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Effect of the structural composition of a Saharan agricultural landscape on bird communities in the Algerian Northen Sahara

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Abstract

In this study, we examined the diversity of bird populations in an agricultural environment in Northern Algerian Sahara (Ghardaia province) over a period of 9 months. Using the point count technique, we collected data on birds at different levels of vertical stratification based on the number of cultivated plant species. An analysis of variance was used to assess the impact of plant strata number and cultivated species number on species richness and bird abundance. During this study, 35 bird species belonging to 7 orders and 18 families were identified. The highest values of Shannon-Wiener diversity index (*H'* = 2.804), Simpson index (*D* = 0.913), and Margalef index (*D* = 4.761) were observed in the most complex areas. The differences in the number of species and abundance were significant between the different levels of complexity in agricultural environments, with areas having three vertical plant strata (trees, shrubs, and herbaceous plants) and a greater number of cultivated plant species hosting the highest number of bird species and displaying high populations.

Key words: agroecosystem, arid environment, diversity index, Ghardaia, vertical stratification.

Introduction

Agroecosystems cover about 40 % of Earth's land surface (Allen et al. 2022) and cover almost half European Union's surface (Bakış et al. 2021), forming one of the most important terrestrial biomes (Foley et al. 2005). Such man-made ecosystems may comprise a variety of ecological conditions and habitats suitable havens for various living beings (Eriksson 2021).

The traditional agroecosystems in

the North African arid and semi-arid regions are the most biotically diversified in the world, the majority being constituted of small private gardens (Sellami 2008). These agricultural lands represent semi-natural ecosystems that may be very complex and include three layers of crops: date palm, fruit trees, and market gardening, surrounded by a harsh desert environment (Mellink 1991, Selmi 2007). The combination of layers of crops in these agricultural landscapes has been found to have a very peculiar and high level of fauna and flora (Tscharntke et al. 2011, Haggar et al. 2019).

Agriculture is a driver decline in global biodiversity and ecosystem degradation than any other sector (Foley et al. 2005, Muñoz-Sáez et al. 2017), including birds (Mellink et al. 2016). According to IUCN data about 60 % of birds included in Red List are threatened by extinction (Johnson et al. 2011, Piratelli et al. 2019) and almost 39 % of farmland bird populations have declined (Gianpasquale and Alberto 2019, Mäkeläinen et al. 2019).

Birds use Saharan agroecosystems for resting and feeding during their trans-Saharan migrations (Lavee et al. 1991, Guezoul et al. 2013), and nesting and foraging during the breeding season (Mellink 1991, Johnson et al. 2011). They play a critical role in these ecosystems, including seed dispersal and pest control (Mulwa et al. 2012). Birds in agricultural environments are a bioindicator of agricultural sustainability (Kross et al. 2016, Muñoz-Sáez et al. 2017).

Several factors influence the structure of avian communities (richness and abundance) in Saharan agroecosystems, including landscape composition (Naidoo 2004, Muñoz-Sáez et al. 2017), habitat change (Shachak et al. 2005, Laube et al. 2008, Chillo et al. 2015) crop type and their structural heterogeneity (Muñoz-Sáez et al. 2017).

The present study aims to establish the diversity of bird populations in an agricultural environment in Northern Algerian Sahara. To achieve the goal, we set ourselves the following 3 tasks: 1) to describe the avian diversity (species richness and abundance) of a Saharan agricultural landscape; 2) to assess the effects of crop change on the spatial distribution of bird species and their densities; and 3) the role of vertical stratification of vegetation (date palm, fruit trees, and market gardening) on the aggregation of bird populations.

Material and Methods

Study area

This study was carried out in El-Guerrara region (in Central Algeria, north of the Sahara, 600 km south of Algiers). This area is located within the geographical position of 32°45′70″ to 32°46′30″ northern latitudes and 04°27′ to 04°33′ eastern longitudes (Guergueb et al. 2024). The climate is arid, characterised by mild winters and hot, dry summers (mean annual temperature 23.27 °C, yearly mean rainfall 80.10 mm) (Bounab et al. 2024, Nedjar et al. 2024).

The study area is an agricultural landscape comprising a 200-hectare mosaic of small private fields (Fig. 1). The vegetation is dominated by date palms (*Phoenix dactylifera* L.), along with fruit trees such as olive, pomegranate, and orange trees. Market gardening is also common, featuring various vegetable crops, including tomatoes, peppers, and cucumbers. Additionally, spontaneous herbaceous plants grow naturally in the uncultivated spaces.

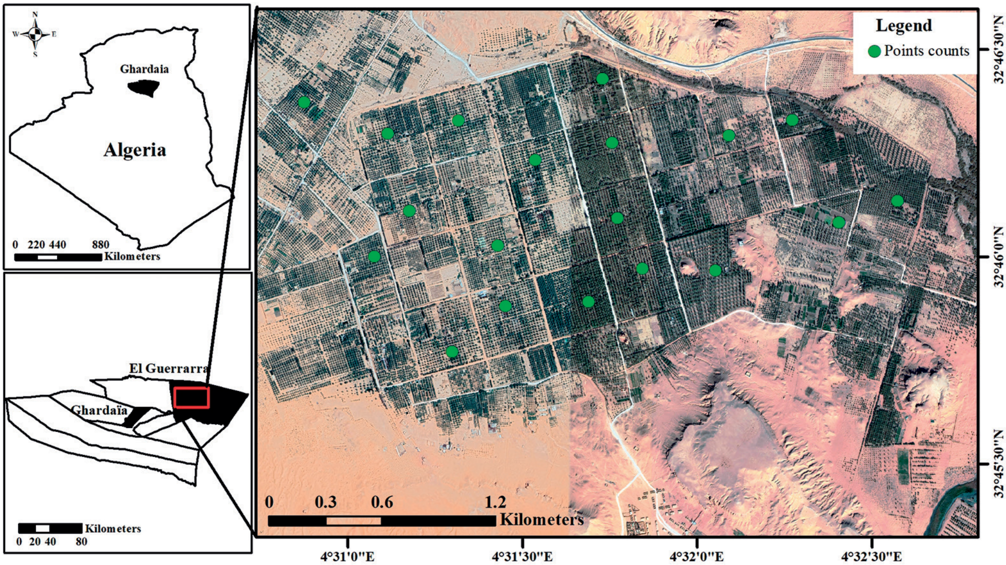

Fig. 1. Study area map with sampling locations.

Bird sampling

We collected our data between October 2022 and June 2023, and bird communities were estimated using the point-count sampling method (Bibby et al. 2000). Nineteen point count sites were randomly distributed to cover the entire study area (radius 50 m, each spaced 300 m apart) (dos Anjos et al. 2011, Hiron et al. 2013, Hamza and Hanane 2021). Each point has a bi-monthly visit, between 30 min before sunrise and 4 h after (Kang et al. 2015, Bouam et al. 2017) to coincide with periods when birds are most active (Terraube et al. 2016). Each point was surveyed for 10 min (Marsden et al. 2001, Jacoboski et al. 2016, Hanane et al. 2019). During this period we recorded all birds seen or heard (Sweeney et al. 2010, Boesing et al. 2018).

To assess the impact of the structural complexity of each habitat (defined by the number of cultivated species and number of vertical strata of vegetation) on avian communities, it is necessary to conduct a comprehensive inventory of cultivated species within a 50 m radius around the observation points. These cultivated species should be categorised into three vertical strata: trees taller than 2 m (such as date palms), shrubs between 50 cm and 2 m (such as fruit trees), and ground cover under 50 cm (such as crops in market gardening).

Data analysis

We categorised the bird species based on their trophic guilds (Granivore, Insectivore, Omnivore, Carnivorous) following Svensson et al. (2012) and their phenological status (Wintering, Breeding, Migration) using the following sources: The Sibley Guide to Birds (Sibley 2014), and their conservation status was determined (LC: Least Concern), (IUCN 2023).

The diversity indices of species, such as Shannon-Weiner index (*H*′) (Spellerberg and Fedor 2003), Simpson index (*D*) (Simpson 1949), and Margalef index (*D*) (Magurran 1988) have been calculated to compare species diversity and abundance among the complexity levels of the vertical stratification of the agroecosystem using a one-way analysis of variance (ANOVA). In addition, a two-factor ANOVA was conducted to test the variations in bird richness and abundance based on the number of vegetation strata (one stratum, two or three strata) and the number of cultivated plant species. The R software was used for the analyses.

Results

Species diversity

During the nine months of study, a total of 35 species was encountered in the different surveyed habitats belonging to 7 orders, 18 families, and 27 genera. The order Passeriformes is the most represented with 12 families and 25 species, followed by Columbiformes with 4 species. The Coraciiformes have 2 species. The Pelecaniformes, Bucerotiformes, Falconiformes, and Strigiformes are weakly represented by one species each (Table 1).

Table 1. Bird phenology status, trophic guild, and conservation status of recorded species.

Family	Scientific name	Ecological status			Occupied habitats		
		PhS	TG	CS	low	medium	high
Ardeidae	*Bubulcus ibis* (Linnaeus, 1758)	M	I	LC	+	+	+
Falconidae	*Falco tinnunculus* (Linnaeus, 1758)	B	Cr	LC	+	-	+
Columbidae	*Columba livia* (Gmelin, JF, 1789)	B	G	LC	+	+	+
	Streptopelia decaocto (Frivaldszky, 1838)	B	G	LC	+	+	+
	Streptopelia senegalensis (Linnaeus, 1766)	B	G	LC	+	+	+
	Streptopelia turtur (Linnaeus, 1758)	B	G	VU	-	+	+
Tytonidae	*Tyto alba* (Scopoli, 1769)	B	Cr	LC	+	-	-
Meropidae	*Merops apiaster* (Linnaeus, 1758)	M	I	LC	-	-	+
	Merops persicus (Pallas, 1773)	B	I	LC	-	+	+
Upupidae	*Upupa epops* (Linnaeus, 1758)	B	I	LC	+	+	+
Alaudidae	*Ammomanes deserti* (Lichtenstein, MHC, 1823)	B	I	LC	+	-	-
	Galerida cristata (Linnaeus, 1758)	B	G	LC	+	-	+
	Galerida theklae (Brehm, AE, 1857)	M	G	LC	+	+	-
Hirundinidae	*Hirundo rustica* (Linnaeus, 1758)	W	I	LC	+	+	+
Motacillidae	*Anthus pratensis* (Linnaeus, 1758)	W	I	LC	-	+	+
	Motacilla alba (Linnaeus, 1758)	W	I	LC	-	-	+

Family	Scientific name	Ecological status			Occupied habitats		
		PhS	TG	CS	low	medium	high
Muscicapidae	*Cercotrichas galactotes* (Temminck, 1820)	B	I	LC	-	+	+
	Ficedula hypoleuca (Pallas, 1764)	M	I	LC	-	+	+
	Muscicapa striata (Pallas, 1764)	M	I	LC	-	+	+
	Oenanthe leucopyga (Brehm, 1855)	B	I	LC	+	+	+
	Oenanthe leucura (Gmelin, 1789)	M	I	LC	+	+	+
	Phoenicurus moussieri (Olphe-Galliard, 1852)	B	I	LC	-	+	+
	Saxicola rubicola (Linnaeus, 1766)	W	I	LC	-	+	-
Sylviidae	*Argya fulva* (Desf, 1789)	B	I	LC	+	+	+
	Curruca melanocephala (Gmelin, 1789)	W	I	LC	+	+	+
Acrocephalidae	*Iduna pallida* (Hemprich & Ehrenberg, 1833)	B	I	LC	-	+	+
Phylloscopidae	*Phylloscopus collybita* (Vieillot, 1817)	W	I	LC	-	+	+
	Phylloscopus sibilatrix (Bechst, 1793)	M	I	LC	-	+	+
	Phylloscopus trochilus (Linnaeus, 1758)	M	I	LC	-	+	+
Laniidae	*Lanius excubitor* (Linnaeus, 1758)	B	I	LC	+	+	+
	Lanius meridionalis (Temminck, 1820)	B	I	LC	-	-	+
Corvidae	*Corvus ruficollis* (Lesson, 1831)	B	O	LC	+	-	-
Passeridae	*Passer domesticus* (Linnaeus, 1758)	B	O	LC	+	+	+
Fringillidae	*Bucanetes githagineus* (Lichtenstein, MHC, 1823)	B	G	LC	+	+	+
Emberizidae	*Emberiza sahari* (Levaillant, 1850)	B	G	LC	+	+	+

Note: PhS: phenology status, B: breeding, W: wintering and M: migrant; TG: trophic guild, I: insectivorous, G: granivorous, O: omnivorous, Cr: carnivorous; CS: conservation status, LC: least concern, VU: vulnerable (IUCN 2023); -: absent species, +: present species.

In terms of species recorded by family, the most represented families are Muscicapidae with 18 % of the total number of species, followed by the family Columbidae with 12 %, the family Phylloscopidae and Alaudidae with 9 %. The families Sylviidae, Laniidae, Motacillidae and Meropidae, each account for 6 % of the species (Fig. 2).

The documented species as a whole have different phenological statuses. Among them, 60 % are breeding, 23 % are migratory, and 17 % have a wintering status in the region.

Regarding trophic guilds, Insectivorous represented 65 % (23 species) of the total avifauna, Granivorous were listed with 8 species (23 %). Omnivorous and Carnivorous included 2 species, 6 % of all recorded birds.

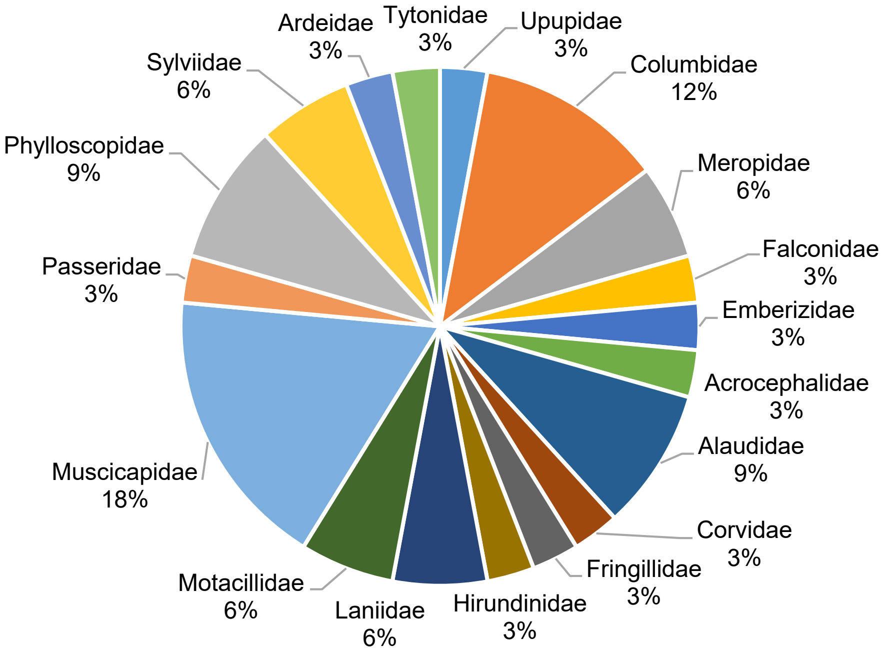

Fig. 2. Species richness and percentage of avian families recorded in El-Guerrara agroecosystem.

According to the BirdLife Red List (IUCN 2023), 97 % of reported species have a conservation status of LC (Least Concern) (Table 1).

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.

Among the 35 species identified in our studied agroecosystems, only 20 species were observed in the least complex environments with a monoculture (one vegetation layer) during the study. Habitats with a more or less high level of complexity with two cultivated vegetation layers have a bird richness of 27 species. The sites with a high structural complexity, combining three vegetation layers and larger cultivated plant species, were the most visited, with a total of 30 species (Table 2).

A Venn diagram (Fig. 3) shows that, during our study period, three bird species were considered exclusive to low structur-

Table 2. Avian diversity among studied habitats.

Indicator	Low complexity	Medium complexity	High complexity
Number of taxa	20	27	30
Shannon-Wiener	2.284	2.591	2.804
Simpson	0.861	0.894	0.913
Margalef	3.458	4.192	4.761

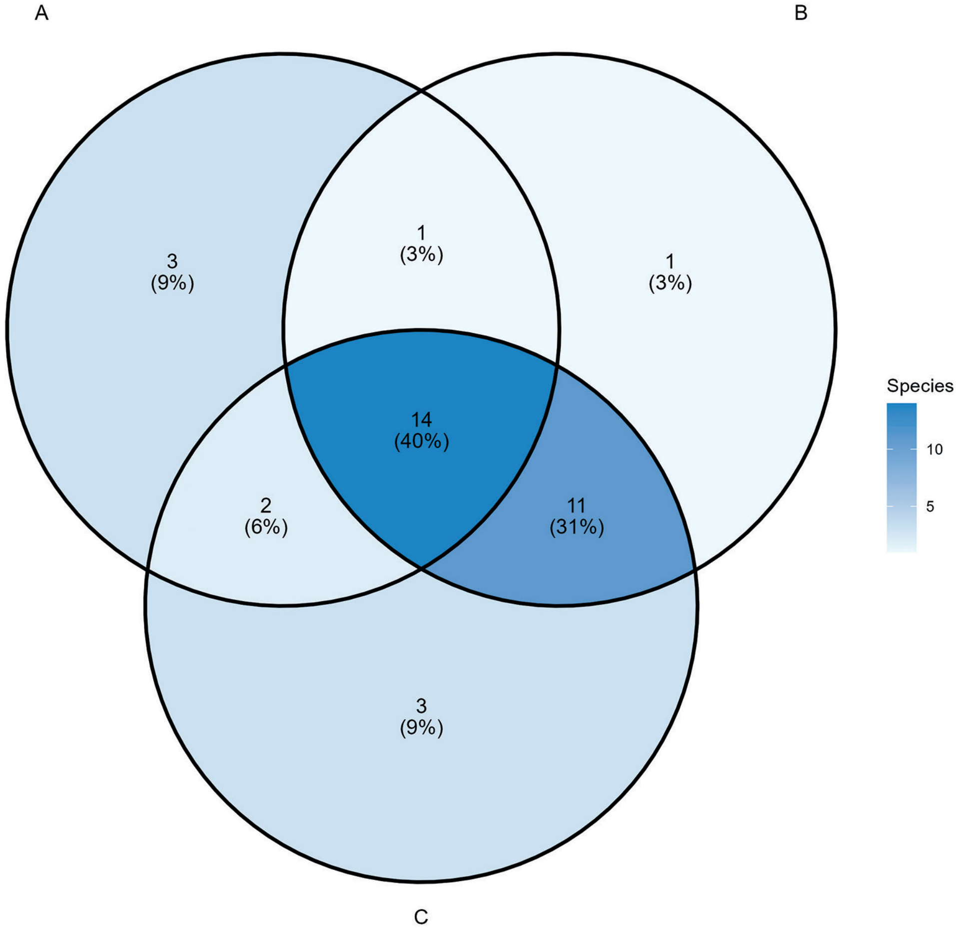

Fig. 3. Venn diagram of species richness among the three levels of crop complexity: A) low complexity, B) medium complexity, C) high complexity.

al complexity plots, one species to medium complexity plots, and three species in the most complex areas. High and medium complexity areas shared 11 species, or 31 % of all species encountered, while low complexity areas shared one species with medium complexity areas and two species with high complexity areas. Finally, 14 species (40 %) were present in all three levels of complexity.

In total, we recorded 1592 birds distributed across the studied zones, with the species having the largest numbers of individuals being the Rock Pigeon (*Columba livia* Gmelin, JF; $n = 369$), the House Sparrow (*Passer domesticus* L.; $n = 351$), the House Bunting (*Emberiza sahari* J. Levaillant; $n = 169$), and the Tawny Rock Thrush (*Argya fulva*; $n = 139$). However, the different studied habitats were dominated by the same species (Fig. 4).

The application of one-way ANOVA test showed highly significant differences for the number of species ($F = 12.47$, $p = 0.000013$) and for abundance ($F = 15.79$, $p = 0.000001$) among the three

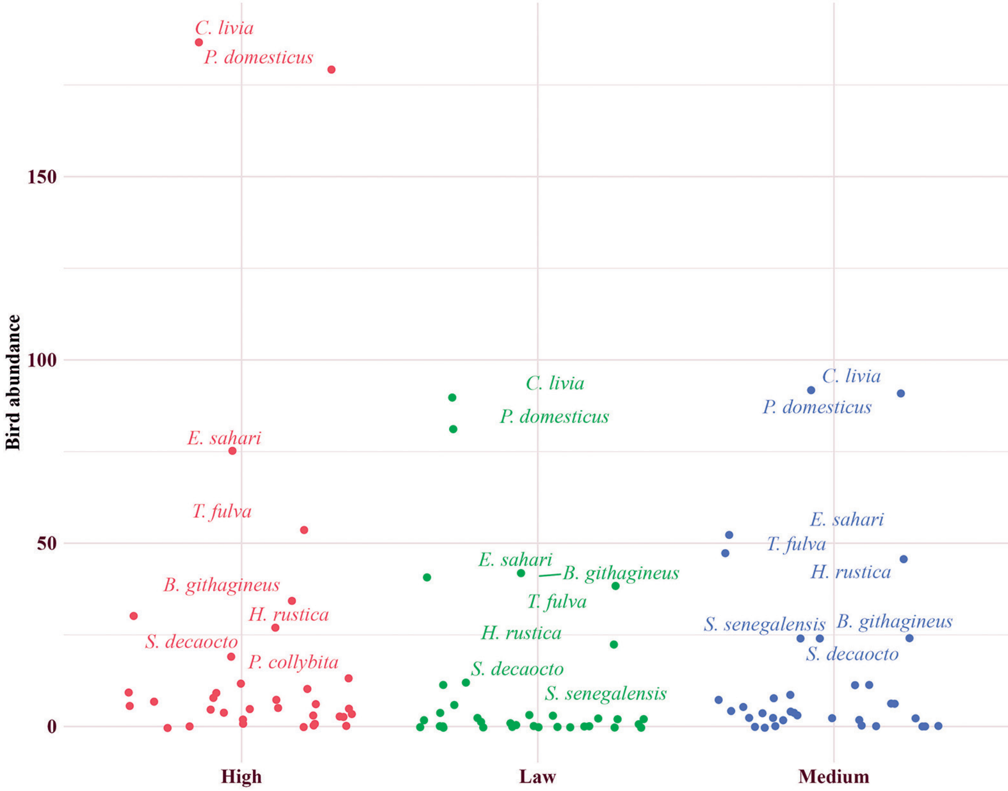

Fig. 4. Rank abundance plot, evidencing the most abundant bird species recorded.

studied habitats. In order to understand the effect of the number of layers and the number of cultivated plant species on bird richness and abundance, we conducted a two-factor ANOVA analysis. The number of layers has a highly significant effect on bird richness (p=0.0000) and on bird abundance (p=0.0000). The crops richness has a significant effect only on bird abundance (p=0.006), and the interaction (number of layers-crops richness) has no significant effect on either bird richness or abundance (Table 3).

Discussion

Our original results on the avian diversity of agricultural environments in a Saharan region located in the middle of a rocky desert show that these environments and their structural complexity play a crucial role in the species richness, abundance, and spatio-temporal occupation of these habitats by breeding birds or trans-Saharan migrants, whether during their winter stay or their passage through the region.

A total of 35 bird species were recorded in the different levels of structural complexity of the agricultural landscape over the nine months, representing 10 % of the 350 species listed by Ledant et al. (1981), or 17.24 % of the total number of species documented by Chedad et al. (2023) after five years of study in the same region. These results are similar to those mentioned by Guerbouz et al. (2024) during their survey of bird populations in rural

Table 3. Two-way ANOVA testing variation of number of species and abundance according to layers, crops richness and their interaction.

Variable sources	Df	SS	MS	*F*	*p*
Species					
Layers	1	110.1	110.14	16.568	0.0000887
Crops richness	1	7.9	7.94	1.195	0.2767
Interaction	1	23.1	23.14	3.480	0.0648
Residuals error		731.2	6.65		
Abundance					
Layers	1	4098	4098	14.682	0.000212
Crops richness	1	2117	2117	7.584	0.006891
Interaction	1	496	496	1.778	0.185132
Residuals error	110	30704	279		

Note: Df is Degrees of Freedom, SS is Sum of Squares, MS is Mean Square.

habitats along an urban gradient in the city of Ghardaia, during the same period (38 species).

The avian richness recorded in our study area seems to be more or less comparable to that of other studied Saharan agroecosystems in Algeria. Guezoul et al. (2013) documented 47 species in the oases of Biskra in 2006, 44 species in the oases of Ouargla in 2008, and 33 species in the same habitats of Oued Souf region in 2009, with a total richness of 59 species in this region of the northeastern Algerian Sahara.

Ababsa et al. (2013), during their surveys in Ouargla region, mentioned that the total richness recorded in Mekhadema palm grove is 34 species, while only 28 species were inventoried at Hassi Ben Abdallah station, with a total richness of 43 species in the region.

Among the 35 species recorded in the surveyed agricultural environment, the species with reproductive status are the most abundant – 21. This represents over 50 % of the species with same status reported by Chedad et al. (2023), and similar to the results published by Guerbouz et al. (2024), collected during the same period in the urban gradient of the city of Ghardaia. Eight species have a migratory status, using the region as a stopover during their trans-Saharan migration, and six species are wintering in the region.

In the present study, we report the dominance of Muscicapidae and Columbidae, representing 30 % of the total number of species recorded, with 7 and 4 species respectively. Furthermore, the order Passeriformes is the most represented in the study area, with 12 families and 25 species. The city of Ghardaia hosts 8 species from the Muscicapidae family and 4 species from the Columbidae family, accounting for 25 % of the species encountered (Guerbouz et al. 2024). In the same region, according to Chedad et al. (2021), the avian population of the Noumerat green belt is dominated by Muscicapidae (13 species) and Alaudidae (7 species), representing 46.51 % of the total number of species. In M’Zab region, Muscicapidae (22 species), Scolopacidae (17 species), and Anatidae (14 species) represent 26 % of all reported species (Chedad et al. 2023).

The structural complexity of habitats studied, due to the number of layers, has a significant effect on species distribution and bird abundance. The results indicate that habitats with a high level of complexity, characterised by the presence of the three vertical layers of crops and a more or less high number of cultivated plant species (palms, fruit trees, and vegetable crops), host the greatest number of species, followed by moderately and weakly complex areas. These results confirm the general trends observed by Ababsa et al. (2013), who linked the high avian richness of Mekhadema station in Ouargla to the great plant heterogeneity of this station, as well as the work of Blondel et al. (1973) and Blondel (1975), which specified that the richness of the avian community is closely linked to the physiognomy, vegetation form, and number of plant layers.

Conclusion

In conclusion, this study on the avifauna of Saharan agricultural environments in relation to their structural complexity highlights the importance of these environments for nesting, wintering, and trans-Saharan migratory birds during their stops in the region. The significant presence of breeding species in these agricultural landscapes underscores the ecological interest of this type of ecosystem for birds. Furthermore, the diversity of bird species and their abundance are strongly influenced by plant heterogeneity and the structural complexity of agroecosystems in the Ghardaia region.

Agroecosystems play a crucial role in biodiversity conservation in Saharan environments by providing varied habitats for numerous species. By promoting sustainable agricultural practices, these systems can support local wildlife and flora while meeting the food needs of the population.

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