RELATIONSHIPS BETWEEN VEGETATION HABITATS AND BIRD COMMUNITIES IN THE URBAN LANDSCAPES OF THE SAHARAN REGION

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Abstract. The biodiversity of urban environments is a major issue for conservation, particularly in arid areas where urban green spaces play a crucial role as refuges for wildlife. Unlike European and Mediterranean cities, the relationship between the structure of urban habitats and bird diversity remains underexplored in Saharan urban landscapes. Between October 2022 and September 2023, we conducted a study on the avifauna of the city of Ghardaïa (northern Algerian Sahara) using the point count method. Three types of habitats were distinguished along an urbanization gradient, based on the estimated percentage of vegetation cover around each point count: green spaces, intermediate environments, and built-up areas. Bird diversity was assessed through species richness, abundance, and the Shannon diversity index. Our results show that green spaces and intermediate habitats host a significantly higher avian diversity than heavily urbanized areas. Furthermore, vegetation cover and floristic richness have a positive and significant effect on species richness, abundance, and avian diversity. NMDS and PERMANOVA analyses also highlight marked differences in community composition between the different types of habitats. These results highlight the importance of green space arrangements for maintaining biodiversity in Saharan urban environments and shed light on their strategic role in sustainable urban planning in the face of increasing environmental pressures.

Keywords: algerian sahara; birds; green spaces; Ghardaia; urbain landscape.

INTRODUCTION

Highly urbanized landscapes are often perceived as biological deserts [28], due to habitat destruction, fragmentation, and homogénéisation from urban spraw. New urban systems, characterized by distinct land uses, confer a strong heterogeneity to cities, ranging from densely built areas to low-density suburban areas, often include green spaces such as private gardens or parks.

Green spaces in the city, defined as fragmented and discontinuous vegetation areas within the urban environment [2, 27, 33], and considered as the last remnants of nature in urban areas [19], can play an important role in the conservation of a portion of biodiversity in urban environments [7, 22] as they provide available habitats for a wide variety of organisms [24], particularly for birds [2].

Birds, as a main component of urban biodiversity [34], are considered good indicators of the effects of urbanization on biodiversity [18] due to their sensitivity to specific habitat characteristics, showing significant variability depending on the types of urban land use [9].

The interaction between avian diversity and vegetation in natural environments has become a critical area of research in recent years [17, 23]. Urban plant communities, through their ecosystem services and their roles for the diversity of avian communities in urban environments, make the launch of such studies in urban settings particularly essential [18].

Saharan cities, despite their location in the middle of the arid desert and their exposure to extreme climatic conditions, exhibit remarkable plant diversity. The urban landscape of Timentit, located in the extreme southwest of Algeria (GPS: 32°28'N, 3°42'E), hosts a floral richness of 32 plant species associated with urban green spaces, according to data provided by Souddi and Bouallala [29]. This richness gives these urban landscapes scattered throughout the Sahara the role of ecological islands in the desert, promoting the establishment of breeding bird populations in the region as well as trans-Saharan migratory species [15].

In this study, we analyze avian communities within the urban tissue of Ghardaïa (Algeria), examining three types of urban habitats: green spaces, intermediate zones, and built-up areas. The objective is to understand how the characteristics of green spaces (size and structure of vegetation), those of the surrounding landscape (area occupied by urban structures and vegetation, floristic diversity), influence species richness, abundance, and the composition of bird communities.

MATERIALS AND METHODS

Study area

Our study was conducted in the northern Sahara of Algeria, in the city of Ghardaïa (32°28'N, 3°42'E), located about 600 km south of the capital, Algiers. This city covers an area of 1,802.4 km² [15]. The climate is arid, characterized by an average annual temperature of 23.27 °C and average annual precipitation of 80.10 mm. The region experiences mild winters and particularly hot summers [5, 16]. The population of the city is 220,310 inhabitants, with a density of 122 inhabitants per km² [14] (Fig. 1).

Data collection

Between October 2022 and September 2023, the study was conducted in the urban tissue of the Ghardaïa city, including small public gardens, green spaces surrounding urban sites, as well as private crops. We used the point counts method, with a radius of 25 m

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around each point [35] and a minimum distance of 200 m between two points [15, 21]. Each point was regularly visited twice a month, starting 30 minutes after sunrise and until 10 a.m. [20], with a sampling duration of 10 to 15 minutes per point [13].

The classification of the different habitats in our urban landscape is primarily based on the percentage of vegetation cover visually estimated around the listening points. This estimation was carried out in the field within a radius of 25 m, taking into account the area occupied by vegetation and recording the different plant species present within this radius [3].

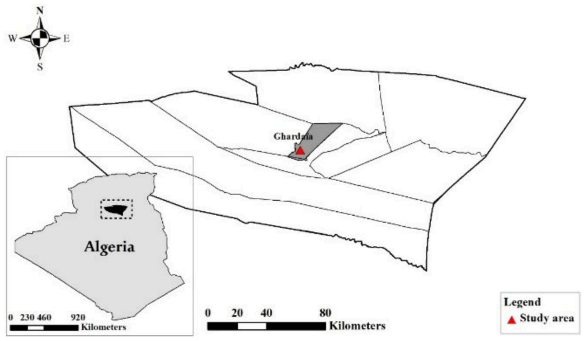

Figure 1. Study area map.

Data analysis

In this study, all bird species recorded in the study area were classified according to their family. The reproductive status of these species (breeding or non-breeding) was determined based on the work of Bekakra *et al.* [3], Guerbouz *et al.* [15], Chedad *et al.* [8], and Isenmann and Moali [17]. To compare bird diversity among different types of urban landscape environments (green spaces, intermediate areas, and built-up zones), several population parameters were considered: the Shannon-Wiener diversity index (H′), abundance, species richness, and frequency of occurrence of species. The non-parametric Kruskal-Wallis test was applied to assess differences in bird diversity among environmental types. Additionally, non-metric multidimensional scaling (NMDS) was used to explore differences in bird assemblage composition based on environmental types. Permutational Multivariate Analysis of Variance (PERMANOVA) was then used to statistically test these compositional differences [1]. Finally, simple linear regression was employed to examine the effect of two structural factors—vegetation cover and vegetaion richness—on birds richness, abundance, and the Shannon diversity index. All analyses were performed using R software, version 4.5.0.

RESULTS

In total, during the study period, we recorded 44 bird species belonging to ten orders, 22 families, and 32 different genera. The Muscicapidae family was the most represented, with eight species, followed by the Columbidae with four species, and then the Alaudidae and Phylloscopidae, each with three species (Table 1).

A Venn diagram (Fig. 2) shows that, among the 44 species recorded in the studied landscape, 19 are common to the three types of environment. Ten species are shared between green spaces and intermediate environments, while three species are common to intermediate environments and highly built environments (built-up). Furthermore, ten species are exclusive to green spaces, and two species are only present in the built-up environment.

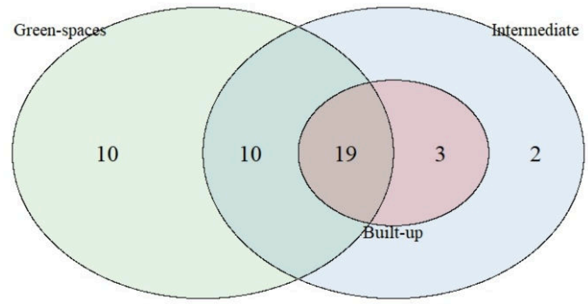

Figure 2. Venn diagram of species richness among the three envirenments (Built-up, Green spaces, and Intermediate)

Out of the bird species recorded, 21 (or 47.72%) do not have breeding status in the study area, while more than 52% are species that breed in the Ghardaïa region.

The frequency of occurrence of the bird species observed in the three types of environments shows that only three species are ubiquitous across all surveyed sites, namely the Rock Pigeon, the Eurasian Collared-Dove, and the House Sparrow (Table 1). These species have been recorded in all three environments: green spaces, intermediate areas, and built-up zones.

The results of the Kruskal-Wallis analysis assessing the effect of environment type on bird species richness (S), abundance (A), and diversity (H’) revealed significant differences among the three environment types for all three metrics: species richness ($p < 0.001$), abundance ($p < 0.001$), and species diversity (H’) ($p < 0.001$) (Fig. 3).

The NMDS analysis reveals a partial separation of bird communities between green habitats and built-up areas, indicating a significant influence of habitat type on the composition of avian populations but differences are ecologically moderate (Fig. 4).

The assembly of birds in the urban landscape of the city of Ghardaia varied significantly between different environments (PERMANOVA: $F_{2,258} = 25.571$, $p = 0.001$). airwise comparisons among the three habitat types (green spaces, intermediate, and built-up areas) confirmed significant differences in bird community composition, as shown by pairwise PERMANOVA results (Table 2).

In order to examine the relationship between species richness, abundance, and bird diversity with the structure of green spaces (vegetation cover and vegetation richness), the results of the simple linear regression indicate that both vegetation cover and the vegetation richness have significant and positive effects on all diversity indicators (species richness, abundance,

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Table 1. Bird breeding status (b: breeding, non-b: non breeding), and frequency of occurrence of recorded species in Ghardaia city.

Scientific name	Family	Breeding status	Frequency of occurrence (%)		
			Green-spaces	Intermediate	Built-up
Apus apus	Apodidae	non-b	0	1.23	7.14
Upupa epops	Upupidae	b	44.44	3.70	0.79
Columba livia	Columbidae	b	100	100	100
Streptopelia decaocto		b	100	100	100
Streptopelia senegalensis		b	57.40	59.25	45.23
Streptopelia turtur		b	51.85	27.16	10.32
Merops apiaster	Meropidae	non-b	12.96	3.70	0
Merops persicus		b	9.26	2.46	0
Ciconia ciconia	Ciconiidae	non-b	12.96	0	0
Falco tinnunculus	Falconidae	b	25.92	3.70	5.55
Alectoris barbara	Phasianidae	b	37.03	0	0
Gallinula chloropus	Rallidae	b	0	17.28	0
Emberiza sahari	Emberizidae	b	37.03	92.59	99.20
Iduna pallida	Acrocephalidae	b	7.41	2.46	0
Galerida theklae	Alaudidae	non-b	11.11	1.23	0
Ammomanes deserti		b	8.52	4.94	0
Galerida cristata		b	37.03	0	0
Corvus ruficollis	Corvidae	b	31.48	1.23	0.79
Bucanetes githagineus	Fringillidae	b	22.22	16.05	0.79
Hirundo rustica	Hirundinidae	non-b	0	9.87	1.58
Delichon urbicum		non-b	11.11	11.11	3.17
Lanius meridionalis	Laniidae	b	37.03	0	0
Lanius excubitor		b	46.29	12.34	0.79
Lanius senator		non-b	12.96	3.70	0
Motacilla alba	Motacillidae	non-b	1.85	19.75	7.14
Anthus pratensis		non-b	9.26	0	0
Oenanthe leucura	Muscicapidae	non-b	57.40	8.64	0
Phoenicurus moussieri		b	7.41	8.64	0
Muscicapa striata		non-b	7.40	18.52	1.59
Cercotrichas galactotes		b	12.96	0	0
Oenanthe leucopyga		b	85.18	75.31	57.94
Ficedula hypoleuca		non-b	16.66	6.17	0.79
Saxicola rubicola		non-b	22.22	0	0
Phoenicurus phoenicurus		non-b	16.66	0	0
Passer hispaniolensis	Passeridae	non-b	12.96	24.69	31.74
Passer domesticus		b	100	100	100
Phylloscopus sibilatrix	Phylloscopidae	non-b	7.41	9.87	0
Phylloscopus trochilus		non-b	12.96	0	0
Phylloscopus collybita		non-b	1.85	0	0
Turdoides fulva	Sylviidae	b	70.37	25.93	3.17
Sylvia melanocephala		non-b	53.70	2.47	0.79
Ardea alba	Ardeidae	non-b	0	6.172	0.79
Bubulcus ibis		non-b	1.23	0	0
Tyto alba	Tytonidae	b	27.77	2.47	0

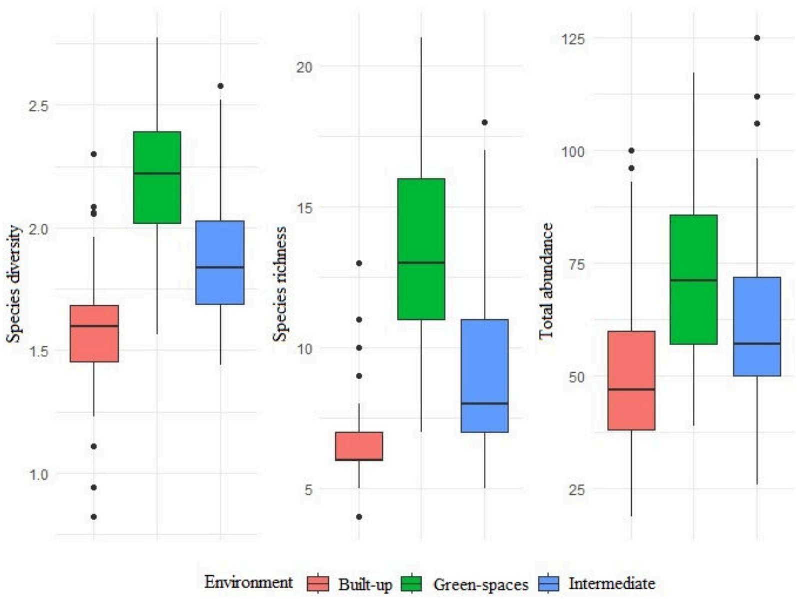

Figure 3. The abundance (A), species richness (B), and species diversity of birds in Built-up, Green spaces, and Intermediate (C).

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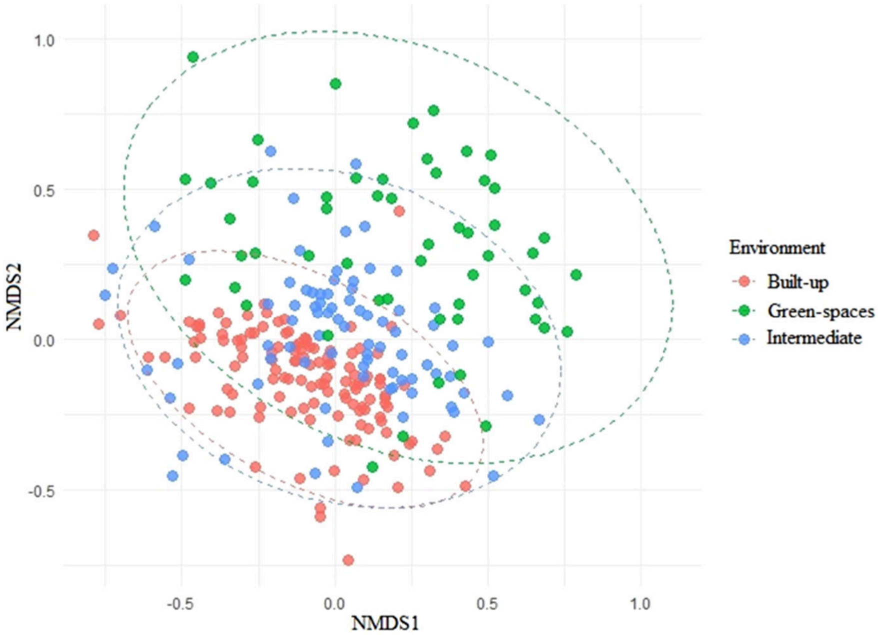

Figure 4. Nonmetric multidimensional scaling (NMDS) analysis ordination biplot based on Bray-Curtis coefficient of similarities

Table 02. Pairwise PERMANOVA result for bird assemblages among the three sampled habitats: Green-spaces, Intermediate and Built-up).

Combinations	R^2	F	*p*
Built-up – Intermediate	0.059	12.854	0.001 **
Built-up – Green-spaces	0.210	47.215	0.001 **
Intermediate – Green-spaces	0.112	16.752	0.001 **

and Shannon index) (Fig. 5; Table 3). Species richness appears to be the most sensitive indicator to plant complexity, with determination coefficients of R^2 = 0.459 for vegetation richness and R^2 = 0.466 for vegetation cover. However, although these effects are statistically significant, the amount of variance in abundance explained by vegetation is relatively low (R^2 = 0.108) (Table 3), this suggests that the ecological impact of plant structure on abundance is modest. Therefore, while vegetation contributes to differences in bird communities, the overall ecological separation between habitats remains limited.

DISCUSSION

The ornithological inventories conducted across all green spaces of the studied urban landscape identified 44 bird species, representing 10.84% of the species reported in Algeria by Isenmann and Moali [17], as well as 21.50% of the species recorded throughout the M'Zab valley between 2015 and 2022 according to Chedad *et al*. [8]. This number also corresponds to nearly all the species observed by Bekakra *et al*. [3] and Guerbouz *et al*. [15] in the same region.

According to numerous studies conducted in Europe[10, 30, 32], in Asia [12, 34] and in America [4, 26, 11], notably that of Norfolk *et al*. [25] on the migration of trans-Saharan birds in the Saharo-Arabian belt in Egypt, it has been shown that wetlands and, in particular, the green spaces of the city of Sainte-Catherine host 26 bird species out of the 34 recorded in the entire study, i.e., 76.47%. Among these, 17 species were observed exclusively in urban green spaces characterized by a complex vegetation structure, composed of fruit trees, market gardening crops, and ornamental plants. In the same context, it was found that bird diversity in the urban areas of Ghardaïa is significantly higher in green spaces with a high percentage of vegetation cover, whether in terms of species richness, abundance, or Shannon diversity index.

Moreover, the specific richness of birds varied significantly depending on the vegetation cover in the different types of urban environments in Ghardaïa, as well as on the number of plant species recorded at the sampling points (50 m radius). These results confirm those of several previous studies, which highlighted close links between different measures of vegetation complexity (such as vegetation cover, NDVI, tree cover, and leaf area index) and the diversity as well as abundance of bird communities in urban environments [6, 11, 31].

The urban landscape of the city of Ghardaïa is home to 20 nesting forest species present in the region, representing 40% of the nesting species recorded by Chedad *et al*. [8] throughout the M'Zab Valley. Furthermore, 24 species of trans-Saharan migratory birds have been observed there, highlighting the essential role of this urban environment as an isolated refuge ("ecological island") within the rocky desert, located on the central migratory pathway of birds. By providing structured habitat and food resources, this space contributes to the maintenance of migratory and resident bird communities.

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This study highlights the crucial role of green spaces in maintaining avian diversity within the Saharan urban landscape. Vegetation cover and vegetation richness appear as determining factors positively influencing species richness, abundance, and diversity birds. The differences in composition between habitats confirm the importance of the structure of the urban environment on avian assemblages. These results emphasize the need to integrate more vegetated arrangements into urban planning. They thus provide essential elements to promote more sustainable Saharan cities that are conducive to biodiversity conservation.

Conflict of interest. There is no actual or potential conflict of interest in relation to this article.

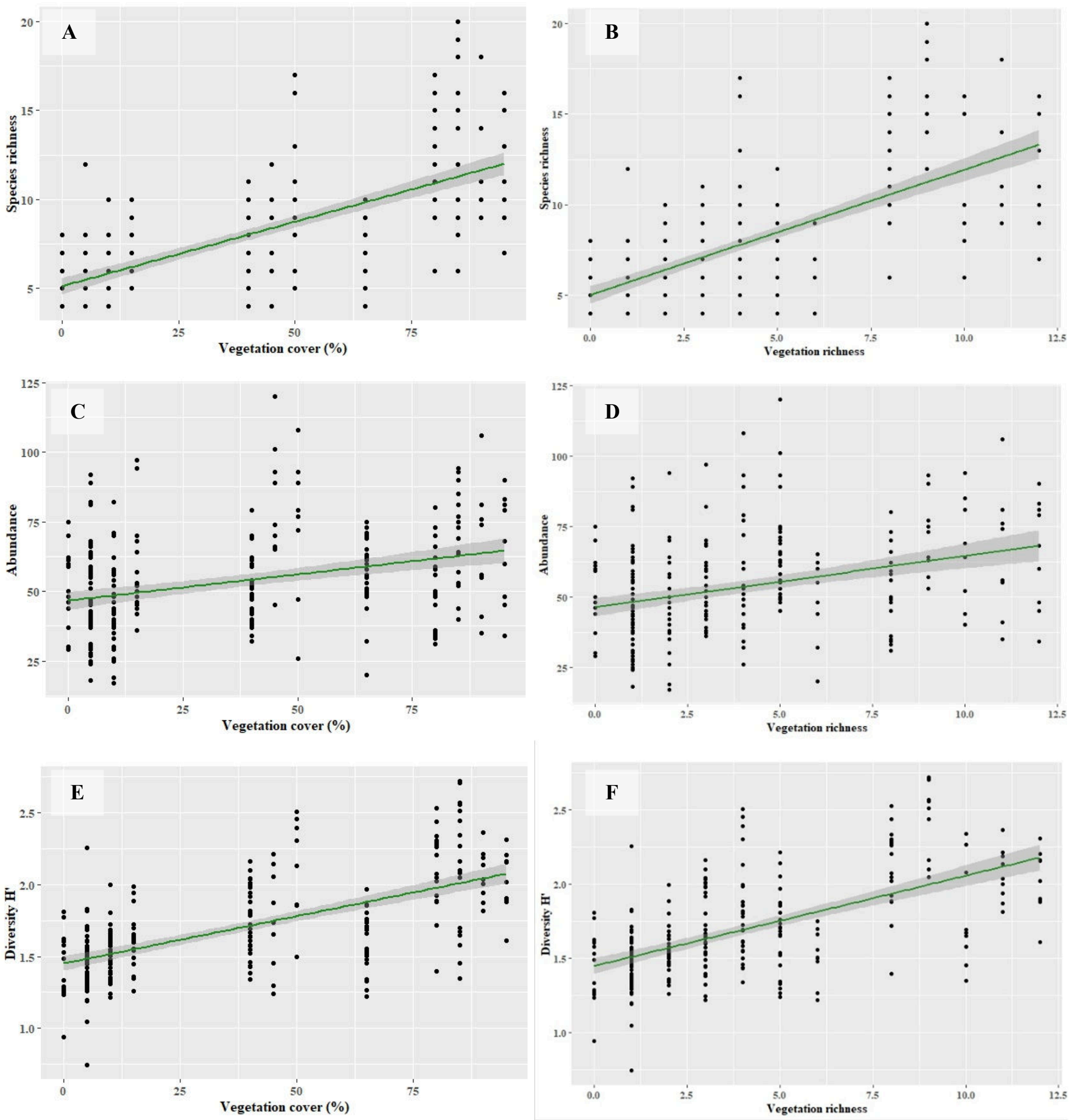

Figure 5. Relationships between bird species richness(A–B), Abundance (C–D) and bird diversity (H') (C–D) and the most associated variables: Vegetation cover and vegetation richness.

Table 3. Results of simple linear regressions between bird diversity indicators (species richness, abundance, and Shannon index) and plant structure variables (vegetation cover and floristic richness).

Variables	R²	F-statistic	*p*-value
Vegetation richness			
Diversity H'	0.354	142	< 0.001 ***
Abundance	0.108	31.51	< 0.001 ***
Bird richness	0.459	219.6	< 0.001 ***
Vegetation cover			
Diversity H'	0.380	159.1	< 0.001 ***
Abundance	0.108	31.33	< 0.001 ***
Bird richness	0.466	225.7	< 0.001 ***

*** : highly significant

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