



Diversity of avian species across urban landscape in Ghardaïa City (Algerian Sahara). Diversidade de espécies de aves na paisagem urbana da cidade de Ghardaïa (Saara argelino).

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Abstract

In this work, we studied the avian diversity of an urban environment in the northern Algerian Sahara (Ghardaïa city). Bird data was collected using point counts distributed across three habitats of the urban-rural gradient. A one-way analysis of variance was used to assess the impact of habitat on species richness, number of families, and species abundance. During this study, 44 bird species belonging to 10 orders and 23 families were identified. The highest values of the Shannon-Wiener diversity index ($H' = 3.82$), Margalef index ($D = 3.66$), and Simpson index ($D = 0.92$) were observed in the rural habitat. The differences in species number, families, and abundance were significant among the different habitats, with rural habitats on the outskirts of the city harboring the greatest number of bird species and families.

Keywords: Diversity index. Bird communities. Rural-urban gradient. Habitat. Ghardaia city.

Resumo

Neste trabalho, estudamos a diversidade avícola de um ambiente urbano no norte do Saara argelino (cidade de Ghardaïa). Os dados sobre aves foram coletados por meio de contagens de pontos distribuídas em três habitats do gradiente urbano-rural. Uma análise de variância de uma via foi utilizada para avaliar o impacto do habitat na riqueza de espécies, no número de famílias e na abundância de espécies. Durante este estudo, foram identificadas 44 espécies de aves pertencentes a 10 ordens e 23 famílias. Os valores mais elevados do índice de diversidade de Shannon-Wiener ($H' = 3,82$), índice de Margalef ($D = 3,66$) e índice de Simpson ($D = 0,92$) foram observados no habitat rural. As diferenças no número de espécies, famílias e abundância foram significativas entre os diferentes habitats, sendo que os habitats rurais nos arredores da cidade abrigavam o maior número de espécies de aves e famílias.

Palavras-chave: Índice de diversidade. Comunidades de aves. Gradiente rural-urbano. Habitat. Cidade de Ghardaia.



Introduction

Birds have long been considered an excellent model for the study of biodiversity, due to their presence in all types of habitats across different climatic zones (AOUISSI et al., 2021; MACHAR et al., 2021; MOSISA et al., 2023), in both natural and modified habitats (CROOKS et al., 2004). Habitats converted by urbanization, for example, can no longer be seen as lost areas for wildlife, but rather as new habitats (COLLINS et al., 2000; SHOCHAT et al., 2015). These urbanized environments were only recognized as structured and functioning ecosystems similar to natural ecosystems starting from the early 1990s (GRIMM et al., 2000; SHOCHAT et al., 2015). These ecosystems, with their habitat heterogeneity ranging from densely built city centers to low-density suburban areas often including green spaces such as parks or private gardens (CHACE; WALSH, 2006; SILVA et al., 2015; STROHBACH et al., 2009), provide food resources for many organisms, including waste materials (KURUCZ et al., 2021; SALMON, 2017). They also offer shelter for predators and a secure breeding ground in certain urban areas such as airports, industrial zones, or military areas (RAYMOND; SIMON, 2015).

The Ghardaïa city, due to its central position in Algeria and north of the Sahara, lies on the central migration route of birds (SAMRAOUI; SAMRAOUI, 2008), which plays a crucial role for desert migrants such as water birds, raptors, and passerines crossing the Algerian Sahara. This urban landscape, composed of a mosaic of ecosystems (urban, agricultural, and aquatic), plays the role of an island in the heart of a rocky desert called Chebka. It thus serves as a stopover and breeding site for many migratory birds.

The aim of this study was to highlight the ornithological value of a Saharan urban pattern for trans-Saharan migratory birds during the winter season. This aimed to determine the richness and abundance of wintering bird species in our study region, as well as to evaluate the impact of the urban gradient on the distribution of these species.

Materials and methods

Study area

This study was carried out in the Ghardaïa city (32°28'N, 3°42'E), 600 km south of Algiers, in the M'zab valley (central Algeria). This region is dominated by an arid climate characterized by a mild winter and hot, dry summer, with an average annual temperature of 23.27°C and an average annual precipitation of 80.10 mm (BOUTMEDJET et al., 2022; CHIKHI et al., 2022). The capital of the wilaya is Ghardaïa, which is composed of three of three nearby communes (Ghardaïa, Bounoura, and El Atteuf). It has a distinct architectural style, with five ksour (Ghardaïa, Melika, BeniIzgen, Bounoura, and El Atteuf) constructed into hills with palm trees. It has been listed as a UNESCO World Heritage site since 1982 (BENSALAH et al., 2018). Ghardaïa is surrounded by new expansions and has an area of 1802.4 km², a population of 220,310 inhabitants, 95.8% of whom are urban, and a population density of 122 people per km² (Figure 1) (DPSB, 2022).

Birds sampling

From October 2022 to Jun 2023, we conducted bi-monthly surveys in the field, covering a total of 270 points counts. We started after 30 minutes of sunrise and finished all surveys before 10:00 am (KURUCZ et al., 2021) to coincide with the maximum activity period of birds. Within a radius of 25 m per point count (XU et al., 2018) and a distance of 200 m to the nearest point

(LEVEAU et al., 2017; SANDSTRÖM et al., 2006), we recorded all individuals of bird species seen or heard (CIACH; FRÖHLICH, 2017; KURUCZ et al., 2021; SANDSTRÖM et al., 2006; SANZ; CAULA, 2015; WOLFF et al., 2018; XU et al., 2018) for 10 to 15 minutes at each point (DOUINI et al., 2022). Each point was visited once, twice or three times a month to increase the sampling frequency.

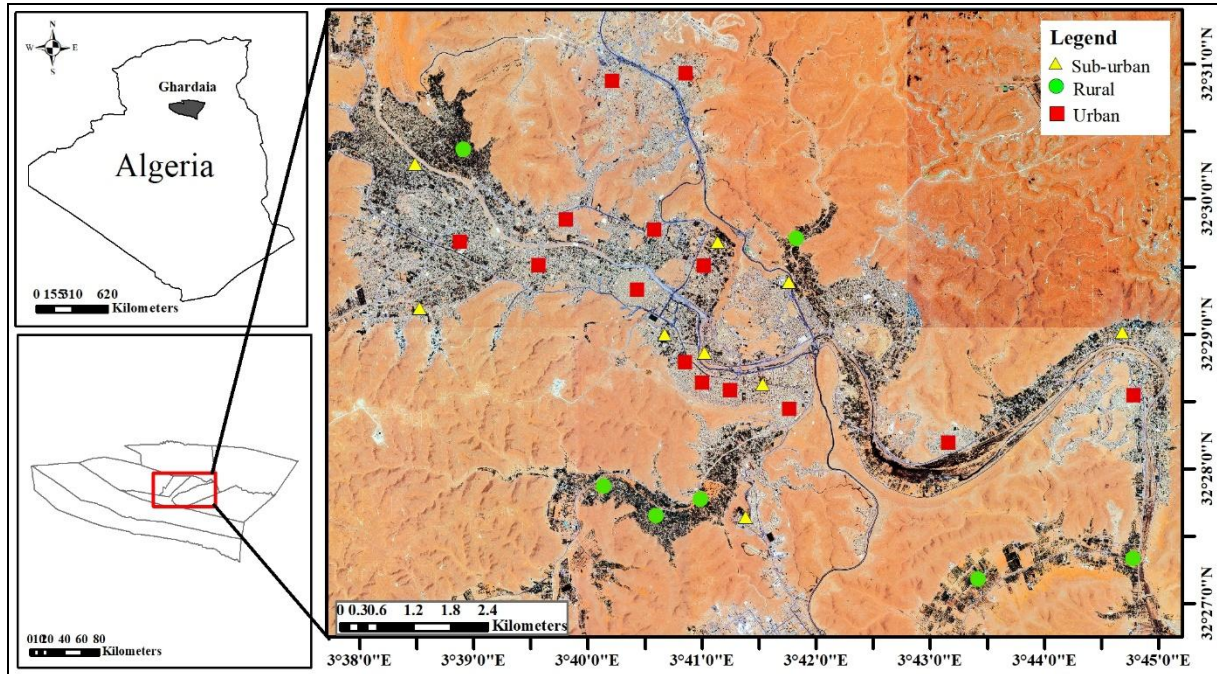


Figure 1 - Study area map with sampling locations.

Habitat classification

Based on the Saharan nature of our study area and its specific architectural style characterized by overlapping palm groves and urbanized areas, we have determined three categories of habitats according to a gradient of urbanization: 1) Urban habitats: as a highly urbanized environment, including Ksour, industrial, public, commercial, private and military units (average building density >80%). 2) Suburban habitats: representing intermediate Between Urban and Rural habitats characterized by the presence of dominant plantations and urbanized palm groves where the building density is between 30% and 80%. 3) Rural habitats: known as agricultural areas, are weakly urbanized zones generally located on the outskirts of the city, dominated by date palm (*Phoenix dactylifera*), fruit trees (orange, pomegranate, lemon...) vegetable crops and spontaneous plants (building density > 30%).

Data analysis

In this study, all recorded species were classified following orders and families. We also determined their phenological and conservation status according the Red List of Birdlife International (2023).

The diversity indices of species such as the Shannon-Weiner index (H') (SPELLERBERG; FEDOR, 2003), the Margalef index (D) (MAGURRAN, 1988), the Simpson index (D) (SIMPSON, 1949) and the Evenness have been calculated to compare species diversity among different habitats. Similarly, the number of species, the number of families and abundance have been calculated and compared using a one-way analysis of variance (ANOVA).

Results

Avifauna diversity

During the nine months of study, a total of 44 species was encountered in the various surveyed habitats belonging to 10 orders, 23 families, and 34 genera. The order Passeriformes is the most represented with 11 families and 29 species, followed by Columbiformes with 4 species. The Coraciiformes, Galliformes, and Pelecaniformes each have 2 species. The Apodiformes, Bucerotiformes, Ciconiiformes, Falconiformes, and Strigiformes are weakly represented by one species each (Table 1).

In terms of species recorded by family, the most represented families are Muscicapidae with 16% of the total number of species, followed by the family Columbidae with 9%. The families Alaudidae, Laniidae, and Phylloscopidae each account for 7% of the species (Figure 2).

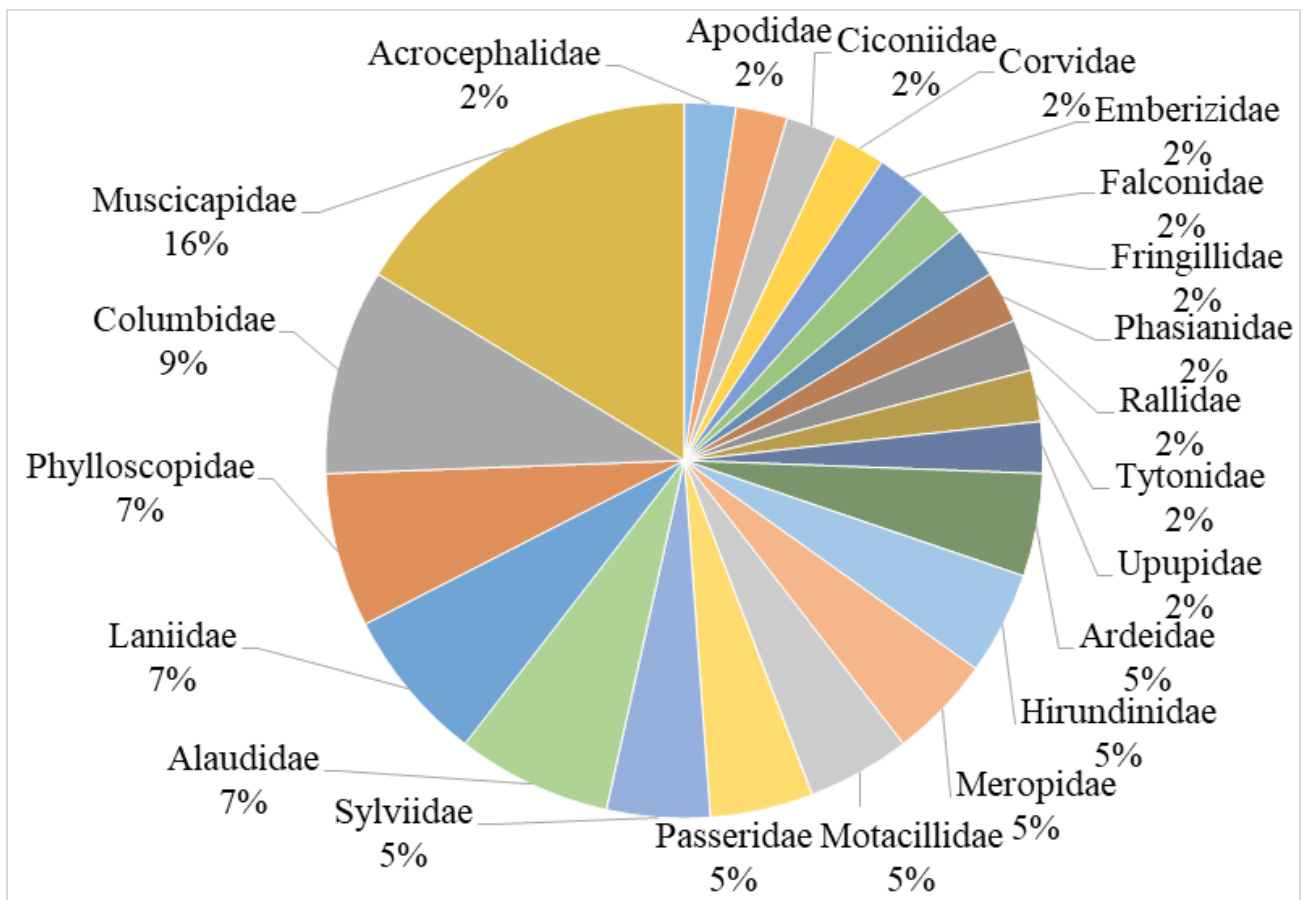


Figure 2 - Species richness and percentage of avian families recorded in Ghardaia city.

The documented species as a whole have different phenological statuses. Among them, 29.54% are migratory, 20.45% are wintering, and 49.72% have a breeding status in the region. From this last group, 77.27% show confirmed reproduction based on one or more indicators during the study period, such as the presence of nests, chicks, or juveniles.

According to the BirdLife Red List (2023), almost all reported species (97.72%) have a conservation status of LC (Least Concern), except for one species considered near-threatened, namely the *Lanius senator* (Table 1).

Table 1 - Bird phenology status (b: breeding, m: migration, and w: wintering), Breeding Status (B. Breeding confirmed, b. Breeding non confirmed, ? Possibly breeds). Breeding index (N nests, C chicks, J Juvenile) and IUCN Red List status 2023 (LC: least concern, NT: near threatened) (IUCN, 2023) of recorded species in Ghardaia city.

Order	Family	Scientific name	Conservation status	phenology Status	Breeding index
Apodiformes	Apodidae	<i>Apus apus</i>	LC	M	.
Bucerotiformes	Upupidae	<i>Upupa epops</i>	LC	B	(N)
Columbiformes	Columbidae	<i>Columba livia</i>	LC	B	(N, C, J)
		<i>Streptopelia decaocto</i>	LC	B	(N, C, J)
		<i>Streptopelia senegalensis</i>	LC	B	(N, C, J)
		<i>Streptopelia turtur</i>	LC	B	(N, C, J)
Coraciiformes	Meropidae	<i>Merops apiaster</i>	LC	M	.
		<i>Merops persicus</i>	LC	B	(N)
Ciconiiformes	Ciconiidae	<i>Ciconia ciconia</i>	LC	M	.
Falconiformes	Falconidae	<i>Falco tinnunculus</i>	LC	B	(N,J)
Galliformes	Phasianidae	<i>Alectoris barbara</i>	LC	B	(N, C)
	Rallidae	<i>Gallinula c. chloropus</i>	LC	B	(J)
Passeriformes	Emberizidae	<i>Emberiza sahari</i>	LC	B	(N, C, J)
	Acrocephalidae	<i>Iduna pallida</i>	LC	B	(N, C, J)
	Alaudidae	<i>Galerida theklae</i>	LC	M	.
		<i>Ammomanes deserti</i>	LC	b	?
		<i>Galerida cristata</i>	LC	b	?
	Corvidae	<i>Corvus ruficollis</i>	LC	B	(N)
	Fringillidae	<i>Bucanetes githagineus</i>	LC	B	(N, C, J)
	Hirundinidae	<i>Hirundo rustica</i>	LC	W	.
		<i>Delichon urbicum</i>	LC	W	.
	Laniidae	<i>Lanius meridionalis</i>	LC	b	?
		<i>Lanius excubitor</i>	LC	B	(N, C)
		<i>Lanius senator</i>	NT	M	.
	Motacillidae	<i>Motacilla alba</i>	LC	W	.
		<i>Anthus pratensis</i>	LC	W	.
	Muscicapidae	<i>Oenanthe leucura</i>	LC	M	.
		<i>Phoenicurus moussieri</i>	LC	b	?
		<i>Muscicapa striata</i>	LC	M	.
		<i>Cercotrichas galactotes</i>	LC	b	?
		<i>Oenanthe leucopyga</i>	LC	B	(N, C)
		<i>Ficedula hypoleuca</i>	LC	M	.
<i>Saxicola rubicola</i>		LC	W	.	
<i>Phoenicurus phoenicurus</i>		LC	M	.	
Passeridae	<i>Passer hispaniolensis</i>	LC	W	.	
	<i>Passer domesticus</i>	LC	B	(N, C, J)	
Phylloscopidae	<i>Phylloscopus sibilatrix</i>	LC	M	.	
	<i>Phylloscopus trochilus</i>	LC	M	.	
	<i>Phylloscopus collybita</i>	LC	W	.	
Sylviidae	<i>Turdoides fulva</i>	LC	B	(N, C, J)	
	<i>Sylvia melanocephala</i>	LC	W	.	
Pelecaniformes	Ardeidae	<i>Ardea alba</i>	LC	M	.
		<i>Bubulcus ibis</i>	LC	M	.
Strigiformes	Tytonidae	<i>Tyto alba</i>	LC	B	(N)

Habitat richness

The results of the bird community composition parameters (Species richness) as well as the analysis of their diversity (Shannon-Wiener index, Margalef index, Simpson index, and evenness index) are represented in table 2.

Table 2 - Avian diversity among studied habitats in Ghardaia city.

	Urban	Suburban	Rural
Number of taxa	22	33	38
Shannon–Wiener	2.542	3.26	3.819
Simpson	0.82	0.88	0.92
Margalef	2.494	3.16	3.659

Among the 44 species identified in our studied urban landscape, only 22 species were observed in the surveyed urban habitats during the 9-month study. The rural habitats scattered on the outskirts of the city were the most visited, with a total of 38 species, followed by suburban habitats with 33 species (Figure 3).

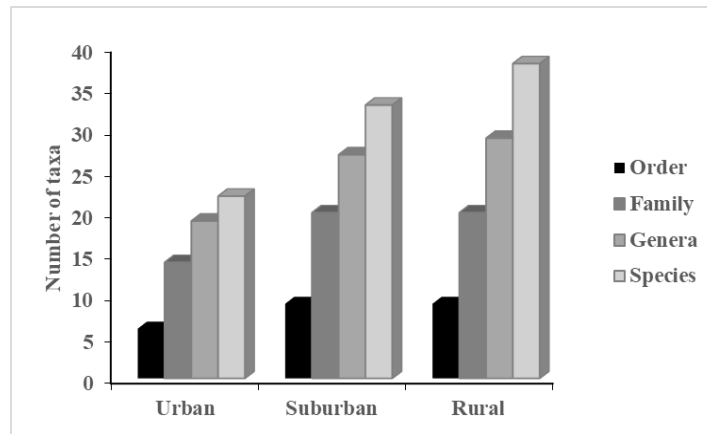


Figure 3 - Number of bird taxa identified in the Saharan urban landscape according to orders, families, genera, and species.

On the other hand, the analysis of variance (ANOVA) revealed variations in the distribution of the number of families, species, and abundance in the different sampled habitats. The test results show a highly significant variation in the number of families ($F= 19.16$, $p = 0.00001$), species ($F= 17.67$, $p = 0.00001$), and abundance ($F= 19.31$, $p = 0.00001$) among the three surveyed habitats (Table 3).

Table 3 - One-way analysis of variance ANOVA test between number of bird families species, and abundance within the three studied habitats.

Variable	Source of Variation	Df	SS	MS	F	P
Families	Between groups	2	267.629	133.81	19.16	0.00001
	Within groups	24	167.55	6.98		
	Total	26	435.18			
Species	Between groups	2	736.22	368.11	17.677	0.000019
	Within groups	24	499.77	20.82		
	Total	26	1236			
Abundance	Between groups	2	397871.18	198935.59	19.319	0.00001
	Within groups	24	247127.33	10296.97		
	Total	26	644998.51			

Discussion

The study of bird community in urban environments generally aims to highlight the negative impact of urbanization on biodiversity and habitat loss (DOUINI et al., 2022; FRAISSINET et al., 2023; XU et al., 2022; YANG et al., 2020). Our study is the first of its kind to highlight the importance of an urban landscape in a Saharan city located in the middle of a rocky desert for avian fauna. We have successfully collected new data describing the avian diversity of our urban environment and the impact of the urban gradient on the spatiotemporal occupation of these habitats by nesting birds or trans-Saharan migrants during their winter stay or stopover in the region.

In this study, the 44 bird species recorded in the three habitats over a period of nine months represent 12.57% of the 350 species mentioned by Ledant et al. (1981), which is 10.84% of the total number of species listed by Isenmann and Moali (2000). Additionally, they constitute 21.67% of the 203 species documented by Cheddad et al. (2023) during their studies on the different biotopes of the M'Zab valley over a period of seven years, between 2015 and 2022.

The avian wealth recorded in our study area appears to be the highest among all the urban areas studied in Algeria. Only 28 species were identified by Aouissi et al. (2021) between 2017 and 2018 in the city of Annaba, in the far northeast of Algeria. In the urban area of Ain Bida, in the Oum El-Bouaghi province in eastern Algeria, only 33 species were reported between 2013 and 2014 (BENCHABANE et al., 2018).

To the southeast of Tunisia, Hamza et al. (2022) reported only 33 species in Gabes, while the data published by Squalli et al. (2022) on a peri-urban area of the city of Fez, in central Morocco, show a significant avian richness of 131 species between 2018 and 2019.

Among the species recorded in the various surveyed habitats, 13 species have a migratory status, using the region as a stopover during their trans-Saharan migration. Eight species are wintering species, and 23 species have a breeding status in the region, representing 59% of the species reported as breeders by Cheddad et al. (2023) in the M'Zab Valley during seven years of studies conducted in different biotopes. Among these, 18 species actually showed signs of reproduction during the study period, such as nest detection, presence of nests with nestlings, or observation of juveniles. The other five species were present during the breeding period and reported as breeders by Cheddad et al. (2021, 2023), but without confirmation in the field during our study.

In our study, the Muscicapidae and Columbidae families represent 25% of all recorded species, with 8 and 4 species respectively. Furthermore, the order Passeriformes is the most represented in the study area, with 12 families and 29 species, which is confirmed by the results mentioned in the same region. In the M'Zab region, Muscicapidae (22 species), Scolopacidae (17 species), and Anatidae (14 species) represent 26% of the recorded species (CHEDAD et al., 2023). As for the green belt of Noumerat in the Ghardaïa region, Muscicapidae (13 species) and Alaudidae (07 species) represent 46.51% of the total number of species (CHEDAD et al., 2021).

The gradient between urban and rural habitats has a significant effect on the distribution of species, families, and bird abundance. The application of a one-way ANOVA test showed highly significant differences for the number of families ($F= 19.16$, $p = 0.00001$), species ($F= 17.67$, $p = 0.00001$), and abundance ($F= 19.31$, $p = 0.00001$) among the three studied habitats. The results indicate that rural habitats, characterized by plant diversity (palm trees, fruit trees, and vegetable crops), harbor the highest number of families and species, followed by moderately urbanized areas

containing plantations and green spaces. On the other hand, heavily urbanized habitats are less frequented by birds. These results are consistent with general trends observed for urban birds in many regions of the world (CROOKS et al., 2004; DOUINI et al., 2022).

As for the other measures of diversity, we did not observe any significant difference between the three habitats. The low values of Shannon-Wiener, Margalef, and Simpson diversity indices were attributed to the high abundance of two species, the Rock Pigeon (*Columba livia*) and the House Sparrow (*Passer domesticus*), which are considered opportunistic species in the study area.

Conclusion

In summary, this pioneering and detailed study on the avifauna of Saharan urban areas and their habitat uses demonstrates the important role it plays for nesting, wintering, and trans-Saharan migratory birds during their stopovers in this region. The significant number of breeding species in this urban landscape arouses ecological interest in this type of ecosystem for birds.

Studies related to the ornithological value of the Saharan urban landscape of trans-Saharan migratory birds, such as this paper, are recommended to be followed by regular work with periodic monitoring at a long-term scale focused on correlation between the whole communities and the majority of environmental factors to determine which ones are the most influenced on species allocations and occurrences if the situation persists at the site.

Also, it is recommended to initiate a study that analyzes the causes and implications of specific birds' proliferation in order to assure long-term management in certain ecological habitats, and to incorporate it into plans and management of these areas.

Interest conflicts

The authors declare no conflict of interest.

Authors' contribution

Affaf Guerbouz and El-Yamine Guergueb - data collection; Soumia Haddad - statistical analysis; Choayb Bounab and Oumayma Zouatine - manuscript writing; Radhia Biad - interpretation of results; Yassine Nouidjem - correction and revision.

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