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RESEARCH

Conservation Value of Sudanese Savannah Land Use Systems for Birds in the Lagdo Area, North Cameroon

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Abstract

Aggregate biodiversity metrics frequently mask profound structural shifts in human-modified savannahs, creating a persistent paradox where apparent ecological stability conceals severe community reorganization and functional degradation. To resolve this tension in the Sudanese savannah of North Cameroon, systematic sampling of 4,166 individuals across 68 species quantified avian responses to landscape conversion into Mixed Rural Habitats, Rice Paddies, and Annual Crop Fields. Although aggregate species richness and abundance remained invariant across these land-use types, pairwise comparisons confirmed that each habitat supports a distinct avian signature, driving systematic community turnover rather than taxonomic attrition. Community identity partitioned decisively by land-use, with Annual Crop Fields supporting 39.7% of unique species, Rice Paddies at 26.5%, and Mixed Rural Habitats at 7.4%. Furthermore, 13.23% of recorded species were exclusively restricted to these agricultural systems, establishing land-use type as a statistically significant predictor of community assembly and confirming that each habitat contributes a unique structural component to the regional species pool. Functional organization mirrored this targeted reconfiguration; while most feeding guilds exhibited resilience to modification, Aquatic predator and Omnivore abundances proved highly sensitive to land-use variation, identifying these specific guilds as critical functional sentinels of anthropogenic disturbance. Ultimately, these dynamics fundamentally reframe the conservation value of agricultural savannahs, shifting the primary metric of success from gross species counts to the preservation of compositional turnover and functional integrity. The persistence of these diverse assemblages remains strictly contingent upon the structural complexity of the land-use mosaic rather than the mere localized absence of human activity. Consequently, effective conservation in the Sudano-Sahelian biome necessitates management frameworks that transcend simple habitat preservation to actively integrate native vegetation within productive agricultural systems, ensuring that unchecked agricultural expansion does not precipitate silent functional homogenization across the rapidly transforming African tropics.

Keywords Avian conservation · Biodiversity · Land use systems · Sahel-Sudanian savannah · Habitat modification · Bird community structure

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Introduction

The Sudano-Sahelian savannah constitutes a semi-arid transitional ecosystem of considerable biophysical significance, functioning as both a critical buffer against desertification and a primary reservoir for regional carbon sequestration across its Cameroonian extent, yet its functional integrity is increasingly subordinated to the pressures of accelerating land-use transition (Osborne et al. 2018; Mirzabaev et al. 2019). The structural transformation of these landscapes is attributable to a convergence of population-induced agricultural expansion, the intensification of commercial land use, and persistent climatic stressors operating against a background of weakened customary tenure and fragmented institutional governance, dynamics that have been systematically documented across West African savannah systems and dryland environments more broadly (Ouedraogo et al. 2015; Atsri et al. 2018; Assede et al. 2023). In the Lagdo area specifically, this trajectory of land-use change is further compounded by the hydrological reorganisation consequent upon the construction of the Lagdo Dam, an intervention that has demonstrably altered river dynamics and accelerated the conversion of riparian and floodplain habitats (Sinclair et al. 2002; Abioro et al. 2025). Whilst the aggregate drivers of savannah degradation, encompassing institutional fragmentation, tenure insecurity, and anthropogenic disturbance, are now extensively characterised in the literature (Ouedraogo et al. 2015; Mrema et al. 2018), a fundamental uncertainty persists as to the capacity of the resulting human-modified mosaics to sustain the biotic communities upon which the long-term ecological health of the region depends (Atsri et al. 2018; Assede et al. 2023).

Avian assemblages serve as high-resolution indicators of landscape shifts, as their functional diversity directly underpins essential services including pest regulation and seed dispersal (Sekercioglu 2012; Dehling et al. 2016; Sekercioglu et al. 2019). While land-use conversion typically precipitates a partitioning of communities toward generalist lineages, the ecological trajectories of heterogeneous Sudanese savannahs remain non-linear and poorly characterized (Donald et al. 2001; Mugatha et al. 2024). A fundamental tension persists in understanding how human-modified mosaics maintain ecological functionality. Specialist guilds, such as insectivores and frugivores, are inherently sensitive to the loss of structural complexity (Azman et al. 2011; De Bonilla et al. 2012; Tchoumbou et al. 2020), yet the extent to which novel agro-ecosystems, specifically the extensive rice paddies of the Lagdo area, function as viable surrogates for natural savannah remains unquantified. Should these agricultural systems primarily support granivorous generalists, the conversion of natural habitats signifies a functional attrition capable of compromising long-term ecosystem resilience (De Bonilla et al. 2012).

The magnitude of biotic dissimilarity and community fluctuations across these specific mosaics constitutes an unresolved imperative for locale-specific conservation (Morelli and Tryjanowski 2015). Evaluating the relative conservation value of these systems provides a necessary foundation for defining avian persistence in modified savannahs. If avian richness and abundance track gradients of structural complexity and vegetation greenness, then community sensitivity to land-use change is likely a trait-mediated process (Donald et al. 2001; Azman et al. 2011). This study therefore interrogates whether land-use systems are significant predictors of variation in key avian community metrics, including species richness, diversity, and functional guild abundances, and examines whether these associations reflect a trait-mediated response to structural modification across the Lagdo mosaic.

Furthermore, the environmental stability inherent in divergent agricultural practices, notably the contrast between the relative permanence of rice paddies and the high-frequency disturbance of annual crop fields, potentially dictates community resilience (Sinclair et al. 2002). This investigation clarifies these dynamics in the Lagdo area to determine whether agricultural intensification facilitates functional continuity or necessitates a fundamental biotic reorganization of the Sudanese avian assemblage.

Methodology

Ecological Context And Site Selection

The Lagdo District of Northern Cameroon (Fig. 1) serves as a critical natural laboratory for examining avian resilience within the Sudano-Sahelian transition zone. Positioned at the northern boundary of the Lagdo reservoir (13° 32' E – 13° 44' E, 9° 3' N – 9° 12' N), the region encompasses a heterogeneous mosaic of wooded savannah and anthropogenic matrices (MINEPAT (Ministry of Economy, Planning and Regional Development), 2020). The landscape is distinguished by a primary productivity gradient driven by the Benue Valley floodplains and a pronounced seasonality, characterised by a distinct dry season (November–March) and a rainy season (April–October), with a mean annual temperature of 28.34 °C (NASA, POWER 2021). The site's epistemic utility lies in its variety of land-management regimes, ranging from traditional agro-pastoral systems to intensive monocultures, providing the necessary environmental contrast to interrogate the impact of land-use turnover on faunal integrity (MINEPAT (Ministry of Economy, Planning and Regional Development), 2020).

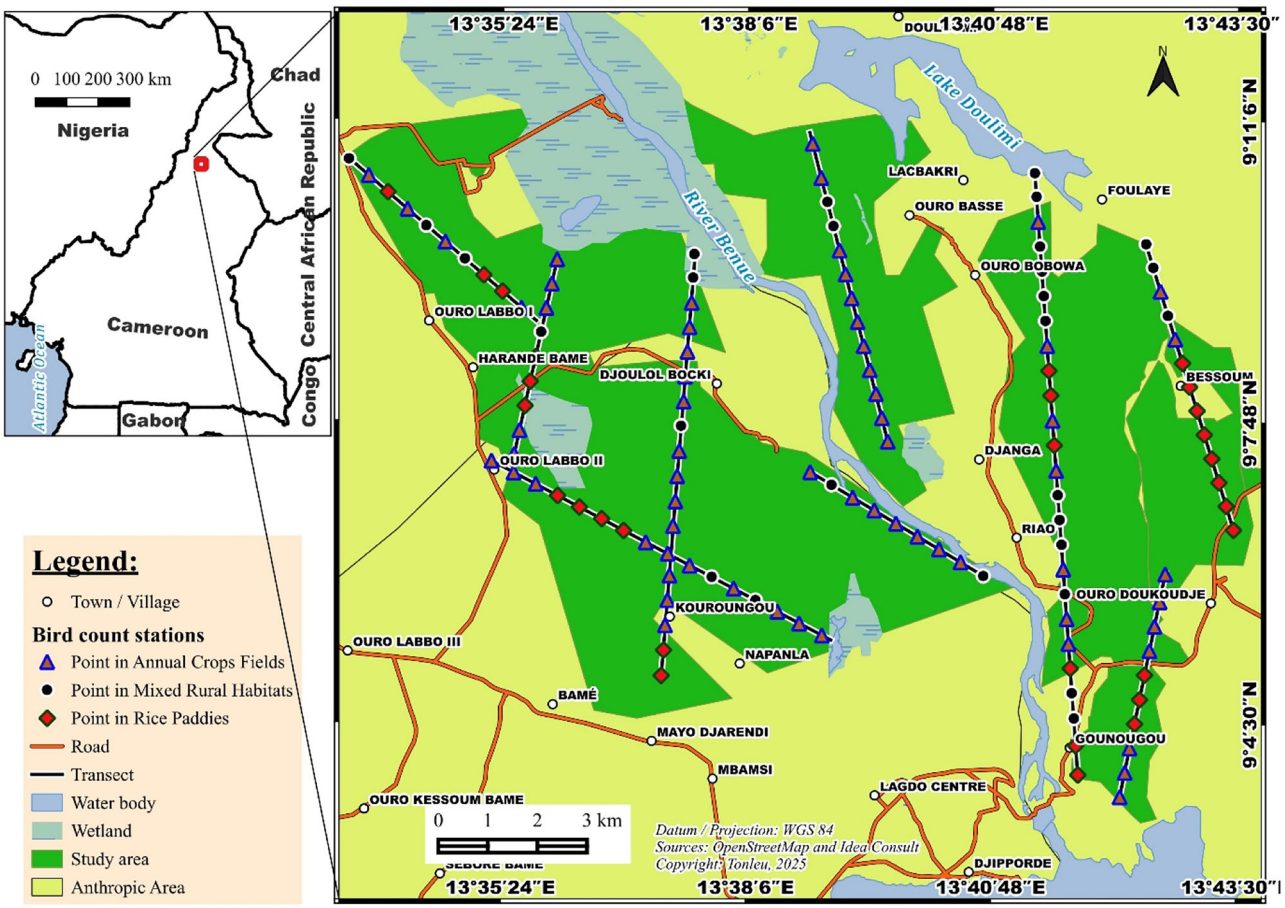

Fig. 1 Map of the study area

Sampling Techniques

To assess the complexity of bird community structure across this mosaic, sampling was stratified across three distinct land-use systems, defined by their structural complexity and intensity of human disturbance: Mixed Rural Habitat (MRH), representing a high-heterogeneity matrix; Annual Crop Fields (ACF), characterised by ephemeral cereal and cotton cultivation; and Rice Paddies (RP), representing stable, low-complexity monocultures.

Avian data were derived from 123 independent point-count stations (Bibby et al. 2000) established along nine linear transects covering 58.4 km within the 11,000-ha research site as follows: 66 in MRH, 28 in ACF, and 29 in RP from September 9th to 17th, 2019. To ensure spatial independence and mitigate the risk of over-sampling, a minimum distance of 500 m was maintained between stations. Observation (Borrow and Demey 2012) periods were restricted to peak activity hours (06:00–11:00) and utilised a 15-min census duration within a 50 m radius, a protocol designed to maximise detection probability while minimising double-counting in dense savannah strata.

Functional composition was characterised by collating morphological and ecological traits from the AVONET database (Tobias et al. 2022). The R environment (R core team 2023) facilitated the extraction of foraging stratum, hand-wing index, body mass, and feeding guild metrics via the avonet package. Data manipulation was performed using the dplyr (Wickham et al. 2023) package. Management of tabular datasets was supported by the readxl (Wickham and Bryan 2023) and writexl (Ooms 2023) packages. Taxonomic nomenclature was standardised before trait values were appended to field survey records, generating a comprehensive functional dataset for quantitative assessment across the three land-use systems.

A "Regional Species Pool" was established to contextualise local assemblages. An avian inventory for the Bénoué National Park was compiled. Occurrence data were sourced from eBird (Sullivan et al. 2009). This protected area served as a reference site. It represents a high-conservation-value, near-natural state of the Sudanian savannah ecosystem under investigation. Ecological and habitat-use data for these species were subsequently retrieved from the AVONET database (Tobias et al. 2022). The analysis

required focusing on species relevant to the study landscape. The reference list was therefore filtered. Only species documented to inhabit savannah-like or analogous environments were retained. These were specifically categorised as grassland, human-modified, riverine, shrubland, wetland, or woodland habitats.

Data Analysis

The conservation value of the Lagdo land-use systems was determined by assessing the representation of regional biodiversity against a high-conservation-value benchmark, Bénoué National Park. Inventory completeness was quantified as the proportion of the regional species pool captured within the study site, providing a metric of the extent to which local land-use systems sustain regional avian diversity. Compositional similarity was subsequently evaluated using the Jaccard similarity coefficient (Ivchenko and Honov 1998), which calculates the ratio of shared species to the total number of unique species across both datasets. This index offers a standardized measure of community divergence between the anthropized Lagdo landscape and the near-natural reference ecosystem. Statistical computations were performed within the R statistical environment (R core team 2023).

The interrogation of diversity followed a logical progression from aggregate metrics to the underlying drivers of community turnover. Taxonomic diversity was quantified via Hill numbers (Hill_q0, Hill_q1, and Hill_q2), providing a robust profile of species richness and evenness (Hill 1973). To address the discrete nature of count data exhibiting non-normality, heteroscedasticity, and overdispersion, total abundance (Individuals) and species richness (Hill_q0) were modelled using Negative Binomial Generalised Linear Models (GLMs) with a log-link function via the MASS package (Venables and Ripley 2002).

Conversely, the exponential Shannon diversity index (Hill_q1) represents a continuous variable that violates normality assumptions; accordingly, its relationship with habitats was investigated using a Gamma GLM with a log-link function. For the inverse Simpson dominance index (Hill_q2), data were stabilised using a log $(x + 1)$ transformation and fitted with a linear model. The overall habitat effect was subsequently assessed using a robust Wald test based on a sandwich covariance matrix estimator (HC3) to control for residual heteroscedasticity, employing the sandwich (Zeileis et al. 2020) and lmtest (Zeileis and Hothorn 2002) packages. For both Negative Binomial and Gamma GLMs, the omnibus effect of the habitat variable was evaluated through Type-II analysis of deviance likelihood-ratio tests (Fox and Weisberg 2018). Model performance and goodness-of-fit were determined by extracting the Akaike Information Criterion (AIC) alongside Nagelkerke's pseudo-R^2 values (Lüdecke et al. 2021).

Variations in avian functional diversity across the studied anthropized land-use types were investigated using statistical frameworks tailored to specific mathematical boundaries and distributional assumptions (Cadotte et al. 2011). Normality of residuals and homogeneity of variances were verified via Shapiro-Wilk and Bartlett tests. Functional dispersion (FDis) met these parametric assumptions and was evaluated using a one-way Analysis of Variance (ANOVA). Conversely, functional evenness (FEve), functional divergence (FDiv), and Rao's quadratic entropy (RaoQ) represent continuous bounded indices exhibiting non-normality. These were analysed using Beta regression models with a logit-link function (Cribari-Neto and Zeileis 2010), allowing for an accurate treatment of rates and proportions. Performance for the Beta regressions was assessed via Akaike's Information Criterion (AIC), and explanatory power was derived using a squared correlation coefficient between observed and predicted values to circumvent the limitations of traditional R^2 metrics on non-linear transformations.

The distribution of bird feeding guilds across the landscape gradient was examined via Generalised Linear Models. Parametric test diagnostics revealed a substantial accumulation of zeros and extensive overdispersion across most specialised guilds. To account for this, Negative Binomial GLMs with a log-link function were fitted for all eight trophic guilds (aquatic predators, aquatic herbivores, frugivores, granivores, invertivores, nectarivores, omnivores, and vertivores) using the MASS package (Ripley et al. 2013). The omnibus significance of the land-use effect within each guild was determined via Type-II Likelihood-Ratio Chi-squared tests (Fox and Weisberg 2018). Post-hoc pairwise comparisons between land-use categories were evaluated using Wald z-test statistics. Goodness-of-fit and the proportion of variance explained by the habitat predictor were quantified by calculating Nagelkerke's pseudo-R^2 (Lüdecke et al. 2021). Finally, community dissimilarity was investigated via Analysis of Similarities (ANOSIM), which permits a comparison of intra-habitat similarity against inter-habitat divergence (Oksanen et al. 2013) based on dissimilarity ranks (Arbizu and Pairwiseadonis 2020).

To delineate the environmental drivers influencing avian community patterns, high-resolution satellite imagery was processed via Object-Based Image Analysis (OBIA) within a Geographic Information Systems framework. This approach aggregates spectrally and spatially homogeneous pixels into ecologically meaningful objects, providing an accurate representation of terrain features such as crops, grassland, urbanisation, and water within 50 m radius buffers of census points. This operationalization is pertinent to the structural heterogeneity characteristic of the Lagdo mosaic (Ez-zahouani et al. 2025). Open-access Landsat 8/9 (30 m spatial resolution) and Sentinel 2 (10 m spatial resolution) imagery provided the foundational dataset.

Segmentation was executed using Mean-Shift (MS), Large Scale Mean-Shift (LSMS), and Region Growing (RG) algorithms. Consistent with previous findings, MS and LSMS algorithms yielded homogeneous segments corresponding to actual terrain boundaries, whereas RG exhibited greater sensitivity to surface heterogeneity (Ez-zahouani et al. 2025). Discrepancies in MS outputs across software platforms, despite identical parameterization, indicate potential for software-induced biases, reinforcing the imperative for cross-platform validation in reproducible remote sensing workflows (Ez-zahouani et al. 2025). Quality was assessed using the Moran Index, the Area-Weighted Variance, and a composite Global Score, with spectral indices incorporated to capture gradients of structural complexity and canopy cover (See Fig. S1).

The structural influence of environmental conditions (percentages of urban, grassland, water, and crops) and spatial coordinates on community composition was modelled using constrained ordination in Canoco v5.0 (Šmilauer and Lepš 2014). Spatial predictors were constructed as distance-based Moran's Eigenvector Maps (db-MEM) from a truncated geographic distance matrix (Dray et al. 2006; Braak and Šmilauer 2018). To isolate the relationship between individual spatial axes and response data, linear correlations were evaluated using Pearson's product-moment correlation coefficient (r). PCNM variables exhibiting positive spatial autocorrelation (positive eigenvalues) were retained, and a forward selection procedure was applied to prevent variance inflation.

Variation partitioning segregated the total explained community variance into pure environmental, pure spatial, and shared fractions based on unbiased adjusted coefficients of determination (Peres-Neto et al. 2006). The statistical significance of the global model and unique explanatory fractions was confirmed using Monte Carlo permutation tests under a reduced model framework. To formally disentangle the independent effects of land-use type from the spatial structure represented by PCNM eigenvectors, the varpart function (Oksanen et al. 2018) estimated the variance explained by each component. To assess whether land-use systems remained a statistically significant driver of community composition after accounting for spatial context, a partial redundancy analysis (pRDA) was conducted. The significance of the pure land-use fraction was determined using analysis of variance (ANOVA) based on 999 permutations, ensuring that conclusions regarding land-use intensification were robust to spatial clustering.

Results

Bird Diversity in Savannah Land Use Systems

The avian assemblage comprised 4166 individuals representing 68 species from 38 families (Supplementary Tables S1, S2). Dominant families included Ploceidae (37.3%), Columbidae (15.6%), and Ardeidae (12.4%), with *Euplectes franciscanus* and *Bubulcus ibis* emerging as the most frequent taxa. Species coverage at the Lagdo study site reached 17.35% of the regional reference pool from Bénoué National Park; however, a Jaccard similarity index of 0.1691 indicates notable divergence in species composition between the study site and the reference ecosystem. While 13.23% of recorded species (nine species) were unique to the study site (Supplementary Fig. S2), these were predominantly restricted to agricultural land use systems, specifically annual crop fields and rice paddies.

Community structures remained homogeneous across the landscape, with habitat type exerting no statistically significant influence on overall abundance (Fig. 2 a,b) or Hill diversity metrics. Total abundance did not vary significantly among habitats (Likelihood-Ratio Test: $\chi^2 = 1.00$, $df = 2$, $p = 0.608$, $pseudo\text{-}R^2 = 0.013$). This pattern of environmental homogeneity persisted across the diversity profile, as no significant habitat effects were detected for species richness (Hill_q0: $\chi^2 = 1.74$, $df = 2$, $p = 0.419$), exponential Shannon diversity (Hill_q1: $\chi^2 = 2.23$, $df = 2$, $p = 0.328$), or inverse Simpson dominance (Hill_q2: Robust Wald Test, $F = 0.24$, $df = 2$, 107, $p = 0.791$). Pairwise comparisons confirmed the absence of localized discrepancies, showing that neither mixed-rural habitats nor rice paddies diverged significantly from the baseline reference habitat across evaluated parameters (Table 2).

Beneath this uniformity in aggregate metrics, a clear gradient of species accumulation emerged, with annual crop fields supporting the highest richness (52 species), followed by rice paddies (45 species) and mixed-rural habitats (41 species). Stability in broad metrics masked a high degree of habitat affinity, with 21% of overall species endemic to a single land-use type, notably 11 species found exclusively within annual crop fields (Fig. 3). Sample-based rarefaction and extrapolation curves substantiate these patterns, showing significant overlap in Hill numbers (q = 0, 1, 2) across land-use types (Fig. 4a, b; Supplementary Fig. S3a-b; Fig. 5). Neither the exponential of Shannon entropy (Linear Regression $\chi^2 = 0.46$, $df = 2$, $p = 0.80$) nor the inverse Simpson concentration index (Linear Regression $\chi^2 = 0.11$, $df = 2$, $p = 0.94$) showed sensitivity to land-use variation (Table 2). Avian functional structure remained stable across the landscape gradient; functional evenness (FEve; Beta regression: $pseudo\text{-}R^2 = 2.42\%$, $AIC = 53.33$), functional dispersion (FDis; ANOVA: $F_{2,\ 107} = 0.96$, $p = 0.387$, $R^2 = 1.76\%$), and Rao's quadratic entropy (RaoQ; Beta regression: $pseudo\text{-}R^2 = 2.19\%$, $AIC = -348.38$) did not differ significantly between land-use types. Global functional divergence (FDiv) also remained homogeneous (Beta regression: $pseudo\text{-}R^2 = 4.14\%$, $AIC = 87.09$), exhibiting only a marginal downward trend within mixed-rural settings

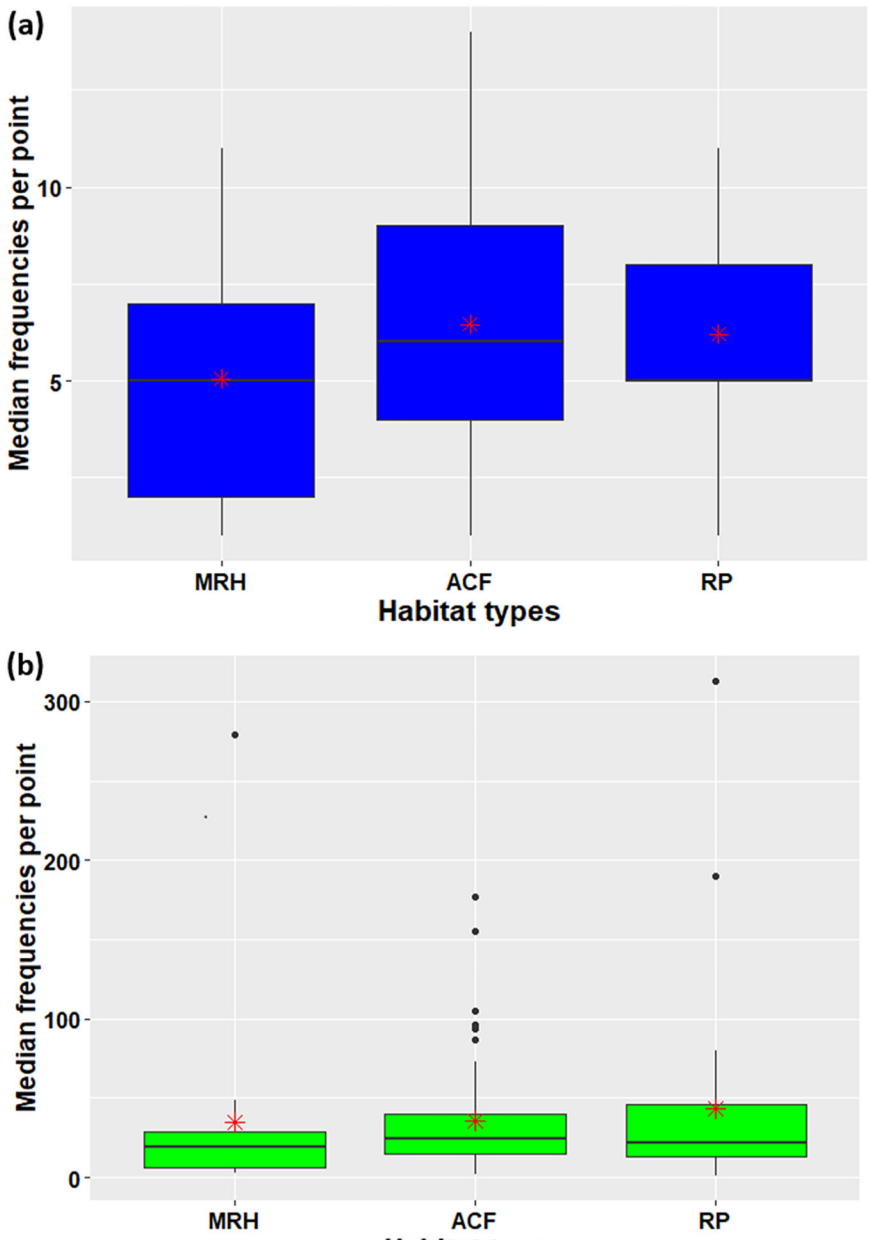

Fig. 2 Differences in the median frequencies of bird species (**a**) and abundance (**b**) across the land use systems (types of habitats: MRH Mixed Rural Habitat, RP Rice Paddy, ACF Annual Crops Field)

(*beta* = -0.45, z = -1.67, $p = 0.096$). This structural consistency indicates that the volume, distribution, and regularity of eco-morphological trait spaces are maintained uniformly across the modified landscape matrix (Table 2).

Community Structure Variation Among Habitats

While aggregate diversity metrics remained invariant, community composition diverged decisively across the surveyed land-use systems (ANOSIM: *global* $R = 0.4901$, $p < 0.001$; Fig. 6). Pairwise comparisons confirm that each habitat type supports a distinct avian signature, indicating that land-use practices in the Lagdo area drive systematic community turnover rather than taxonomic attrition (Table 1). This high degree of compositional distinctiveness suggests that each habitat contributes a unique structural component to the regional species pool. Principal Coordinate Analysis of Neighbour Matrices (PCNM) corroborates this partitioning, with land-use types explaining 4.61% of total variability (*pseudo-F* = 0.9, $p = 0.002$). The resulting ordination reveals discrete species assemblages: the annual crop field community is defined by granivorous and generalist species such as *Euplectes franciscanus* and *Ploceus cucullatus*, whereas mixed-rural habitats are characterized by *Microcarbo africanus* and *Buphagus africanus*. Conversely, the rice paddy assemblage is dominated by water-associated taxa, specifically *Scopus umbretta*, *Dendrocygna viduata*, and *Ardeola ralloides* (Fig. 7).

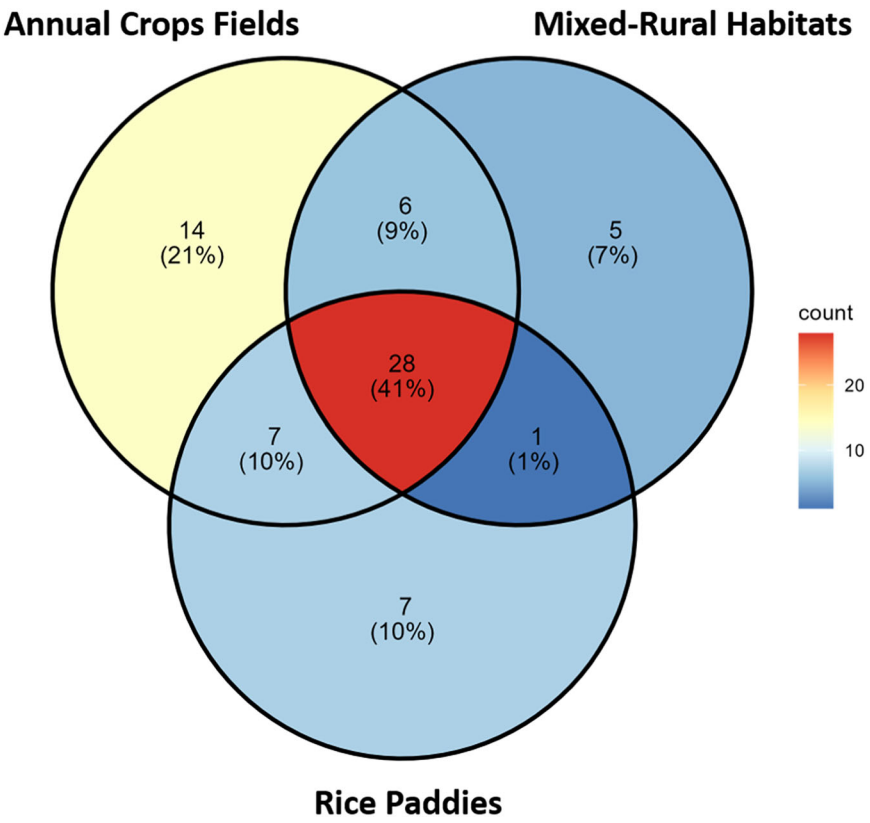

Fig. 3 Shared and unique bird species across land-use systems

Variation partitioning using PCNM eigenvectors revealed that land-use type accounted for 31.83% of the variation in community composition (fraction [a]), whereas spatial configuration accounted for only 1.29% (fraction [c]). The shared fraction attributable to both factors was 6.75% (fraction [b]). This dominance of the pure land-use component indicates that agricultural intensification acts as a primary filter for community assembly, largely independent of broader landscape spatial structure (Supplementary Fig. S4). Partial Redundancy Analysis (pRDA) confirmed that land-use type remains a statistically significant predictor of community composition ($F = 13.168$, $p < 0.001$), reinforcing the distinctiveness of the avian assemblages observed within annual crop fields, mixed-rural habitats, and rice paddies.

Avian Functional Guilds in Savannah Land Use Systems

Guild structure across the Lagdo area is dominated by granivores ($n = 2269$), with omnivores, invertivores, nectarivores, aquatic predators, aquatic herbivores, frugivores, and vertivores following in descending order of abundance (Supplementary Table S3). Trophic guild dynamics exhibited localized responses to specific land-use types, driven by significant shifts in the abundances of aquatic predators and omnivores. Aquatic predator abundance was modulated by habitat structure (Negative Binomial GLM: $LR\ \chi^2 = 21.29$, $df = 2$, $p < 0.001$, Nagelkerke's $pseudo\text{-}R^2 = 0.351$), with a 22-fold increase within mixed-rural habitats relative to annual crop fields ($z = 3.80$, $p < 0.001$). Omnivore abundance was significantly structured by the landscape (Negative Binomial GLM: LR $\chi^2 = 9.31$, $df = 2$, $p = 0.009$, Nagelkerke's $pseudo\text{-}R^2 = 0.126$), with a 3.6-fold proliferation within rice paddies compared to the annual crops baseline ($z = 2.63$, $p = 0.008$). No statistically significant variations in abundance were observed for the remaining feeding guilds, including aquatic herbivores ($p = 0.278$), frugivores ($p = 0.672$), granivores ($p = 0.290$), invertivores ($p = 0.352$), nectarivores ($p = 0.431$), and vertivores ($p = 0.623$), suggesting that landscape modification triggers targeted trophic reorganisations rather than systemic community-wide shifts (Table 2).

Impact of Environmental Variables on Avian Community Structure

Structural divergence in these communities is significantly mediated by specific environmental drivers ($pseudo\text{-}F = 0.9$, $p = 0.002$). The primary axis of variation reveals an ecological trade-off between crop cover and grassland (Fig. 7). Increasing crop density (correlation coefficient $r = 0.61$) acts as a positive predictor for the abundance of *Ploceus cucullatus*, *Vanellus spinosus*, and *Lophoceros*

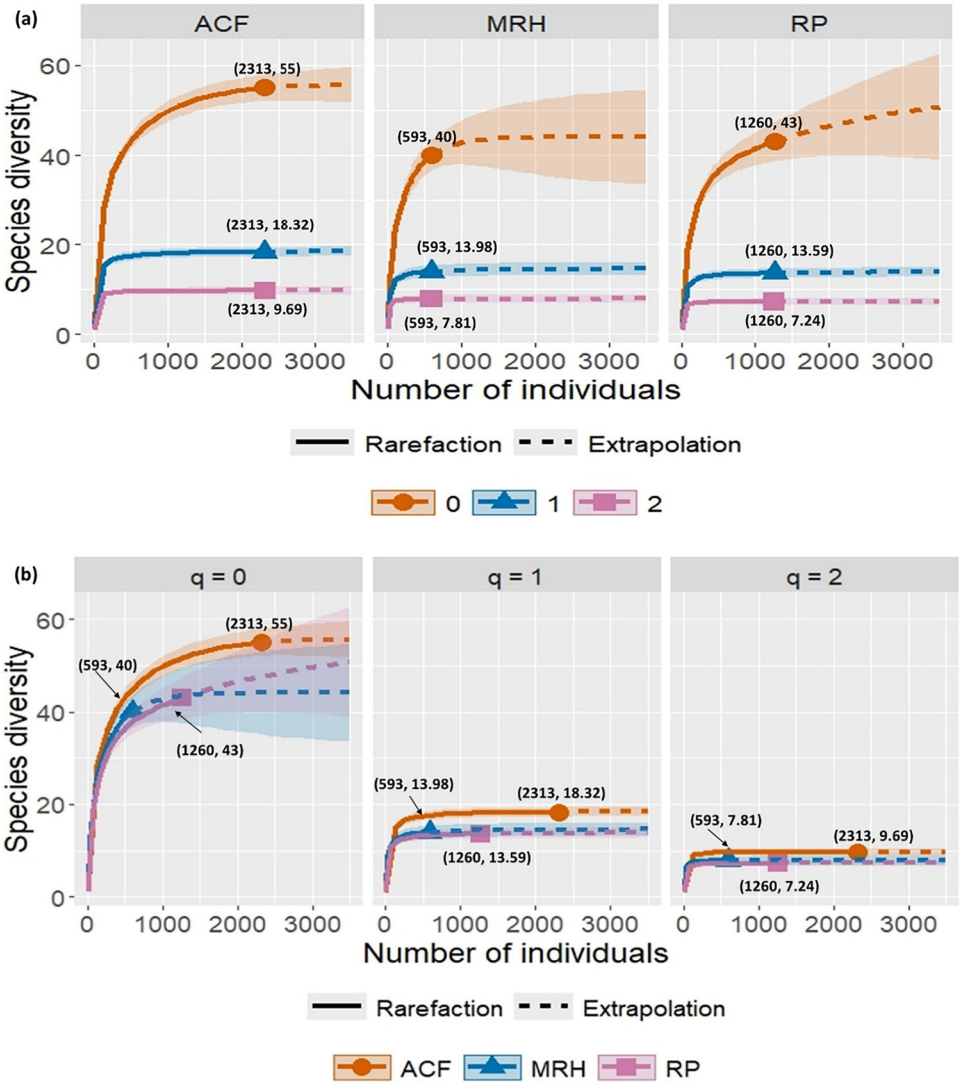

Fig. 4 **a** Sample-size-based rarefaction (solid lines) and extrapolation (dashed lines, up to double the reference sample size) of bird species diversity based on the Hill numbers (q = 0, 1, 2) for the land use systems of the Lagdo area. **b** Comparison of sample-size-based rarefaction (solid lines) and extrapolation (dashed curves), up to the base sample size of 4236 individuals of bird species diversity for Hill numbers. The numbers in parentheses are the sample size and the observed Hill numbers for each reference sample

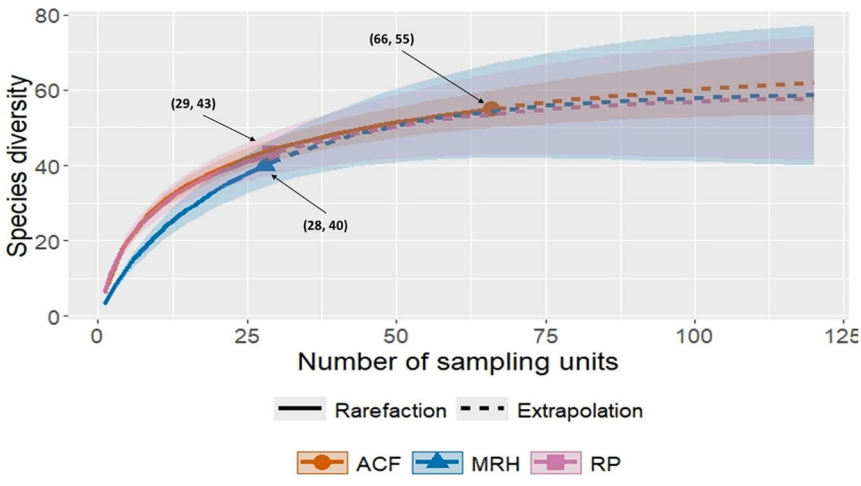

Fig. 5 Sample-size-based rarefaction (solid lines) and extrapolation (dashed lines, up to double the reference sample size) of the land use systems of the Lagdo area for species richness for each of the zones of the urbanisation gradient. The 95% confidence intervals were obtained by a bootstrap method based on 200 replications. All curves were extrapolated up to the base sample size of 120. Reference samples are denoted by solid dots. Sample sizes and the observed species richness for each reference sample are indicated for each point

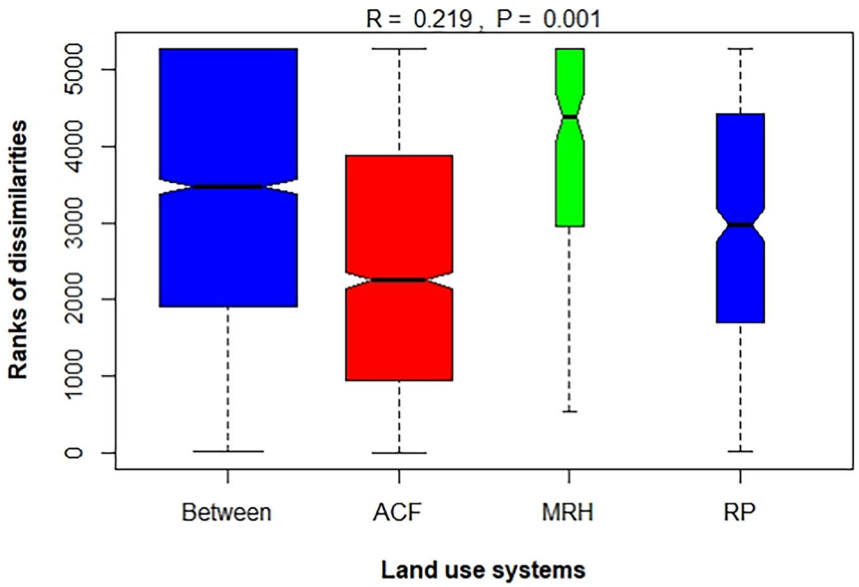

Fig. 6 Ranks of dissimilarity in avian community composition across land-use systems. The boxplot illustrates pairwise dissimilarities between and within groups, highlighting the significant structural divergence between Annual Crop Fields (ACF), Mixed Rural Habitats (MRH), and Rice Paddies (RP)

Table 1 Pairwise similarities based on bird abundance data between land use systems

ANOSIM pairwise	ANOSIM R^2	*F*	*P. value*
ACF vs MRH	0.03241	2.68	*0.002*
ACF vs RP	0.03479	3.316	*0.001*
MRH vs RP	0.04322	1.988	*0.003*

MRH mixed rural habitat, *RP* rice paddy, *ACF* annual crops field.

nasutus. Conversely, species such as *Cinnyris cupreus*, *Passer griseus*, and *Merops nubicus* are positively associated with grassland percentages. This inverse relationship defines the core tension in the community structure: taxa optimized for agricultural landscapes are systematically replaced as grassland becomes the dominant land cover, though a subset of the community remains indifferent to these specific shifts.

Discussion

The stability of avian species richness across the Lagdo land-use gradient masks a profound restructuring of community architecture. While aggregate metrics of abundance and diversity remained invariant across the Sudanese savannah, these figures conceal a systematic turnover of species and functional guilds. This decoupling of taxonomic richness from community composition suggests that land-use modification in North Cameroon does not necessarily trigger a collapse in bird numbers, but rather an ecological reassembly driven by specific environmental trade-offs.

Land Use Systems And Bird Diversity

The challenge of managing biodiversity in tropical agricultural matrices rests on a taxonomic illusion: aggregate richness often masks profound compositional decay (McKinney and Lockwood 1999; Filippi-Codaccioni et al. 2010). In the Lagdo area, rarefaction and diversity indices reveal that rice paddies and annual crop fields sustain community breadth comparable to mixed-rural habitats. This functional stability is not a sign of pristine health, but rather an indicator of high species redundancy where generalists occupy niches vacated by specialists (Devictor et al. 2008). Our study leverages this functional comparison to demonstrate that human-modified matrices maintain volume through redundancy rather than identity. These findings suggest that regional biodiversity assessments must transition from aggregate counts to quantifying compositional turnover to accurately assess landscape health.

Global biotic homogenization theory posits that human activities drive ecosystems toward functional uniformity by eliminating specialized native lineages (McKinney and Lockwood 1999). The invariance in Hill numbers across Lagdo land-use types qualifies this framework by revealing how landscape heterogeneity preserves distinct functional signatures even amid taxonomic replacement (Tscharntke et al. 2012). Field-level intensification acts as an environmental filter that disproportionately penalizes slow-living specialists while favouring fast-living generalists (Rigal et al. 2023; Guerrero et al. 2024). With only 17.35 percent species coverage relative to the national park reference, these systems demonstrate that agricultural landscapes are actively restructured rather than merely degraded. Conventional land-sparing paradigms argue that intensive

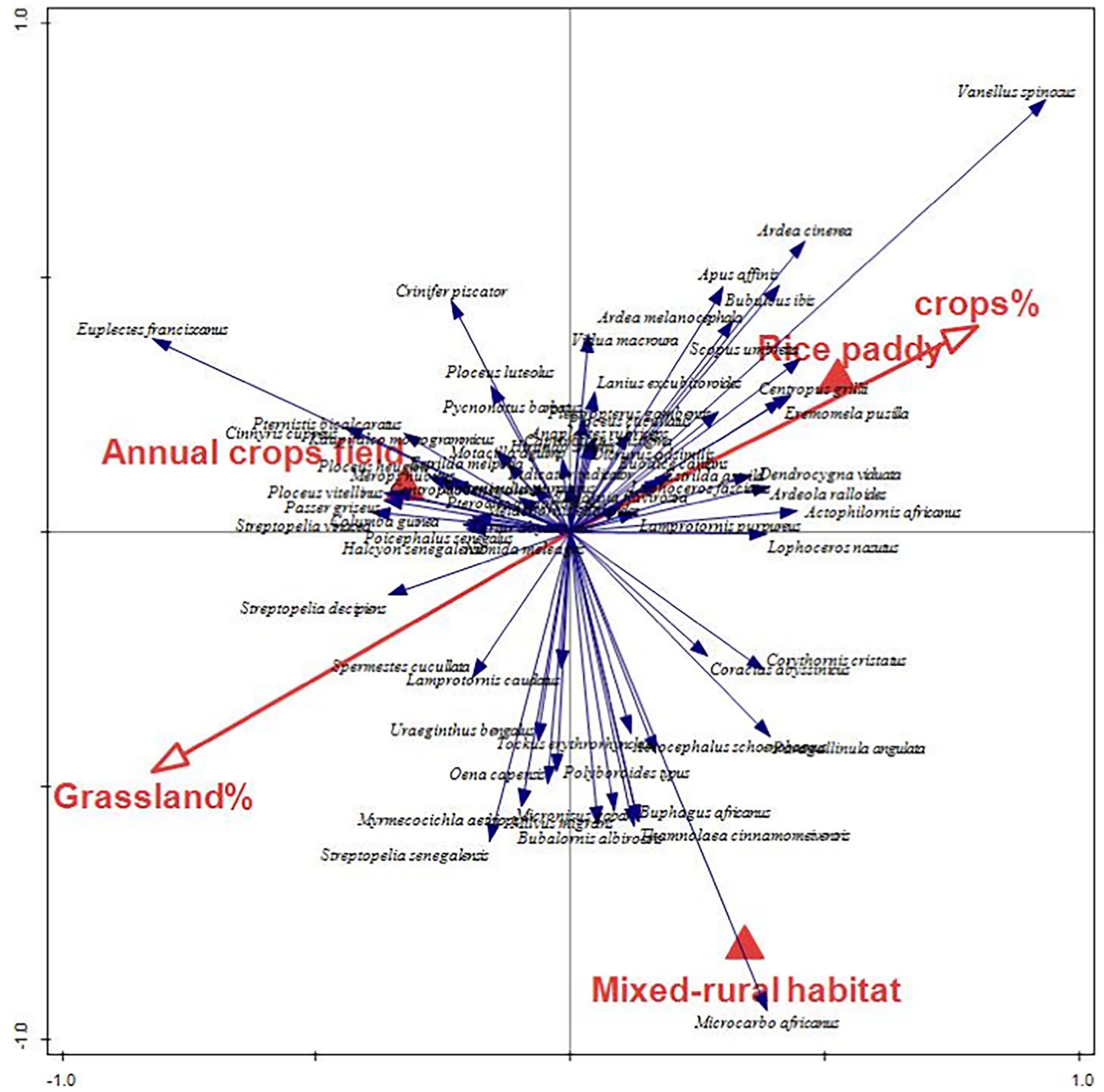

Fig. 7 PCNM analysis visualizing the distribution of bird species (blue-tipped arrows) and different land use systems (red triangle) in the ordination space of the two axes in the land uses systems of the savanna ecosystem of Lagdo. I. and II. ordination axes together explained 8.25% of variability

agriculture combined with strict habitat protection maximizes biodiversity (Phalan et al. 2011). The Lagdo findings complicate this dichotomy by demonstrating that modified rural habitats retain significant conservation value when structural complexity supports colonizing generalists and adaptable specialists. Policy frameworks must consequently incentivize high-quality matrix management that balances crop productivity with the structural heterogeneity required to sustain both generalist resilience and specialist refugia (Perfecto and Vandermeer 2008; Phalan et al. 2011).

Land use Systems And Avian Community Structure

Managing tropical biodiversity requires decoding how landscape configuration filters assembly beyond mere habitat loss (Tscharntke et al. 2012). In the Lagdo area, local environmental filtering explains nearly one-third of compositional variance, dwarfing the influence of spatial factors. This statistical separation reveals that local habitat heterogeneity, rather than broad connectivity, drives the systematic taxonomic turnover observed across the mosaic

Table 2 Results of generalized linear models (GLMs) for total number of birds, number of birds grouped by feeding guilds and diversity and richness indices in the different habitats

Models	ACF	MRH	RP	AIC (Pseudo R^2)
Total number of birds	3.57 ± 0.11***	0.04 ± 0.25	0.02 ± 0.2	1026.8 (0.02)
Taxonomic Diversity				
Species richness	1.87 ± 0.06***	−0.2 ± 0.15	−0.04 ± 0.12	566.84 (0.02)
Shannon's entropy	1.48 ± 0.07***	−0.22 ± 0.17	−0.01 ± 0.12	474.23 (0.02)
Inverse of Simpson	0.91 ± 0.04***	0.06 ± 0.09	−0.01 ± 0.06	61.48 (0.01)
Functional Diversity				
Functional Evenness	0.03 ± 0.03	−0.04 ± 0.08	0.07 ± 0.07	53.33 (0.02)
Functional divergence	0.6 ± 0.12***	−0.44 ± 0.27	0.16 ± 0.21	87.09 (0.04)
Functional Distribution	0.2 ± 0.01***	0.02 ± 0.03	0.03 ± 0.02	−202.11 (0.02)
Rao's Quadratic Entropy	−2.55 ± 0.08***	0.17 ± 0.15	0.15 ± 0.12	−348.38 (0.02)
Feeding guilds				
Aquatic predators	−0.96 ± 0.4*	3.08 ± 0.8***	0.63 ± 0.69	−348.38 (0.02)
Aquatic Herbivores	0.27 ± 0.38	−0.64 ± 0.88	0.8 ± 0.67	279.82 (0.05)
Frugivores	−0.32 ± 0.3	−0.36 ± 0.7	−0.48 ± 0.57	222.84 (0.02)
Granivores	3.15 ± 0.14***	−0.22 ± 0.32	−0.41 ± 0.25	892.1 (0.03)
Invertivores	0.82 ± 0.21***	0.47 ± 0.45	0.44 ± 0.36	465.98 (0.03)
Nectarivores	0.66 ± 0.25**	−0.8 ± 0.6	−0.22 ± 0.45	361.38 (0.03)
Omnivores	1.65 ± 0.27***	−0.26 ± 0.61	0.27 ± 0.48**	559.87 (0.13)
Vertivores	−0.92 ± 0.27***	−0.25 ± 0.64	−0.51 ± 0.54	173.55 (0.02)

Model AIC and the variance explained by the different habitats (Pseudo R^2) are also presented. Significant effects are marked with the following significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Habitat types: *ACF* Annual Crop Fields, *MRH* Mixed-Rural Habitats, *RP* Rice Paddies.

Estimates ± Standard error of each habitat are presented

(Soininen et al. 2018). Our findings confirm that each habitat operates as an independent ecological niche, validating the importance of structural complexity over simple connectivity metrics in tropical systems (Skowno and Bond 2003; Sirami et al. 2009). Consequently, conservation initiatives must prioritize local-scale habitat heterogeneity to preserve specialized community assemblages.

Beta diversity patterns in global biomes confirm that species turnover dominates community assembly across spatial and latitudinal gradients (Soininen et al. 2018). Our data demonstrate that landscape simplification through monoculture expansion erodes unique community components, mandating the retention of diverse vegetation structures to prevent functional homogenization (Haddad et al. 2015). Although habitat fragmentation acts as an independent driver of loss, local agricultural management exerts stronger control over community structure than regional connectivity. High edge-density configurations boost functional biodiversity and pest control without compromising yields, proving that ecological complexity and economic productivity are compatible (Martin et al. 2019). Policy directives must transition from standardized regional targets to locally tailored mosaic management that actively maintains the structural heterogeneity required for both specialist survival and ecosystem service delivery (Tscharntke et al. 2012; Gil-Tena et al. 2015).

Land Use Systems And Avian Feeding Guilds

Our observation that trophic guild structure remains largely robust across the Lagdo landscape mirrors findings from global meta-analyses suggesting that agricultural intensification does not precipitate immediate systemic functional collapse (Newbold et al. 2020). Instead, we document targeted reorganization wherein trophic groups are filtered by land-use specific resources, such as the increased aquatic subsidies available to omnivores in rice paddies (Katayama et al. 2021). While this apparent stability might suggest broad resilience, we acknowledge that aggregate metrics frequently mask the underlying attrition of narrow-niche specialists (Clavel et al. 2011). Non-random functional restructuring dictates that human land use acts as a severe environmental filter that disproportionately removes specialized ecological roles from modified landscapes (Flynn et al. 2009; Newbold et al. 2020). The Lagdo community exhibits a striking 22-fold increase in aquatic predators within mixed-rural habitats alongside a 3.6-fold proliferation of omnivores in rice paddies. These dramatic numerical shifts demonstrate that specific land-use configurations operate as high-quality anthropogenic subsidies that selectively favour adaptable trophic strategies. Management strategies must therefore preserve distinct habitat patches to

maintain the trophic redundancy that sustains localized biological pest control across heterogeneous agricultural systems.

Global analyses confirm that land use systematically downgrades ecosystems by eliminating top predators and specialized carnivores while simultaneously favouring resilient omnivore populations (Newbold et al. 2020). One might interpret this guild-specific proliferation as evidence of ecosystem recovery, but it more accurately reflects a resource-driven tracking of ephemeral subsidies that mask underlying specialist declines (Clavel et al. 2011). The dominance of generalist foraging strategies within simplified crop matrices indicates that agricultural expansion inevitably compresses functional trait distributions. Tropical agroecosystems must simultaneously secure food production and maintain the functional diversity that underpins critical ecosystem services for agricultural communities (Perfecto and Vandermeer 2008). The Lagdo findings demonstrate that maintaining a mosaic of mixed-rural habitats and rice paddies sustains specialized trophic hotspots that intensively managed monocultures actively degrade. Agricultural certification schemes and regional planning initiatives must therefore mandate structural complexity retention to safeguard the functional integrity that sustains both biodiversity and farming productivity (Clough et al. 2009; Katayama et al. 2021).

Environmental Variables And Avian Community Structure

The conversion of natural vegetation into cultivated landscapes fundamentally alters the spatial distribution of avian species through predictable crop-grassland trade-offs (Krook et al. 2007; Bled et al. 2019). In the Lagdo area, the inverse relationship between crop density and grassland cover defines precise environmental thresholds where systematic species replacement occurs. This structural divergence confirms that agricultural expansion forces taxonomic reorganization rather than causing uniform community decline across tropical mosaics (Frishkoff et al. 2014). Species with high adaptive plasticity rapidly colonize crop-dominated zones while grassland-dependent taxa become systematically marginalised. Agricultural systems act as severe environmental filters that eliminate species reliant on ancestral habitat features while permitting adaptable generalists to exploit novel resource pulses (Frishkoff et al. 2014). The positive correlation of *Ploceus cucullatus*, *Vanellus spinosus*, and *Lophoceros nasutus* with increased crop cover demonstrates how cultivated landscapes subsidize opportunistic taxa through predictable resource availability. Management frameworks must consequently preserve remnant grassland patches within crop matrices to prevent the total exclusion of species unable to exploit agricultural subsidies.

Biotic homogenization theory posits that agricultural landscapes globally converge toward functional uniformity as specialized lineages are replaced by widespread generalists (McKinney 2008; Clavel et al. 2011). The identification of a functionally indifferent avian subset in the Lagdo area reveals how flexible taxa maintain aggregate diversity stability during intensive grassland-to-crop transitions. This biological buffer effectively masks the gradual loss of specialized components when conservation monitoring relies exclusively on broad richness metrics. One might interpret this aggregate stability as ecosystem health, yet it more accurately represents the progressive filtering of phylogenetically distinct lineages that erodes evolutionary heritage (Frishkoff et al. 2014). Agricultural intensification inherently simplifies landscape heterogeneity at both spatial and temporal scales, systematically removing the diverse resources required by complex farmland life cycles (Benton et al. 2003). The Lagdo mosaic demonstrates that maintaining the crop-grassland equilibrium is essential for sustaining the dual populations of agricultural opportunists and native grassland specialists. Conservation policies must therefore shift from fragment-based preservation to active mosaic management that protects the interplay between productive crops and remnant native vegetation to prevent silent functional collapse (Benton et al. 2003; Clavel et al. 2011).

Conclusion

The Lagdo agricultural matrix functions as a series of selective environmental filters. Taxonomic richness proves an inadequate metric for biodiversity in Sudanese savannahs, as it obscures the habitat-specific partitioning of avian assemblages. While isolated reserves remain essential for regional planning, they fail to capture the compositional complexity of the broader landscape. Sustaining unique species assemblages requires a shift toward land sharing within this heterogeneous matrix. Maintaining agricultural mosaicism emerges as the most pragmatic strategy for the Sudano-Sahelian context. Conservation value relies not on static similarity to historical references, but on the capacity to provide functional refugia within an anthropogenic matrix.

Agricultural intensification triggers targeted reorganization rather than systemic collapse. Evidence from unique specialist assemblages suggests that aggregate richness metrics mask critical losses in hidden diversity (Filippi-Codaccioni et al. 2010). Policies favouring land-use simplification risk eroding these assemblages despite stable taxonomic indices. Preserving regional functionality necessitates a management transition from maximizing yield-per-hectare to maintaining the structural integrity of the agricultural mosaic. This biodiversity-friendly approach

reconciles food security with avian conservation in African savannahs (Perfecto and Vandermeer 2008). Mosaic structural integrity serves as a primary proxy for biodiversity health and a metric for balancing utilitarian objectives with intrinsic conservation goals (Tscharntke et al. 2012).

The crop-grassland gradient governs community divergence, identifying the precise environmental thresholds at which avian assemblages reorganize. As human-dominated landscapes expand across the continent (Zwarts et al. 2023), the preservation of Sudanese savannahs necessitates managing high-value agricultural mosaics rather than relying solely on fragment-based preservation. The introduction of exotic flora, such as *Azadirachta indica*, risks decoupling avian assemblages from their evolutionary niches, further emphasizing the need for restoring native vegetation. Addressing the socioeconomic dependencies driving such conversions is essential for preventing silent functional collapse (Anjos et al. 2025). The persistence of these savannahs is ultimately contingent upon replacing monoculture expansion with stewardship that protects the interplay between managed crops and natural remnants.

Data availability

The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

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