of the variables account for 56% of the total information, with the four most representative bird groups being (Figure 3 (a-b)).

Anatidae, Podicipedidae, Rallidae, and Recurvirostridae are mainly positioned on the winter axis, corresponding to the months of November to February, a period marked by the arrival of Palaearctic migrants exploiting deep water bodies. Ardeidae and Threskiornithidae, on the other hand, cluster around the spring and summer months (March to August), reflecting their nesting activity in wetlands with emergent vegetation. Charadriidae and Scolopacidae appear mainly during the transition period (September–October), when falling water levels expose muddy areas. The common coot *Fulica atra*, associated with the wintering group, confirms its status as a breeding resident, reinforced in winter by migratory arrivals. This structure reflects the strong dependence of functional guilds on seasonal habitat variation.

2. In 2023, principal component analysis shows that axes 1 and 2 of the variables account for 57% of the total information. The four most representative groups of birds are (Figure 3 (c-d)).

This year, the factorial configuration remains similar, but the temporal separation between groups is more pronounced. The months of January to March remain associated with Anatidae and Podicipedidae, confirming the winter predominance of these aquatic families. Ardeidae and Threskiornithidae dominate the spring and summer period (April to August), indicating an intensification of reproductive activity, as in the case of the glossy ibis and the little egret. Charadriidae and Scolopacidae, on the other hand, are concentrated in late summer and early autumn, corresponding to post-nuptial migration. The red-crested coot *Fulica cristata* is more prevalent in spring, highlighting its local reproduction and attachment to stabilized marsh areas. This spatial and temporal distribution reflects an increased synchronization between the biological cycles of the species and the hydrological conditions of the site.

3. In 2024, principal component analysis shows that axes 1 and 2 of the variables account for 55.7% of the total information, with the four most representative bird groups being (Figure 3 (e-f)).

Anatidae, Podicipedidae, and Rallidae remain dominant in winter (December to February), while Ardeidae and Threskiornithidae remain typical of spring–summer. Charadriidae, Scolopacidae, and Burhinidae remain associated with autumn transition periods, confirming their dependence on water level variation.

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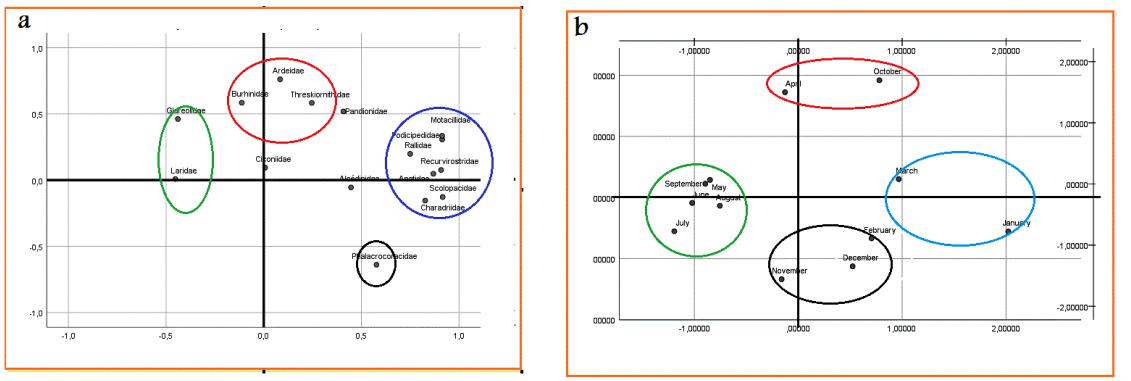
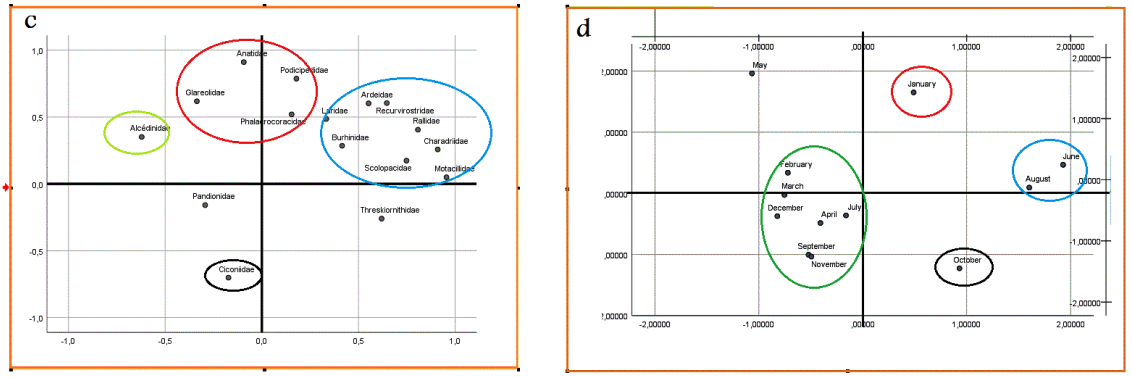
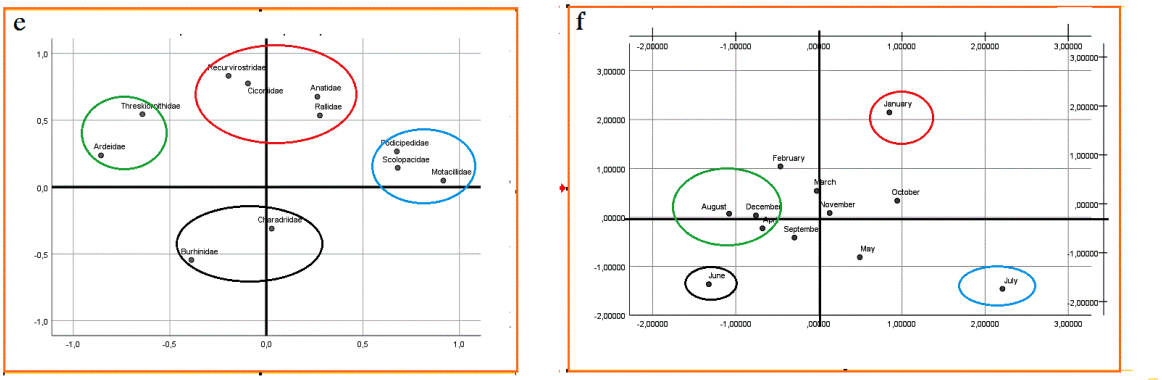


in 2022 : (a) observed variables on factorial plan 1-2 , (b) obsersations on factorial plan 1-2



in 2023 : (c) observed variables on factorial plan 1-2 , (d) obsersations on factorial plan 1-2



in 2024 : (e) observed variables on factorial plan 1-2 , (f) obsersations on factorial plan 1-2

Figure 3.
Principal component analysis of the bird population at Oued Fez from 2022 to 2024.

4. Discussion

Monthly monitoring of birdlife in the Oued Fez area from January 2022 to December 2024 enabled us to identify 67 species of water birds, one of the highest numbers in Moroccan wetlands, exceeding the Smir complex, which recorded 58 species between 2005 and 2009 [26] and also higher than those recorded in the Rabat Bouznika coastal area between 1999 and 2001 with 24 species [27] and the Middle

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 12: 513-529, 2025
DOI: 10.55214/2576-8484.v9i12.11381

Atlas, which is home to only 24 species [28]. However, it remains lower than those recorded in Idriss Premier with 78 species and in the coastal wetlands of Martil, which has 93 [29]. In Algeria, 79 species were counted in the Setif wetland eco-complex [30] and 21 species in Oum El Boughi in the north of the country [31]. In Tunisia, 34 species were observed in the Douz wetlands in the south [32]. In Italy, 60 species have been observed in the Sardinian wetlands [33]. In Turkey, 67 species have been recorded in the western part of the country (Anatolia) [34].

Analysis of the specific composition highlights the precise organization of waterbird communities according to their phenological status [35]. There are three main groups: breeding birds, winter visitors, and migratory birds passing through. In addition to these groups, there are sedentary species or species with mixed status, such as the coot, the crested coot, the mallard, the moorhen, and the little egret, which are present all year round. This distribution demonstrates the functional and seasonal diversity of birds on the site.

Confirmed by Student's t-test, the Oued Fez area has suffered significant degradation of its natural habitats, mainly due to hydraulic developments involving the canalization of the main watercourse, with the aim of combating the spread of the invasive plant *Pistia stratiotes*. These changes have led to the reduction of the marshland area and its total disappearance in 2024 (Figure 4), fragmentation of habitats, and alteration of hydrological regimes, compromising the conditions necessary for the reproduction, feeding, and resting of waterbirds [2, 16, 36]. As a result, local biodiversity has shown a marked decline, both in terms of species richness and abundance, reflecting the sensitivity of these ecosystems to anthropogenic disturbances [11, 14, 37].

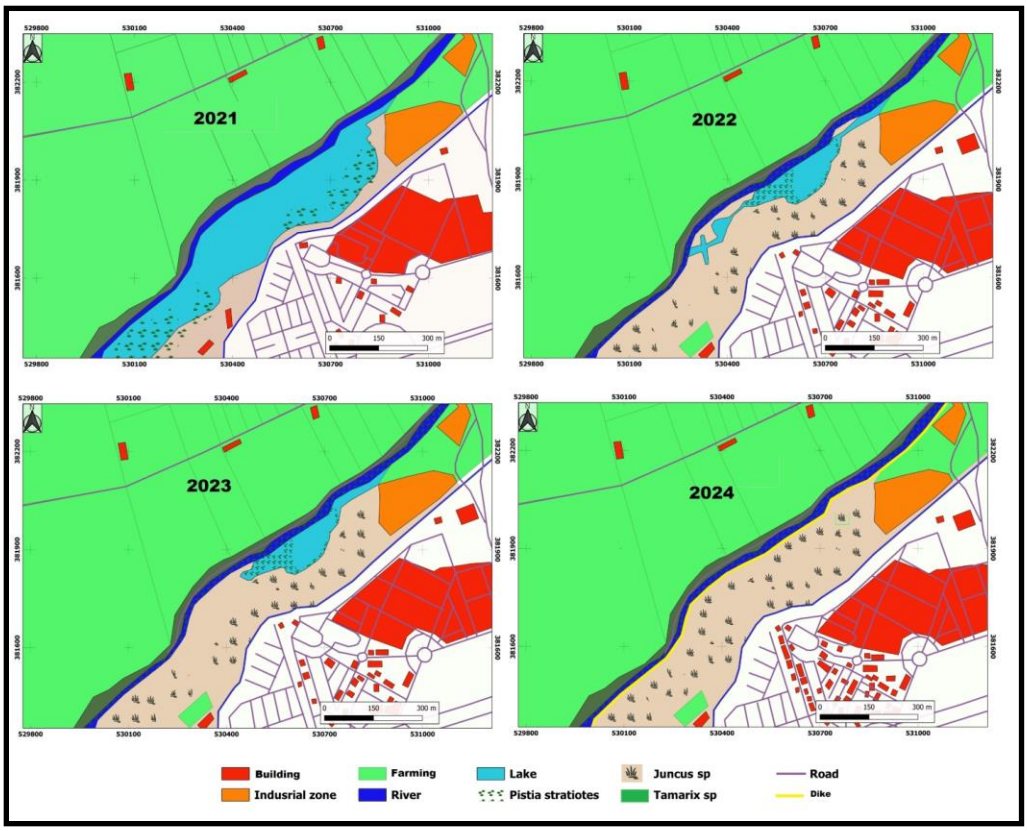


Figure 4.
Changes to the water body from 2021 to 2024.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 12: 513-529, 2025
DOI: 10.55214/2576-8484.v9i12.11381

According to census results, the degradation of this habitat particularly affects migratory and wintering birds, especially waders, whose presence is closely linked to the availability of resting and feeding areas [33, 38, 39]. The disappearance of land areas, the canalization of riverbanks, and the disruption of mudflats generally lead to a significant reduction or even total disappearance of habitats favorable to birdlife, limiting their migratory stopovers and thus compromising their annual migration cycle [33, 40, 41]. The presence of *Pistia stratiotes*, used as a perch by large wading birds for fishing, particularly the Squacco Heron, Little Egret, Night Heron, Glossy Ibis, Little Bittern, Cattle Egret, Grey Heron, and Purple Heron, encourages the presence of these species in the site despite the developments. On the other hand, this invasive plant limits the activities of the duck group, mainly divers, by reducing the area of transparent water.

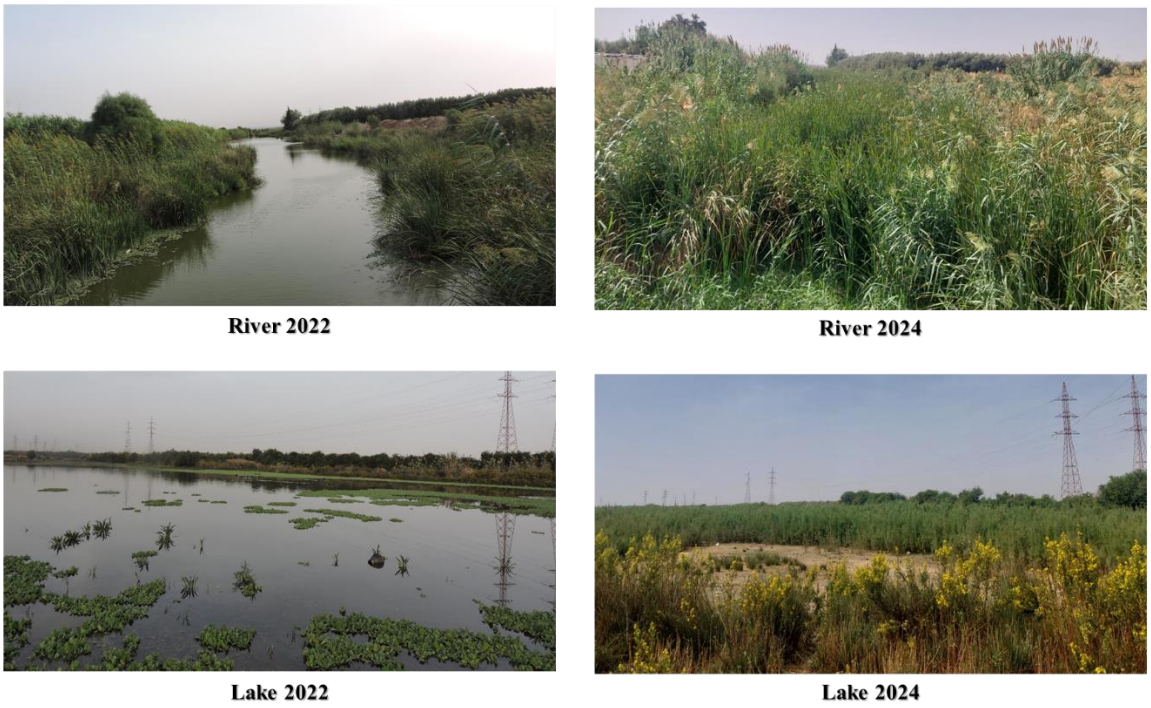


Figure 5.
View of the study site before and after hydraulic improvements.

Numerous wetland creation and restoration projects have been carried out in recent decades [40, 42-44] but wetland management does not always produce the expected results [45]. It has been reported that foraging rates of waterbirds in managed habitats are not as high as those observed in natural sites [46]. Managed restored habitats are not used by the same species as natural habitats [47], and constructed habitats can only support species of interest for a limited period, as plant succession subsequently alters habitat characteristics [48]. Therefore, a better understanding of the impact of habitat management on waterbirds is needed to develop a more effective strategy for the conservation of wetlands and waterbirds.

However, habitat loss is the main threat to biodiversity, leading to population decline and the extinction of many species [49, 50]. More than half of wetlands have disappeared over the last century [42] and the remaining sites often suffer varying degrees of degradation due to anthropogenic pressures, including urbanization, which alters natural landscapes and fragments habitats [36, 51, 52]. This

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 12: 513-529, 2025
DOI: 10.55214/2576-8484.v9i12.11381

situation is even more concerning as wetlands are particularly sensitive to climate change and land use, causing differential effects on waterbird species and affecting their abundance and distribution [53-55].

5. Conclusion

The Oued Fez represents a site of high ecological importance for aquatic bird species, supporting up to 67 species, including the white-headed duck *Oxyura leucocephala*, the common pochard *Aythya ferina*, and the ferruginous duck *Aythya nyroca*. The area is particularly critical for migratory and breeding species, such as the red-crested coot *Fulica cristata*, the common coot *Fulica atra*, the common pochard *Aythya ferina*, the collared pratincole *Glareola pratincola*, and the black-winged stilt *Himantopus himantopus*, which rely on its habitats for reproduction, foraging, and resting.

However, development work in 2024 to combat *Pistia stratiotes* led to a significant deterioration of these environments, resulting in a decrease in diversity from 3.28 in 2022 to 2.55 in 2024, the number of species from 66 in 2022 to 28 in 2024, and the total population, which fell from 2,887 to 758 individuals, the majority of which are Ardeidae.

These ill-considered anthropogenic transformations have altered the ecological balance of the site and weakened the most vulnerable populations, which have disappeared completely from the site, such as the white-headed duck, the common pochard, the ferruginous duck, the ruff, and the collared pratincole. It appears essential to carry out exhaustive and integrated studies of the entire ecosystem in consultation with all stakeholders before any development actions are taken, to reconcile development and the preservation of biodiversity, and to guarantee the ecological sustainability of sites of high ornithological value.

Due to declining growth factors, limited distribution, and fragmentation of bird habitats, it is imperative to protect species with a sensitive and fragile conservation status.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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References

[1] S. Dournel, M. Franchomme, and B. Sajaloli, "Geohistory of a resurgence of troubled waters: Urban wetlands and river cities of Northern France (early 19th-20th century)," *Revue du Nord. Collection Histoire (Hors série)*, vol. 26, pp. 169-187, 2011.

[2] S. Maleki, A. R. Soffianian, S. S. Koupaei, S. Pourmanafi, and S. Saatchi, "Wetland restoration prioritizing, a tool to reduce negative effects of drought; An application of multicriteria-spatial decision support system (MC-SDSS)," *Ecological Engineering*, vol. 112, pp. 132-139, 2018. https://doi.org/10.1016/j.ecoleng.2017.12.031

[3] R. Mott *et al.*, "Measuring habitat quality for waterbirds: A review," *Ecology and Evolution*, vol. 13, no. 4, p. e9905, 2023. https://doi.org/10.1002/ece3.9905

[4] R. Horner, *Overview of the Puget Sound wetlands and stormwater management research program: Introduction. Wetlands and urbanization: Implications for the future.* Boca Raton, LA: Lewis Publishers, 2001.

[5] T. Elmqvist, W. C. Zipperer, and B. Güneralp, *Urbanization, habitat loss and biodiversity decline: Solution pathways to break the cycle. In K. C. Seto, W. D. Solecki, & C. A. Griffith (Eds.), The Routledge handbook of urbanization and global environmental change.* Abingdon, UK; New York, USA: Routledge, 2016.

[6] Y. Rayadin *et al.*, "Scholar (8)," 2016. https://pesquisa.bvsalud.org/

[7] S. Dolnicar and A. Chapple, "The readability of articles in tourism journals," *Annals of Tourism Research*, vol. 52, pp. 161-166, 2015. https://doi.org/10.1016/j.annals.2015.03.003

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 12: 513-529, 2025
DOI: 10.55214/2576-8484.v9i12.11381

[8] S. Nakhli, "Environmental pressures and new management strategies on the Moroccan coastline," *Méditerranée. Revue géographique des pays méditerranéens/Journal of Mediterranean Geography*, vol. 115, pp. 31-42, 2010. https://doi.org/10.4000/mediterranee.4996
[9] P. Bergier, M. Thevenot, A. Qninba, and J.-R. Houllier, *Birds of Morocco*. Mérignac, France: SEOF, 2022.
[10] K. Abdelmajid, M. Libiad, and A. Ennabili, "An updated checklist of the wetland vascular flora from Morocco," *Moroccan Journal of Biology*, vol. 17, pp. 1-35, 2020. https://doi.org/10.6084/m9.figshare.12937823.v3
[11] S. I. Cherkaoui, S. Hanane, N. Magri, M.-A. El Agbani, and M. Dakki, "Factors influencing species-richness of breeding waterbirds in Moroccan IBA and Ramsar wetlands: a macroecological approach," *Wetlands*, vol. 35, pp. 913-922, 2015. https://doi.org/10.1007/s13157-015-0682-y
[12] M. Dakki, "Ecological classification of wetlands in Morocco," *Travaux de l'Institut Scientifique, Rabat*, vol. 9, pp. 1–124, 2021.
[13] A. J. Green, M. El Hamzaoui, M. A. El Agbani, and J. Franchimont, "The conservation status of Moroccan wetlands with particular reference to waterbirds and to changes since 1978," *Biological Conservation*, vol. 104, no. 1, pp. 71-82, 2002. https://doi.org/10.1016/S0006-3207(01)00155-0
[14] W. Squalli *et al.*, "Diversity of avian species in peri-urban landscapes surrounding fez in Morocco: Species richness, breeding populations, and evaluation of menacing factors," *Diversity*, vol. 14, no. 11, p. 945, 2022. https://doi.org/10.3390/d14110945
[15] C. Chadli, M. Libiad, A. Khabbach, R. Bouslamti, and A. Ennabili, "Functional aspects of Pistia stratiotes, an invasive plant of lentic freshwater habitats of Al Jawahir Wadi (Fez, Morocco)," *Botanica Complutensis*, vol. 46, p. e80494, 2022. https://doi.org/10.5209/bocm.80494
[16] A. Khabbach, M. Libiad, and A. Ennabili, "Invasion increasing risk of Al Jawahir Wadi lentic habitats by Pistia stratiotes L.(North-Central Morocco)," *Botanica Complutensis*, vol. 43, pp. 97-107, 2019. htttps://dx.doi.org/10.5209/bocm.64280
[17] C. Mohammed, B. Cherai, M. Benabdelhadi, and C. Falguères, "Quaternary neotectonic impact on the Saïs sedimentary dynamic (Morocco): From Pliocene basin fore-chain to Quaternary continental shelf," *Quaternaire*, vol. 18, no. 4, pp. 327–334, 2007.
[18] D. Fassi, "The surface formations of the Saïs of Fez and Meknes: From geological time to current soil use," Unpublished Doctoral Thesis. Paris 1 (Sorbonne), Paris, France, 1993.
[19] J. L. Perrin, N. Raïs, N. Chahinian, P. Moulin, and M. Ijjaali, "Water quality assessment of highly polluted rivers in a semi-arid Mediterranean zone Oued Fez and Sebou River (Morocco)," *Journal of Hydrology*, vol. 510, pp. 26-34, 2014. https://doi.org/10.1016/j.jhydrol.2013.12.002
[20] M. Lamotte and F. Bourlière, *Ecological problems: Sampling of animal populations in terrestrial environments*. Paris, France: Masson et Cie, 1969.
[21] L. Svensson, K. Mullarney, D. Zetterström, and P. J. Grant, *The Bird Guide: The most comprehensive guide to the birds of Europe, North Africa and the Middle East*. Paris, France: Delachaux, 2021.
[22] G. Maroc, H. Maroc, J. Franchimont, V. Schollaert, and B. Maire, *Birds of Morocco: An identification guide*. Rabat, Morocco: Ibis Presse, 2010.
[23] C. R. T. D. Barlow and T. Dodman, *African East atlantic flyway guide*. Wilhelmshaven, Germany: BirdLife International / Wadden Sea Flyway Initiative, 2015.
[24] C. E. Shannon and W. Weaver, "The theory of mathematical communication," *International Business*, vol. 131, pp. 164-174, 1949.
[25] P. Ingrand, "Student's t-test," *Journal d'imagerie diagnostique et interventionnelle*, vol. 1, no. 2, pp. 81-83, 2018. https://doi.org/10.1016/j.jdi.2018.02.001
[26] M. A. El Agbani, A. Qninba, M. Amezian, F. Cuzin, and M. Dakki, "The waterbird population of the Smir wetland complex (Northern Morocco): Current status, heritage value and evolution over the last four decades," *Bull l'Inst Sci*, vol. 31, pp. 103-110, 2009.
[27] S. Hanane, H. Jaziri, and M. Dakki, "Composition and phenology of the waterbird population of the Atlantic coastal zone of Rabat-Bouznika (Morocco)," *Bulletin de l'Institut Scientifique*, vol. 26–27, pp. 51–65, 2005.
[28] I. Mansouri *et al.*, "Avifauna diversity in the gate between humid atlas and saharan desert: Midelt province, Morocco," *International Journal of Zoology*, vol. 2021, no. 1, p. 5557921, 2021. https://doi.org/10.1155/2021/5557921
[29] N. Mars, O. Haddad, M. Jaouani, A. Maouni, and R. Saïdi, "A review of the avifauna visiting the wetland environments of the Martil plain (Tetouan region, northern Morocco): Preliminary results," in *E3S Web of Conferences (Vol. 412, p. 01068). EDP Sciences*, 2023.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 12: 513-529, 2025
DOI: 10.55214/2576-8484.v9i12.11381

[30] N. Baaziz *et al.*, "Phenological status and reproduction of waterbird populations in the Setif wetland eco-complex (High Plateaus, Eastern Algeria)," *Bulletin de l'Institut Scientifique de Rabat*, vol. 32, no. 2, pp. 77-87, 2011.
[31] N. Nouri, O. Merabet, M. Houhamdi, and Z. Bouslama, "Biodiversity and phenology of aquatic birds in Highlands's wetlands of Oum El Boughi (North-eastern Algeria)," *Advances in Environmental Biology*, vol. 10, no. 5, pp. 39-46, 2016.
[32] F. Hamza and S. Selmi, "Diversity of waterbirds wintering in Douz wetlands (south Tunisia): Factors affecting wetland occupancy and species richness," *Ecological Research*, vol. 33, no. 5, pp. 917-925, 2018. https://doi.org/10.1007/s11284-018-1587-z
[33] A. Ferrarini, M. Gustin, and C. Celada, "Wetland attributes significantly affect patterns of bird species distribution in the Sardinian wetlands (Italy): An uncertain future for waterbird conservation," *Journal of Applied Ecology*, vol. 60, no. 4, pp. 650-660, 2023. https://doi.org/10.1111/1365-2664.14355
[34] F. Saygili, N. Yiğit, and Ş. Bulut, "The spatial and temporal distributions of waterbirds in Lakes Akşehir-Eber and Lake Köyceğiz in western Anatolia, Turkey-a comparative analysis," *Turkish Journal of Zoology*, vol. 35, no. 4, pp. 467-480, 2011. https://doi.org/10.3906/zoo-0911-99
[35] C. Duby and S. Robin, "Principal component analysis," *Institut National Agronomique Paris-Grignon*, vol. 80, p. 53, 2006.
[36] K. Stagoll, A. D. Manning, E. Knight, J. Fischer, and D. B. Lindenmayer, "Using bird–habitat relationships to inform urban planning," *Landscape and Urban Planning*, vol. 98, no. 1, pp. 13-25, 2010. https://doi.org/10.1016/j.landurbplan.2010.07.006
[37] M. Chedadi *et al.*, "Impact of anthropogenic activities on the physicochemical and bacteriological quality of water along Oued Fez River (Morocco)," *Scientific African*, vol. 19, p. e01549, 2023. https://doi.org/10.1016/j.sciaf.2023.e01549
[38] R. El Hamoumi and M. Dakki, "Phenology of waders in the Sidi Moussa-Walidia coastal wetlands, Morocco," *Wader Study Group Bull*, vol. 117, no. 2, pp. 73-84, 2010.
[39] M. A. Colwell, *Shorebird ecology, conservation, and management*, 1st ed. Berkeley, CA: University of California Press, 2010.
[40] F. Hamza *et al.*, "Landscape context and wetland attributes influence wintering waterbirds in important bird and biodiversity areas: implications for conservation and management," *Landscape Ecology*, vol. 39, p. 151, 2024. https://doi.org/10.1007/s10980-024-01942-9
[41] B. M. Sheta, "Biodiversity and habitat use of wintering and breeding waterbirds in Burullus Lake (Ramsar site), Egypt," *Catrina: The International Journal of Environmental Sciences*, vol. 19, no. 1, pp. 47-54, 2019. https://doi.org/10.21608/cat.2019.49179
[42] Z. Ma, Y. Cai, B. Li, and J. Chen, "Managing wetland habitats for waterbirds: An international perspective," *Wetlands*, vol. 30, no. 1, pp. 15-27, 2010. https://doi.org/10.1007/s13157-009-0001-6
[43] Y. Zhang, L. Zhou, L. Cheng, and Y. Song, "Water level management plan based on the ecological demands of wintering waterbirds at Shengjin Lake," *Global Ecology and Conservation*, vol. 27, p. e01567, 2021. https://doi.org/10.1016/j.gecco.2021.e01567
[44] M. Khaffou and A. Chahlaoui, "Impacts of climate change on the dysfunction of Mediterranean wetlands: Case of Aguelmam Afennourir-Ramsar Site-the Middle Atlas–Morocco," in *IOP Conference Series: Earth and Environmental Science (Vol. 1090, No. 1, p. 012037). IOP Publishing*, 2022.
[45] M. K. La Peyre, M. A. Reams, and I. A. Mendelssohn, "Linking actions to outcomes in wetland management: An overview of US state wetland management," *Wetlands*, vol. 21, pp. 66-74, 2001. https://doi.org/10.1672/0277-5212(2001)021[0066:LATOIW]2.0.CO;2
[46] M. N. Rajpar *et al.*, "Artificial wetlands as alternative habitat for a wide range of waterbird species," *Ecological Indicators*, vol. 138, p. 108855, 2022. https://doi.org/10.1016/j.ecolind.2022.108855
[47] E. Sebastián-González and A. J. Green, "Habitat use by waterbirds in relation to pond size, water depth, and isolation: Lessons from a restoration in Southern Spain," *Restoration Ecology*, vol. 22, no. 3, pp. 311-318, 2014. https://doi.org/10.1111/rec.12078
[48] A. Mouhcine *et al.*, "From aquatic to terrestrial: An examination of plant diversity and ecological shifts," *Open Agriculture*, vol. 9, no. 1, p. 20220347, 2024. https://doi.org/10.1515/opag-2022-0347
[49] C. D. Santos, T. Catry, M. P. Dias, and J. P. Granadeiro, "Global changes in coastal wetlands of importance for non-breeding shorebirds," *Science of The Total Environment*, vol. 858, p. 159707, 2023. https://doi.org/10.1016/j.scitotenv.2022.159707
[50] D. Dudgeon *et al.*, "Freshwater biodiversity: Importance, threats, status and conservation challenges," *Biological Reviews*, vol. 81, no. 2, pp. 163-182, 2006. https://doi.org/10.1017/S1464793105006950
[51] V. Manisha, Elangovan, and A. Dwivedi, "Reproductive behaviour and habitat use of cattle egret (Bubulcus Ibis) in Lucknow," *Online International Journal* vol. 9, pp. 21–29, 2020.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 12: 513-529, 2025
DOI: 10.55214/2576-8484.v9i12.11381

[52] K. C. Seto, B. Güneralp, and L. R. Hutyra, "Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools," *Proceedings of the National Academy of Sciences*, vol. 109, no. 40, pp. 16083-16088, 2012. https://doi.org/10.1073/pnas.1211658109

[53] I. Bouregbi *et al.*, "Threatened birds in a changing mediterranean wetland: Long-term trends and climate-driven threats," *Life*, vol. 15, no. 6, p. 892, 2025. https://doi.org/10.3390/life15060892

[54] I. M. Maclean, M. M. Rehfisch, S. Delany, and R. A. Robinson, "The effects of climate change on migratory waterbirds within the African-Eurasian flyway," *BTO Research Report*, vol. 486, 2007.

[55] F. Verniest *et al.*, "Anticipating the effects of climate warming and natural habitat conversion on waterbird communities to address protection gaps," *Biological Conservation*, vol. 279, p. 109939, 2023. https://doi.org/10.1016/j.biocon.2023.109939.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 12: 513-529, 2025
DOI: 10.55214/2576-8484.v9i12.11381