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Sowing seeds, Soaring feathers:

Exploring the role of temporal and spatial heterogeneity in shaping bird assemblages of Guinea-Bissau's freshwater rice fields

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Dedicatória

Nem sei por onde começar, que viagem longa. E que insano o apoio que me foi dado ao longo deste tempo. Ana, a tua paciência é inesgotável. Aprendendo muito a lidar uma com a outra, fomos desenvolvendo um trabalho que com o tempo já me parecia intrínseco. Foste o meu resgate a todas as horas e não houve uma única vez em que não estivesses lá. Obrigada por nunca teres desistido de mim, por teres acreditado sempre nos meus "posso tentar só mais isto? É que eu acho mesmo que vai fazer a diferença". Sérgio, o chamado salvador da minha análise! Obrigada por estares sempre pronto a falar e por encontrares sempre solução para os meus problemas, literalmente. Obrigada pela prontidão que sempre mostraram e que tão bem vos define, apesar de terem um milhão de outras coisas mais importantes para fazer.

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Resumo Alargado

O aumento atual da atividade agrícola é cada vez mais uma grande preocupação para a conservação da natureza. Durante o século XX, uma revolução nas práticas agrícolas aumentou os impactos das mesmas, levando à redução e degradação de habitats prístinos, e consequente perda de biodiversidade. A produção de arroz é um setor significativo da agricultura, servindo o arroz de alimento básico para mais da metade da população mundial. Os campos de arroz são habitats de grande importância devido à sua rica biodiversidade e às complexas cadeias alimentares que albergam. Além disso, a sua biodiversidade fornece serviços de ecossistema essenciais, desde dispersão de sementes a controlo de pragas. Os arrozais servem então como áreas essenciais para algumas aves, oferecendo recursos como alimento ou locais de nidificação. A conservação de áreas húmidas - incluindo campos de arroz - é vital, devido à sua importância na manutenção da biodiversidade global.

A África Ocidental, incluindo a Guiné-Bissau, enfrenta atualmente desafios na produção de arroz devido à atual migração humana de áreas rurais para centros urbanos, levando ao abandono e degradação dos arrozais. Apesar da necessidade proeminente de estudos das aves em paisagens agrícolas, especialmente em campos de arroz, muitos dos trabalhos desenvolvidos nesse âmbito ignoram alguns aspetos cruciais. Em primeiro lugar, estudos são escassos em países africanos em vias de desenvolvimento, como o caso da Guiné-Bissau. Além disso, muitos estudos focam-se apenas em grupos específicos de aves ou famílias, negligenciando a restante comunidade de aves nestes locais. Os arrozais da Guiné-Bissau constituem uma paisagem de mosaico variado de cultivos, como plantações de arroz ou caju, intercalados com pequenos fragmentos de habitat naturais ou não cultivadas. Deste modo, é essencial que a pesquisa considere campos de arroz e os habitats circundantes como um sistema no seu todo, já que muitas espécies dependem simultaneamente de campos de arroz, florestas próximas e outros habitats.

A gestão adequada de campos de arroz pode garantir a alta produtividade agrícola e, simultaneamente, um habitat estável para as populações de aves. Espécies de aves com diferentes necessidades ecológicas ocupam naturalmente ambientes diferentes, o que leva a variações nas comunidades de aves, não apenas entre diferentes locais, mas também ao longo do tempo. Este estudo visa contribuir para a gestão sustentável de campos de arroz, para a conservação de aves e para a produtividade agrícola. Este trabalho investiga de que modo a heterogeneidade espacial e temporal molda as comunidades de aves em arrozais da Guiné-Bissau, considerando fatores como a largura do campo de arroz, o coberto vegetal, distância a áreas arborizadas e os estágios de desenvolvimento do arroz. Prevê-se que a comunidade de aves varie espacialmente de acordo com esses fatores, e que a riqueza e abundância das espécies de aves e guildas ecológicas se altere ao longo do ciclo de crescimento do arroz, devido sobretudo à variação na disponibilidade de água. Este estudo preenche lacunas de pesquisa muito importantes e fornece informações essenciais para a conservação da biodiversidade, a gestão agrícola sustentável e o entendimento das interações entre aves e campos de arroz na África Ocidental e na Guiné-Bissau.

Este estudo foi então realizado na região de Oio da Guiné-Bissau, entre outubro e dezembro de 2021, em campos de arroz ao redor de cinco aldeias entre Mansabá e Farim. A região é caracterizada por clima tropical e por uma paisagem maioritariamente plana; uma estação seca de novembro a maio e uma estação chuvosa de junho a outubro, com precipitação máxima em julho e agosto. O processo de cultivo de arroz decorre ao longo das várias fases de estágio do arroz, desde o plantio que se inicia em julho a setembro até à colheita do arroz em dezembro.

Para recolher dados, foram usados dez gravadores acústicos automáticos em diferentes paisagens ao redor das aldeias, em campos de arroz, área florestal, plantações de caju e campos de pousio. Os gravadores registaram os sons das aves em intervalos específicos ao início e ao fim do dia, com pequenos intervalos adicionais nas horas de maior calor. Além disso, foram realizados transetos diários ao longo dos arrozais, para avaliar a variação temporal das comunidades de aves. Os dados recolhidos incluíram informações sobre a presença ou ausência das espécies, sua abundância, uso de habitat e o estágio de desenvolvimento do arroz, caso aplicável. As espécies de aves foram agrupadas em quatro guildas ecológicas (espécies de planícies alagadas; espécies de pastagens; espécies de savana/zonas arbustivas; espécies florestais). Os dados foram analisados temporalmente tendo em conta então variáveis como o tipo de paisagem, coberto vegetal, distância para aldeias, distância para áreas florestais e largura dos campos de arroz, como já mencionado.

As análises incluíram ANOVA, teste de Kruskal-Wallis, análise de similaridade, análise de regressão multivariada e outras técnicas estatísticas para avaliar como as variáveis espaciais afetaram a riqueza de espécies de aves. Além disso, foram realizadas análises de variação temporal das comunidades de aves.

Foram identificadas espécies das quatro guildas ecológicas consideradas, o que demonstra a coexistência de uma grande variedade de espécies de aves neste ambiente agrícola. As aves da ordem Passeriformes foram as mais detetadas no estudo. A presença das aves da ordem Coraciiformes, bastante comuns na África Ocidental, demonstrou a forte componente residente das comunidades de aves na região. Por sua vez, as famílias Columbidae e Accipitridae foram consistentemente detetadas, o que condiz com a sua tendência para utilizar habitats próximos às populações humanas. Além disso, o estudo revelou que as espécies raras superam em número as espécies comuns, indicando uma dinâmica de substituição de espécies nas comunidades de aves, justificado por variações nos habitats e na paisagem ao longo do tempo.

Na análise da variação espacial, as espécies de zonas alagadas foram principalmente detetadas em campos de pousio e de arroz, justificado pelo maior teor de água nesses tipos de paisagem. Espécies de pastagens foram mais detetadas em campos de arroz e só depois nos campos de pousio, pois esses habitats são mais adequados para a guilda de aves em questão devido à vegetação menos diversificada do arrozal, à qual estão adaptadas. As comunidades de aves das áreas de floresta e campos de caju apresentaram semelhanças em termos de composição de espécies, devido ao caráter mais denso e fechado desses habitats. Algumas espécies mostraram associações fortes com diferentes tipos específicos de paisagem simultaneamente, realçando a importância da manutenção da heterogeneidade da paisagem. O estudo também revelou que fatores como cobertura vegetal e distância a refúgios influenciam significativamente a riqueza de grupos ecológicos de maneiras diferentes. A presença de habitats florestais nativos próximos às áreas cultivadas foi identificada como importante para a riqueza específica nos campos de arroz.

Na análise da variação temporal, foram comprovadas flutuações na riqueza e abundância de espécies e das respetivas guildas ao longo do ciclo de crescimento do arroz, o que indica uma entrada e saída significativa de aves durante esse período. Os picos de abundância e riqueza de aves ocorreram durante a transição entre as fases de crescimento do arroz que contribuíram para a mudança generalizada da paisagem, destacando assim a influência das condições dos habitats na presença das aves. As espécies de zonas alagadas diminuíram à medida que os campos secaram, enquanto espécies de pastagens aumentavam. Espécies de áreas de savana/arbustivas e de floresta exibiram padrões semelhantes entre si, provavelmente refletindo as mudanças na disponibilidade de alimentos ao longo do ciclo de crescimento do arroz. Destaca-se ainda a importância da complexidade estrutural de habitat, com aves a usar diferentes estratos vegetais em momentos específicos do ciclo do arroz.

Estes resultados têm implicações significativas para a conservação, destacando a necessidade de um equilíbrio entre os campos de arroz e os habitats circundantes para sustentar a diversidade de espécies de aves na região. O estudo realça ainda a importância dos esforços de conservação e respetiva

conscientização, em colaboração com organizações locais para a preservação dessas áreas. É recomendada a continuação de pesquisa nesta região, para uma compreensão mais completa das aves e dos seus hábitos alimentares, comportamentais e de migração, bem como esforços de gestão sustentável dos arrozais, para as populações de aves e humanas.

Palavras-chave: Comunidades de aves, Uso de Habitat, Contextos de paisagem, Época de cultivo do arroz, Rotatividade de espécies

Summary

In the 20th century, a revolution in agriculture practices escalated its impacts on biodiversity. One substantial sector of agriculture is rice cultivation. Rice fields consist of croplands designed for flooding, acting as wetlands. These habitats hold a complex food chain and support rich biodiversity that provides significant ecosystem services. In Guinea-Bissau rice is the main staple food. This study assesses the influence of temporal and spatial heterogeneity in shaping the bird assemblages through the cultivation season of lowland freshwater rice fields in Guinea-Bissau. In particular, we aim to address the following questions: a) how do some landscape factors influence the bird assemblage composition and species richness? – spatial variation; b) how do the bird assemblages and its rice field habitat usage vary throughout the rice growth cycle? – temporal variation. The study was conducted in five rice-producing villages of the Oio region. Birds were sampled through space using automatic acoustic recorders, and in time using transects. A total of 127 species were identified across 16 different orders and 49 diverse families. The overlap in composition within various landscape units underscores the significance of the landscape gradient and confirms the need for heterogeneity. Species richness was positively influenced by the density of vegetation cover and negatively by the distance to villages. Grassland and wetland species' abundance varied inversely in time. Gradual turnover of species followed the habitat progressive conditions. As expected, shrubland species were the overtime-turnover's strongest drivers. Habitat complementarity was demonstrated, further highlighting the importance of structural complexity. This study provides updated information on all groups of birds occurring in this region while tacking multiple dimensions. Despite production value, rice fields can also contribute to biodiversity conservation. Conservation efforts, strict regulation and awareness campaigns should be implemented to develop sustainable ecosystems, that benefit humans and wildlife communities.

Keywords: Bird communities, Habitat use, Landscape contexts, Rice cultivation season, Species-turnover

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1. Introduction

1.1. Global agriculture and rice production

The current increase in agricultural activity is a major concern for nature conservation (Curran et al., 2016). During the 20th century, a revolution in agricultural practices escalated its impacts (Donald et al., 2006; Geiger et al., 2010) particularly leading to a degradation of pristine habitats, which combined with landscape homogenisation drives biodiversity loss (Traba and Morales, 2019). One substantial sector of agriculture is rice production. Rice (*Oryza sativa*; Linnaeus, 1753) serves as staple food for over half of the world's population (Prasad et al., 2017).

Rice fields are cultivated lands intentionally designed for flooding, resulting in what is commonly known as "paddy fields", where rice is planted (Fujioka et al., 2010). During the rainy season, rice fields also function as wetlands (Maclean et al., 2002). These habitats are important due to their rich biodiversity and the complex food webs they support (Acosta et al., 2010; Cruz-Garcia and Price, 2011). This biodiversity provides essential ecosystem services, such as seed dispersal and pest control (Green and Elmberg, 2014; Sutton-Grier and Sandifer, 2019), however can also be perceived as rice pests in some regions (Toffa et al, 2021).

While freshwater wetlands cover only 1% of the Earth's surface, they provide habitat to nearly 40% of the world's species (Güitrón–lópez et al., 2018). Consequently, wetlands rank among the most valuable yet endangered ecosystems globally, primarily due to human activities (Sebastián-González et al., 2013). However, rice fields may serve as a substitute for natural wetlands (Herring and Silcocks et al., 2014). Moreover, rice fields serve also as crucial grounds for birds, with numerous avian species relying on these habitats (Reeder and Wulker, 2017). This is verified for both waterbirds and landbird species (Strum et al., 2013; Luo et al., 2014; Rolon and Maltchik, 2010), offering essential resources such as food and nesting sites (Masero et al., 2011; Katoh et al., 2009).

Due to their high mobility, birds respond rapidly to habitat changes (Fraixedas et al., 2015) making them excellent bioindicators of the environment (Green and Elmberg, 2014(Amat and Green, 2010; Aguilar et al, 2020).

1.2. The case study of West Africa and Guinea-Bissau's rice production

Developing African countries, especially those with significant rice production, encompass critical habitats for African and Palearctic migratory birds (Wymenga and Zwarts, 2010). In many rice- producing regions, most farmers struggle to meet their socioeconomic needs, primarily because they have limited access to essential rice cultivation resources (Temudo, 2011). While rice production is rising across Africa, there is a notable trend of people in West Africa migrating from rural areas to urban centres. This demographic shift leads to farmland abandonment and degradation, particularly of rice fields. Some fields regain a wetland character, while others turn bare and saline (Wymenga and Zwarts, 2010). The rapid deterioration of these vital habitats underscores the immediate requirement for ecological research (Prăvălie, 2021).

In Guinea-Bissau, socioeconomic history has significantly influenced land use patterns (Rosa et al., 2007). This is particularly evident in the abandonment of subsistence farming practices, which led to changes in vegetation cover and spatial structure (Temudo and Abrantes, 2013). Rice holds a central role as the primary staple food in Guinea-Bissau, yet farmers often struggle with rice shortages (Temudo, 2011). In this region, rice cultivation occurs through various systems, including mangrove swamp rice along the coast, upland slash-and-burn rice, and freshwater rice produced in lowland and inland valleys (Wymenga and Zwarts, 2010).

1.3. Research Gaps & study relevance

There is a growing argument for farmlands to contribute to biodiversity conservation (Nilsson et al., 2019), given the significant proportion of species that depend on them for survival (Sanz-Pérez et al., 2019). Despite the pressing need for studies on birds within agricultural landscapes, particularly in rice fields, research often overlooks crucial aspects. While such studies have been extensively conducted in countries such as Japan, Malaysia or Cuba (Amano et al., 2008; Munira et al., 2014; Aguilar et al. 2020), they remain scarce in African developing countries like Guinea-Bissau. To match the extensive literature on birds in other agricultural systems (reviewed in Ormerod & Watkinson 2000; Amano et al., 2008), research on birds within rice fields in Africa is a pressing task (Fasola et al., 2010). Moreover, many studies do not consider all avian groups (Elphick, 2015), often focusing only on specific bird groups such as waterbirds or families such as Ardeidae (Nam et al., 2015; Shuford and Dybala, 2017; Santiago-Quesada et al., 2014; Zhang Lu et al., 2017).

In Guinea-Bissau, rice fields exhibit a mosaic landscape consisting of cultivated crops, such as rice fields, often interspersed with small isolated patches of natural or non-cultivated lands (Petry et al., 2006). These areas may include secondary forest, shrubland or small tree thickets, and additionally orchards (Amano et al., 2008; Katoh et al., 2009; King et al., 2010). Rice fields, as well as their surrounding areas, have a significant impact on bird communities (Munira *et al*, 2014). However, only a few studies have comprehensively assessed all major bird habitat types (Šálek et al., 2018; Sandström et al., 2006). As a result, research needs to consider rice fields and their surrounding habitats as a whole system (Momose et al., 2005).

There has been little research into the conditions that shape bird assemblages and their temporal fluctuations, particularly in tropical ecosystems (Brown, 2014). Overall, most studies have paid limited attention to the effects of spatial and temporal heterogeneity, especially on a landscape scale. To address this gap in understanding, it is crucial to identify the key factors that drive bird biodiversity in rice field farmland systems (Benton et al., 2003; Amano et al., 2008).

1.4. Main aims & hypothesis

Rice fields can provide high crop yield while securing stable foraging grounds for bird populations, if well managed. Bird species with different ecological needs tend to occupy distinct environments, sometimes requiring spatial or temporal heterogeneity (Toon et al., 2010). This leads to variations in bird assemblages among different locations and over various periods (Atkinson, 2014).

Therefore, we aim to contribute to a scientifically informed sustainable management of rice fields, bird conservation and crop productivity. Using transect bird counts and acoustic monitoring, we assessed how temporal and spatial heterogeneity shapes bird assemblages in lowland freshwater rice fields in Guinea-Bissau. Specifically, we investigated:

a) How do some landscape factors influence bird assemblage composition and species richness – spatial variation, at a landscape scale;
b) How bird species richness, abundance, and habitat use change throughout the rice growth cycle – temporal variation, at a habitat scale.

We expect that bird composition will vary with woody vegetation cover, with more open habitat species in rice and fallow fields and more forest species in wooded areas and cashew plantations (Amano et al., 2008; Petry et al., 2006). Rice field width and distance to wooded areas are expected to positively affect open habitat species. At the same time, human infrastructures like roads and villages will have a negative impact on bird richness (Katayama et al., 2020; Aguilar, et al., 2020).

Additionally, as suggested in studies by Santillán, et al. (2018) and Supahan (2022) we anticipate changes in bird assemblage composition, species richness, and abundance over the season due to precipitation and associated land cover changes. Different rice developmental stages will attract different bird species and ecological guilds, with more water-dependent species at the beginning of the rice cycle and species adapted to dryer conditions towards the end. We also predict temporal variations in bird abundance and composition related to differences in vegetation types and strata across rice fields (Munira, et al., 2014; Supahan, 2022).

2. <u>Methods</u>

2.1. Study area

This study was conducted in the Oio region of Guinea-Bissau, from October to December 2021, in rice fields surrounding five villages between Mansabá (12.29ºN, 15.18ºW) and Farim (12.49ºN, 15.21ºW): Djalicunda, Bironqui, Lenquebato, Bereco and Demba Só (Figure 2.1). The landscape is generally flat and the climate tropical, with a dry season from November to May and a rainy season from June to October. The highest precipitation occurs between July and September. Annual rainfall varies between 2200 to 2600 mm. The average humidity is 76% and the average yearly temperature is 26ºC (Bichet and Diedhiou, 2018).

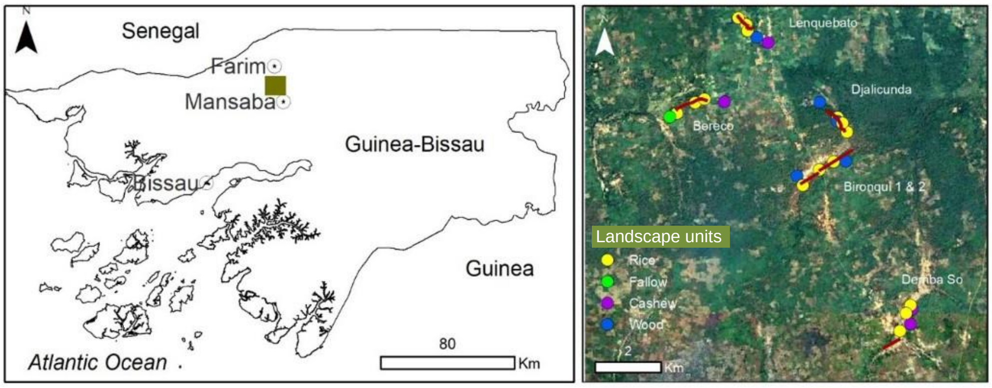

Figure 2.1 - Map of Guinea-Bissau (left) and study area (right). Dots represent the location of the acoustic stations and lines the transects conducted in the rice fields.

In this region, lowland rice production is one of the main activities of the local communities. The landscape is characterised by a patchy mosaic of small urban areas (<40 inhabitants/km2), woodlands and flooded grasslands, along with cashew orchards and abandoned cultivation fields (Catarino et al., 2008). Rice is planted in floodplains with secondary dikes built according to where water accumulates and flows. Before the rice farming season the soil is dry and hard, and rice paddies are open spaces dominated by new and remaining grass from previous harvests.

The rice cultivation process unfolds in several phases. It begins with seeding, typically in July or September, shortly after heavy rains have softened the soil making it suitable for tilling. Seed germination starts a few weeks later lasting until the beginning of October. This is followed by the vegetative stage, during which the rice plants crack and grow, and by the mature stage when the rice plants begin to produce grains, usually in November. Finally, the ripening phase takes place in December, as the soil in the rice paddies dries out, and rice grains turn yellow, indicating that they are fully ripe and ready for harvest (Supahan, 2022).

2.2. Data collection

2.2.1. Spatial variation

Ten automatic acoustic recorders (AudioMoth 1.0.0 full-spectrum detectors – Open Acoustic Devices, United Kingdom) were deployed to study the influence of spatial heterogeneity on the bird assemblage. Within the main landscapes surrounding each village, five locations were selected (5 villages x 5 locations = 25 sampling sites; Figure 2.1) and classified according to land cover type: “rice fields”, “forest areas”, “cashew orchards” and “fallow fields”. Acoustic recorders remained at each sampling site for three days, with nine nights between deployments. Devices were set to record for two 4-hour periods: in the morning from half an hour before sunrise, and in the afternoon ending one hour after sunset. Additionally, we recorded two 20-minute periods at heat peaks around noon. The recorder sample rate was set to 48 kHz, with medium gain, producing files with a duration of 5 minutes.

We employed aural identification to register species calls while analysing the acoustic recordings. We constructed a presence/absence matrix based on species occurrence in each file. We used accumulation curves by employing the ‘speccaccum’ function from the R package Vegan (Oksanen, 2013) to determine the necessary number of listening hours for achieving a representative sample of species richness. We analysed four 5-minute files per hour each day (3 hours and 20 minutes analysed per day). The selection of the days analysed was stratified and balanced between land cover types, villages and dates. A total of 22 days of rice field sampling, 14 days of forest area, 13 days of cashew orchard and 8 days of fallow field were analysed. Despite the small sample size, we included data from fallow fields because farmland birds frequently use these areas that are thus relevant for landscape management (Fujioka et al., 2001).

2.2.2. Temporal variation

Two observers conducted daily transects in the rice fields to assess the temporal variation of the bird assemblage throughout the rice growth cycle. In each, we established one transect, except in Bironqui, where we included two separate transects due to its larger area (Figure 2.1). Transect length ranged from 600 m to approximately 1.2 km, corresponding to the length of each rice field and based on pre-existing trails and ditches. The census area covered the width of the rice field plus 20-30 meters into the surrounding wooded edge, to survey the influence of neighbouring habitats. Transects were carried out at a constant pace, starting at sunrise, sampling the period of highest bird activity. All birds detected visually or acoustically during the transects were recorded and counted. It was also recorded if birds were detected in the “tree layer”, “shrub layer” or “herb layer”, and in “rice field”, “fallow field” or “wooded edge” (Figure 2.2). If birds were detected in the rice field, the rice development stage was also recorded. We used photographs and audio recordings made during the transects to aid in species identification. Human disturbance (e.g., women working in the rice field), and adverse climate conditions (e.g., fog or light showers) were recorded to prevent any possible bias. Extreme weather conditions were avoided. All bird movements were followed to prevent duplicates. Whenever individuals of the same species used different habitats or exhibited multiple habitat-use behaviours, priority was given to those with a higher impact on rice cultivation. For example, an Orange-cheeked waxbill *Estrilda melpoda* in both shrub and herb layers of rice fields and wooded areas was registered as primarily observed at herb layers within rice fields.

Figure 2.2 – Typical landscape of a lowland freshwater rice field of the Oio region of Guinea-Bissau. In this photo, it is possible to observe the different horizontal (rice field and wooded edge in the distance) and vertical habitats (tree, shrub and herb layers).

Species were classified into four ecological guilds (Table 2.1, appendix) adapted from the work by Katayama et al., 2020: Wetland (WL), Grassland (GL), Shrubland (SL) and Woodland species (WDL). Open Water, Wet Woodland and Urban species guilds were not considered due to the small number of occurrences. They were included in the four main guilds according to their ecologies. Taxonomic nomenclature follows the Clements Checklist of August 2021. Species classification into the four guilds was based on the habitat information available on Avibase (Tobias et al., 2021) and on a bird field guide for the region (Borrow and Demey, 2014).

2.3. Data analysis

2.3.1. Spatial variation

To evaluate how spatial variables affected the community of birds in this system we used the number of detected species per day (species richness) of each guild as the response variable. Each sampling site was characterised using a set of landscape variables (Table 2.2). The categorical variable is the landscape types, mentioned before. The density of vegetation cover was accounted as the percentage of wooded areas (forest areas and cashew orchards, which were merged due to difficult visual differentiation). This percentage was measured in the QGIS-LTR v.3.22.10-Białowieża (QGIS Core Development Team, 2019), within a 250 m-radius area (Barbe et al., 2018) of the sampling site. Radius distance was based on averaged landscape unit sizes. This was calculated by creating georeferenced polygons encompassing these forested areas overlaid to satellite images (© CNES/Airbus, 2019) of the sites sampled. We also considered four continuous variables: (1) the distance to the nearest village, (2) the distance to the nearest forested area, (3) the distance to the nearest road and (4) the total width of the rice fields. These measures were calculated using satellite images (© CNES/Airbus, 2019) and the digital distance tools from Google Earth Pro v. 7.3.6.9345 (Google Earth Core Development Team, 2022).

Most statistical analyses were performed on Past v.1.0.4 (Hammer et al., 2001). The effect of spatial variation on bird richness was first assessed through graphical analysis, gathering information from different landscape types. One-way analysis of variance (ANOVA) was used to test the differences with Kruskal-Wallis test and pairwise comparisons with Dunn's test to identify in which pairs the differences occurred (Munira et al., 2014). A Non-metric Multidimensional Scaling Ordination (NMDS) (Clarke and Warwick, 2001) was carried out using Jaccard dissimilarity index to visualise the degree of dissimilarity of species distribution among landscapes. The value of stress adequate to evaluate the goodness of fit of NMDS was set at 0.3. An overlap of the guilds' orientations was incorporated for better reading. An Analysis of Similarity (ANOSIM) was used to test the dissimilarities of the bird assemblage. This is a non-parametric permutations test, similar to ANOVA but designed for similarity matrices. An R-value close to one indicates dissimilarity between groups, negative values suggest that dissimilarities are greater within groups; and an R-value close to 0 suggests an even distribution of dissimilarities within and between groups. The influence of the landscape variables on bird composition was visualised through a Principal Component Analysis (PCA).

To measure the overall influence of our set of spatial variables on bird guild composition, a Multiple Multivariate Regression was conducted using the package "car" (Fox and Weisberg, 2019) in R v4.1.2 (R Development Core Team, 2021). These Multiple Multivariate Models (MMMs) are applied to multiple dependent variables, generating a compilation of several Generalised Linear Models (GLM) (Dray et al., 2012). Firstly, Pearson correlation tests were employed to evaluate all explanatory variables correlations. Although the correlation coefficients between most explanatory variables were moderate ($r < 0.7$), there was one exception: distance to the road and distance to the nearest village ($r = 0.802$), so distance to the road was excluded from the analysis. We conducted two MMMs: 1) one including mainly landscape variables such as density of vegetation cover, distance to the nearest village and distance to the nearest forested area; and 2) a within rice field univariate model with rice field width as a single explanatory variable.

2.3.2. Temporal variation

To assess changes in bird assemblages over time, we analysed data from all 57 days when transects were sampled. Data was standardised using transect length. Species richness was thus converted into "species/kilometre" and abundance in "individuals /kilometre" (Beja et al., 2010).

As one of the purposes of this study component is to assess the variation of bird habitat use over time, we used either day or fortnight periods as the main predictor variables. Habitat use data was organised into "rice field habitat use" (horizontal use) and "vegetative strata use" (vertical use), plus "rice development stage use" (Table 2.2).

Table 2.2 – Explanatory variables recorded throughout data collection and analyses, at a landscape scale involving all landscape types for spatial variation, and at a habitat scale inside rice fields for temporal variation.

Acronym	Variable description	Type	Range	Source
Spacial Variation on a Landscape Scale: Acoustic Stations				
landscape (land_rice, land_fallow, land_forest, land_cashew)	Types of landscapes where stations were setted	Categorical	Rice field Fallow field Forest area Cashew orchard	Field data
den_vegcov	Density of vegetative cover of the station's area	Proportion	0.210 - 0.870	Google Earth Pro
dis_forested	Distance from each station to the nearest forested area	Continuous	0 - 1 (km)	Google Earth Pro
dis_road	Distance from each station to the nearest road	Continuous	0.0350 - 1.370 (km)	Google Earth Pro
dis_village	Distance from each station to the nearest village	Continuous	0.065 - 1.580 (km)	Google Earth Pro
ricefield_width	Width of the rice field	Continuous	0 - 0.360 (km)	Google Earth Pro
Temporal Variation on a Habitat Scale: Transects				
hab	Habitat use of the individuals detected in the rice fields	Categorical	Rice Fallow field Wooded edge	Field data
rice_stage	Growth stage of the rice in which the individuals were detected	Categorical	1- Germination phase 2- Vegetative phase 3- Mature phase 4- Ripening phase 5- Ripened rice	Field data
strata	Vegetative strata use of the individuals detected in the rice fields	Categorical	Herb Layer Shrub Layer Tree Layer	Field data

Graphical representations of bird composition and habitat use variation over time were plotted using the packages ggplot2 (Wickman, 2009) with LOESS curve (Sprafke and Obreht, 2016) smoothing method to illustrate the variation peaks. The bird assemblage turnover was estimated with the package vegan (Oksanen, et al., 2020). The function 'vegdist' produced a pairwise distance matrix, with the Jaccard method. To identify the fortnights that differed from each other, this matrix was tested with the 'adonis' function resorting to a Permutational Multivariate Analysis of Variance (PERMANOVA) (Anderson, 2009). This was conducted using the Binomial method and 99999 permutations. A SIMPER analysis was performed with the 'simper' function, to identify which species contributed the most to the observed differences (Supahan, 2022).

The significance of statistical tests was considered at $\alpha = 0.05$, although weaker statistics ($\alpha = 0.10$) were also documented in some cases.

3. Results

We detected 127 species from 16 orders and 49 families (Figure 3.1). Passeriformes, Pelecaniformes and Coraciiformes were the most represented orders and Ardeidae, Columbidae and Accipitridae were the most represented families. Common birds accounted for 24.4% of the sampled species (31 species occurring on over 30% of the sampled days). The remaining species were classified as rare (21.3%, 27 species occurring between 15-30% of the days), very rare (19.7%, 25 species occurring between 5-15% of the days) or accidental (34.6%, 44 species occurring in less 5% of the days). The most frequently recorded species was the Vinaceous Dove (*Streptopelia vinacea*), followed by the Double-spurred Francolin (*Pternistis bicalcaratus*) and the Long-tailed Glossy Starling (*Lamprotornis caudatus*). In terms of guilds, 67 species (53.2%) were classified as shrubland species, 29 species (23%) as woodland species, 22 species (17.5%) as wetland species and 8 species (6.3%) as grassland species.

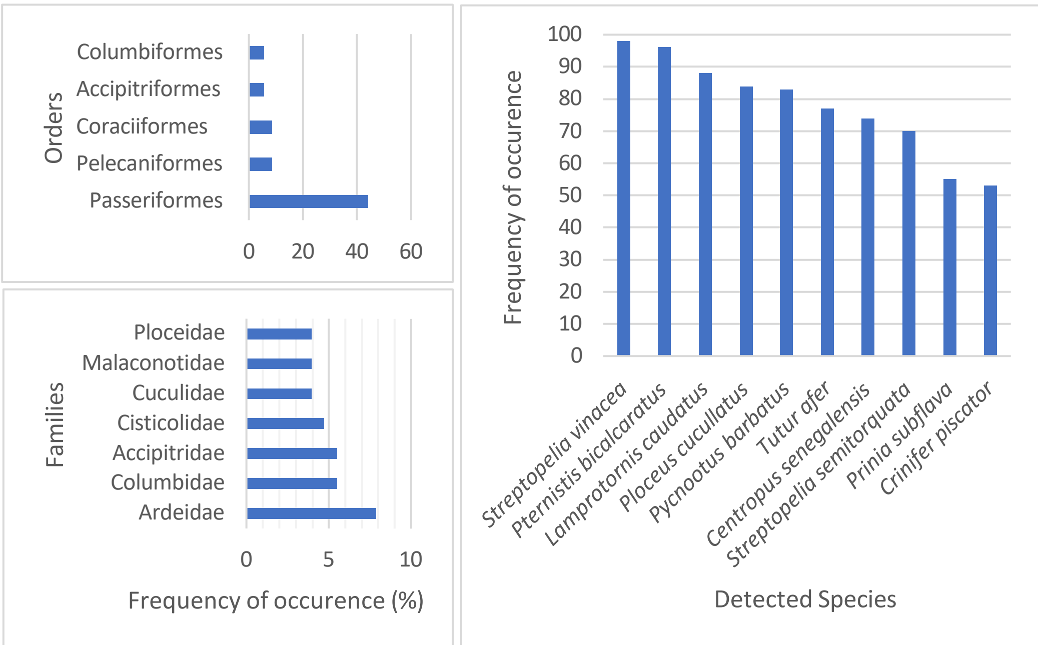

Figure 3.1 – Barplots of the most species-rich orders (top left), families (down left) and most frequent species (right) in the bird assemblages.

3.1. Spatial variation

We recorded 5725 bird vocalisations during acoustic sampling, encompassing 93 distinct species. There were significant differences in species richness between landscape types (Kruskall Wallis test, H = 17.3, df = 3, p-value <0.001), with lower species richness in cashew orchards and a higher in the rice fields (Figure 3.2). The median was similar between forest areas and fallow fields (Dunn's test, statistic = 0.293, p-value = 0.770). Almost all the other pairwise comparisons showed minor differences between landscape types; the only landscapes significantly different were rice fields and cashew orchards, with rice fields having a much higher species richness (Dunn's test, statistic = -4.178, p-value < 0.001).

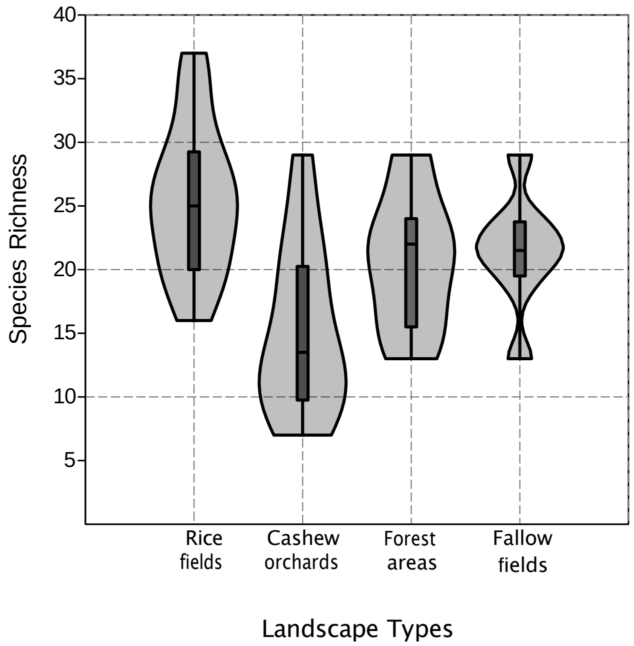

Figure 3.2 - Violin plot of the species richness of the assemblages of different landscape types.

The four guilds occurred in all landscape types considered (Figure 3.3). Wetland species were mostly recorded in fallow (65.64%) and rice fields (22.2%). Most grassland species were detected in rice (40.2%) and fallow fields (30.5%). Shrubland species and woodland species exhibited a more balanced occurrence between landscape types.

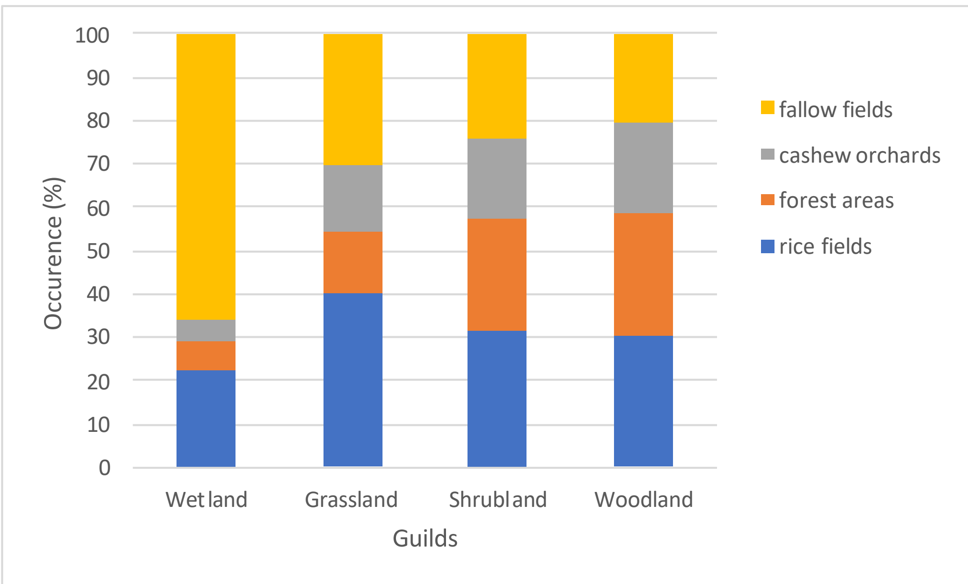

Figure 3.3 - Cumulative occurrence of each ecological guild across landscape types.

The assemblages overlap on the NMDS (Figure 3.4, left) confirms the pattern of guild occurrence in Figure 3.3. Woodland species showed no marked landscape tendencies and the remaining guilds generally preferred fallow and rice fields. The NMDS (stress value = 0.26) revealed a substantial overlap between species composition among the various landscape types. The bird assemblage in the rice fields displayed high levels of overlap with all other landscape types. While forest areas shared species with cashew orchards, the fallow fields exhibited a distinct composition. The Analysis of Similarities (ANOSIM) confirmed there is some degree of similarity in bird assemblage composition among landscape types, with a low R-value = 0.361 (p-value < 0.001), showing an even distribution of dissimilarities between and within landscape types. The pairwise comparison between all landscape types was significant, indicating that assemblages were as different from each other as within themselves.

The PCA (Figure 3.4, right) showed that the distance to the nearest forested area (forest area or cashew orchard) had the highest influence on the bird assemblage composition; followed by rice field width and density of vegetation cover - as well as the distance to the road with the distance to the nearest village. The field width had a slightly positive association with species richness. Distance to the nearest forested area influenced rice fields' species richness negatively. For this ordination, the first axis accounted for 66.569 and 20.748% of the variance. The second axis accounted for 40.227 and 27.506% of the correlation (Table 3.1, appendix).

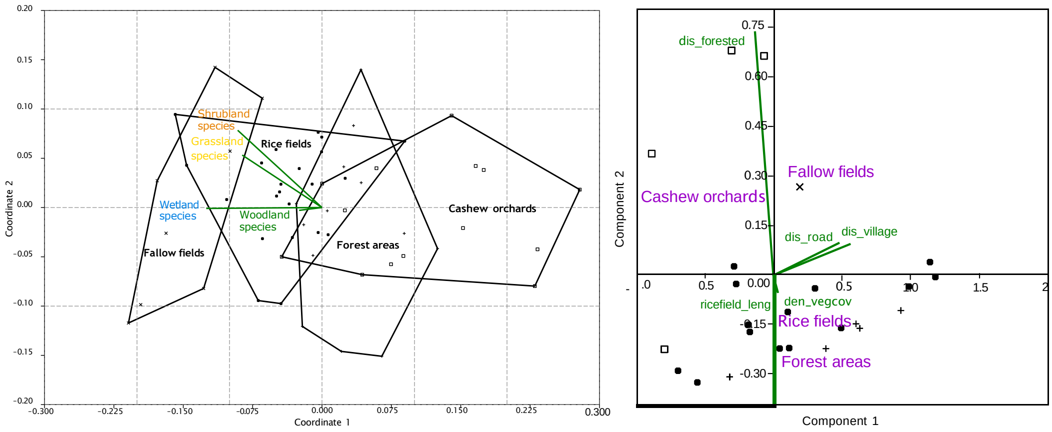

Figure 3.4 –Non-Metric Multidimensional Scaling (NMDS) ordination based on the species richness of the bird assemblages of the different landscape types, with an overlap of the tendencies of each ecological guild (left). Biplot from a Principal Component Analysis (PCA) of the landscape variables (in green) sampled (dots – rice fields, crosses – forest areas, squares – cashew orchards, exes – fallow field) (right).

Two models were adjusted using multiple multivariate regression to understand how landscape scale and rice field scale variables influenced each guild´s species richness (Table 3.2). The model at the landscape level revealed that total species richness decreased with distance to the nearest village and was lower in cashew orchards and forest areas in comparison to rice fields. Wetland species showed lower richness in cashew orchards and higher in fallow fields compared to rice fields. No differences were found in wetland species richness between rice fields and forest areas. For grassland species, species richness showed a negative relation with vegetation density. It was lower in cashew orchards and fallow fields. For shrubland species, richness was positively associated with density of vegetation cover and negatively with the distance to the nearest village. Once more, species richness was much lower in cashew orchards and forest areas than in rice fields. Lastly, woodland species richness was negatively associated with distance to the nearest village and richness was lower in cashew orchards. The density of the vegetation cover showed no effect on the species richness of this guild.

Table 3.2 - Results of Multiple Multivariate Regression for the effect of the landscape variables measured on species richness of the bird assemblage and each guild.

Dependent Variables	Independent Variables	Estimate	Std. error	P-value	Significance
All Species	(Intercept)	24,0064	3,6568	<0,001	***
	den_vegcov	11,4323	6,2241	0,072	.
	dis_forested	1,5578	4,0071	0,700	
	dis_village	-6,1453	2,1674	0,007	**
	land_cashew	-15,358	3,285	<0,001	***
	land_forest	-6,3477	2,285	0,008	**
	land_fallow	-0.8878	3,137	0,778	
Wetland Species	(Intercept)	1,308	0,6262	0,042	*
	den_vegcov	0,1816	1,0658	0,865	
	dis_forested	0,9433	0,6861	0,175	
	dis_village	-0,35	0,3711	0,350	
	land_cashew	-1,6403	0,5625	0,005	**
	land_forest	-0,7466	0,3913	0,062	.
	land_fallow	2,1505	0,5372	<0,001	***
Grassland Species	(Intercept)	2,31518	0,49746	<0,001	***
	den_vegcov	-2,07219	0,84672	0,018	*
	dis_forested	0,69768	0,54512	0,207	
	dis_village	0,08243	0,29486	0,781	
	land_cashew	-0,98742	0,44689	0,032	*
	land_forest	-0,40289	0,31084	0,201	
	land_fallow	-1,08193	0,42675	0,014	*
Shrubland Species	(Intercept)	14,428	2,339	<0,001	***
	den_vegcov	8,389	3,982	0,040	*
	dis_forested	-1,021	2,564	0,692	
	dis_village	-3,28	1,387	0,022	*
	land_cashew	-8,446	2,102	<0,001	***
	land_forest	-4,15	1,462	0,007	**
	land_fallow	-1,022	2,007	0,613	
Woodland Species	(Intercept)	5,9549	1,5939	<0,001	***
	den_vegcov	4,9336	2,7129	0,075	.
	dis_forested	0,9376	1,7466	0,594	
	dis_village	-2,5973	0,9447	0,008	**
	land_cashew	-4,2839	1,4318	0,004	**
	land_forest	-1,0486	0,9959	0,297	
	dis_forested	-0,9344	1,3673	0,498	

At the rice field scale the model showed that the width of the rice fields had no significant effect on species richness, whether considering each guild separately or the entire assemblage (Table 3.3).

Table 3.3 - Results of Multiple Multivariate Regression for the effect of rice field width on species richness of the bird assemblage and each guild.

Dependent Variables	Independent Variables	Estimate	Std. error	P-value	Significance
All Species	(Intercept)	27,863	2,877	<0,001	***
	ricefield_width	-14,076	14,891	0,356	
Wetland Species	(Intercept)	1,349	0,5393	0,021	*
	ricefield_width	-0,6982	2,7913	0,805	
Grassland Species	(Intercept)	0,9702	0,4712	0,053	.
	ricefield_width	1,9964	2,4391	0,423	
Shrubland Species	(Intercept)	17,896	1,803	<0,001	***
	ricefield_width	-9,574	9,331	0,317	
Woodland Species	(Intercept)	7,647	1,27	<0,001	***
	ricefield_width	-5,8	6,574	0,388	

3.2. Temporal variation

During the transects we detected 8650 birds (mean ± SE: 24.11 ± 14.94 birds per transect, but only 11.57 ± 47.59 if excluding Village weaver *Ploceus cucullatus*) belonging to 110 species (6.12 ± 7.17 species per transect) (Table 3.4).

Table 3.4 - Average and standard error values for species richness and abundance (including and excluding *P. cucullatus*) per sampled week.

Species Richness

	02/oct	09/oct	16/oct	23/oct	30/oct	06/nov	13/nov	20/nov	27/nov	4/dec	11/dec	total
Mean	5,71	8,87	6,96	4,99	5,56	7,06	5,77	6,24	6,85	5,73	3,92	6,12
Standard Error	7,41	8,89	9,11	5,30	6,74	7,54	7,21	5,58	8,29	5,88	5,21	7,17

Abundance

	02/oct	09/oct	16/oct	23/oct	30/oct	06/nov	13/nov	20/nov	27/nov	4/dec	11/dec	total
Mean	20,20	37,35	20,43	18,90	17,51	30,18	20,10	25,02	20,46	41,95	11,33	24,11
Standard Error	14,02	16,71	17,12	10,48	15,72	15,17	13,76	10,44	21,86	12,35	14,69	14,94
Mean (without *Ploceus cucullatus*)	10,49	16,56	11,86	9,26	10,84	11,92	11,09	10,88	14,78	11,17	11,12	11,57
Standart Error (without *Ploceus cucullatus*)	35,14	51,28	28,41	22,08	24,12	39,11	23,43	40,33	27,52	106,86	15,18	47,59

Figure 3.5 summarises the number of bird observations in the rice fields across various crop development stages, highlighting the turnover between these stages. At the end of the germinative stage (first week of October), the vegetative stage thrived, with many parcels at this stage. However, as October progressed into the second half, corresponding to the onset of the reproductive stage, observations of this rice development phase began to decline. By the end of October, the mature grain phase dominated and persisted throughout most of November. In the final weeks of November, this stage gradually receded as the ripening stage evolved, lasting until the end of the sampling period.

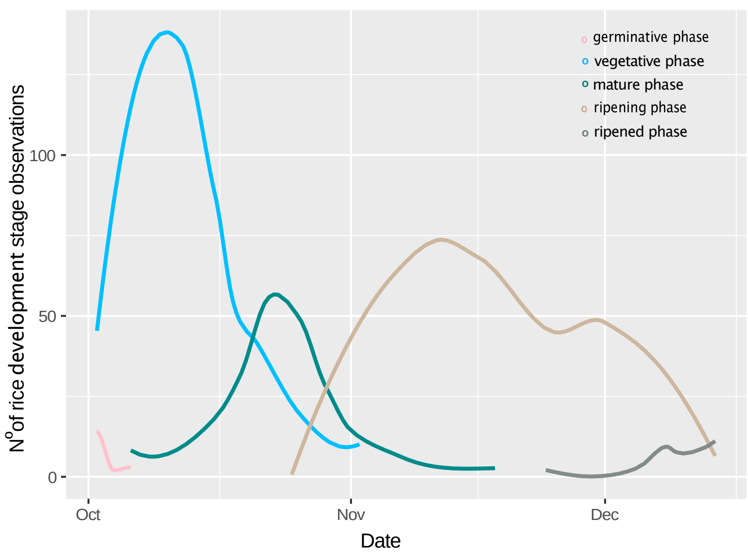

Figure 3.5 - Plot representation of the progress of rice development stages throughout the sampling period.

Bird abundance and richness varied throughout the rice growth cycle (Figure 3.6). There are two noticeable waves with peaks of abundance and richness by the middle of October and by the end of November – the beginning of December.

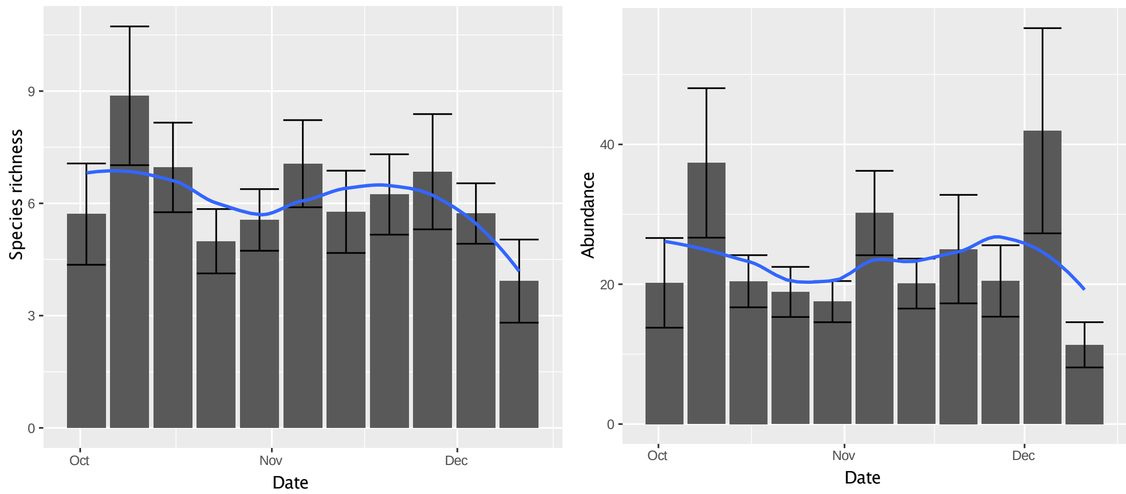

Figure 3.6 - Bar plots (average values with 95% confidence values) of the species richness (left) and abundance (right) variation along the cultivation season sampled from the beginning of October to the middle of December (joined with LOESS smoothing curve).

In terms of ecological guilds, each exhibited distinct patterns of variation in both richness and abundance over time. Wetland species (Figure 3.7) significantly decreased in both richness and abundance throughout the sampling period. Grassland species (Figure 3.8) revealed the inverse trend, showing an increase throughout the rice growing season.

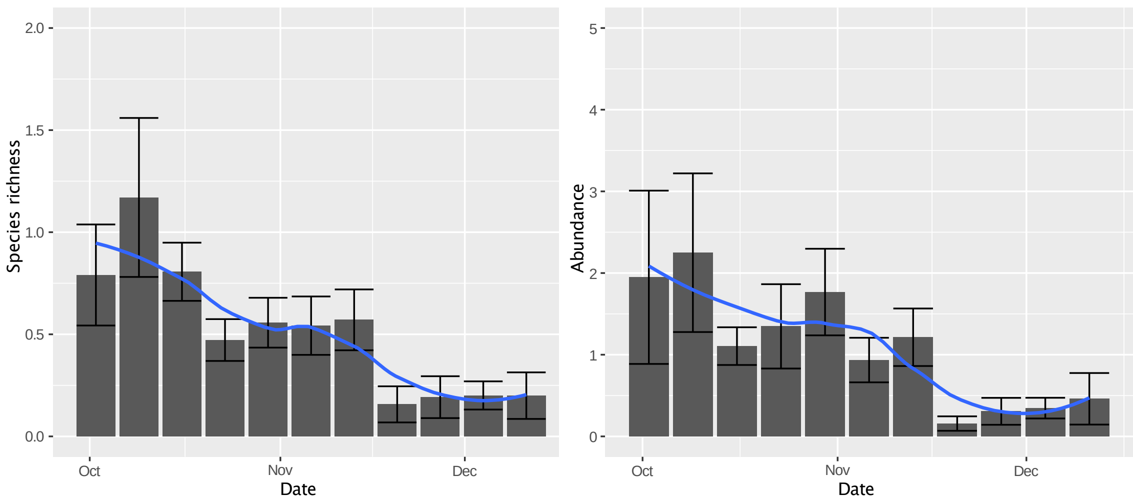

Figure 3.7 - Bar plots (average values with 95% confidence values) of the species richness (left) and abundance (right) variation of Wetland species, along the cultivation season sampled (joined with LOESS smoothing curve).

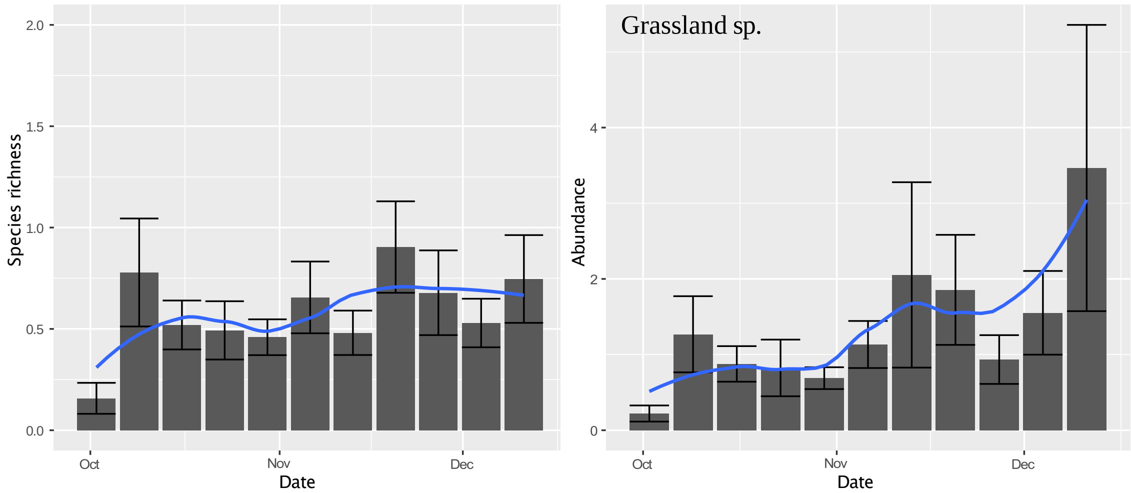

Figure 3.8 - Bar plots (average values with 95% confidence values) of the species richness (left) and abundance (right) variation of Grassland species, along the cultivation season sampled (joined with LOESS smoothing curve).

Shrubland and woodland species (Figure 3.9) did not exhibit such clear patterns. Both revealed similarly marked curves across time, with lower periods: the first in the final October/onset of November and a more prominent one at the end of November/onset of December.

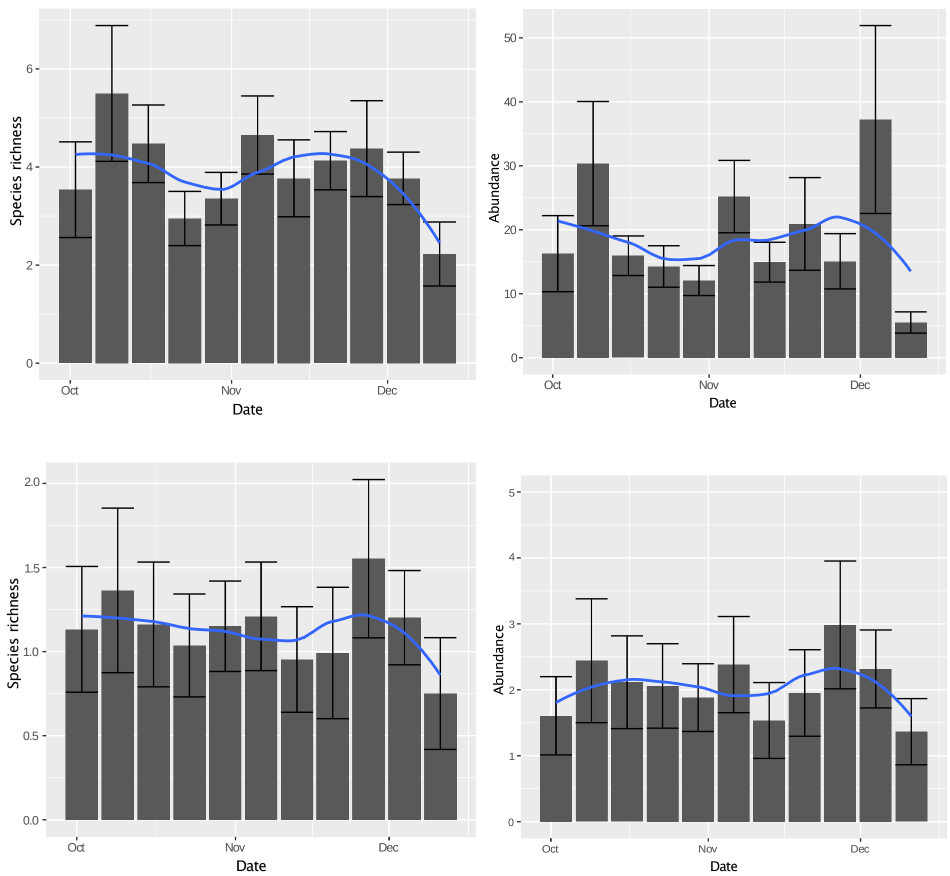

Figure 3.9 - Bar plots (average values with 95% confidence values) of the species richness (left) and abundance (right) variation of Shrubland species (above) and Woodland species (below), along the cultivation season sampled (joined with LOESS smoothing curve).

For the turnover of species analyses, the PERMANOVA revealed very significant differences between fortnights (df = 4, R2 = 0.121, F= 1.784, p-value = 1e-05). Differences were found between most fortnights (Table 3.5).

Fortnights Comparisons	F	R2	p-value
2/out vs 16/out	1,609	0,082	0,059
2/out vs 30/out	1,861	0,089	**0,026**
2/out vs 13/nov	1,952	0,122	**0,030**
2/out vs 27/nov	3,315	0,131	**<0,001**
16/out vs 30/out	1,364	0,056	0,162
16/out vs 13/nov	2,113	0,105	**0,006**
16/out vs 27/nov	2,965	0,102	**<0,001**
30/out vs 13/nov	1,174	0,058	0,295
30/out vs 27/nov	2,607	0,088	**<0,001**
13/nov vs 27/nov	1,635	0,069	**0,048**

Table 3.5 - Pairwise PERMANOVA testing values for the effects of fortnights on species occurrence. Significant values (<0,005) are in bold.

The bird assemblage composition turnover was verified, as illustrated in the bigraph with the most frequent species (present in at least 30% of sampling) signaled (Figure 3.10). Wetland species had more significant differences between the first fortnight of October and all the other periods. Most of these species showed a frequency decrease over time. There was no significant variation over time in the composition of grassland species. Being the most frequent ecological guild, shrubland species were the strongest driver of the composition turnover of the bird assemblage. Generally, shrubland species showed more significant differences from the middle of October to the middle of November. Woodland species displayed the highest differences in the last two fortnights of the sampling season.

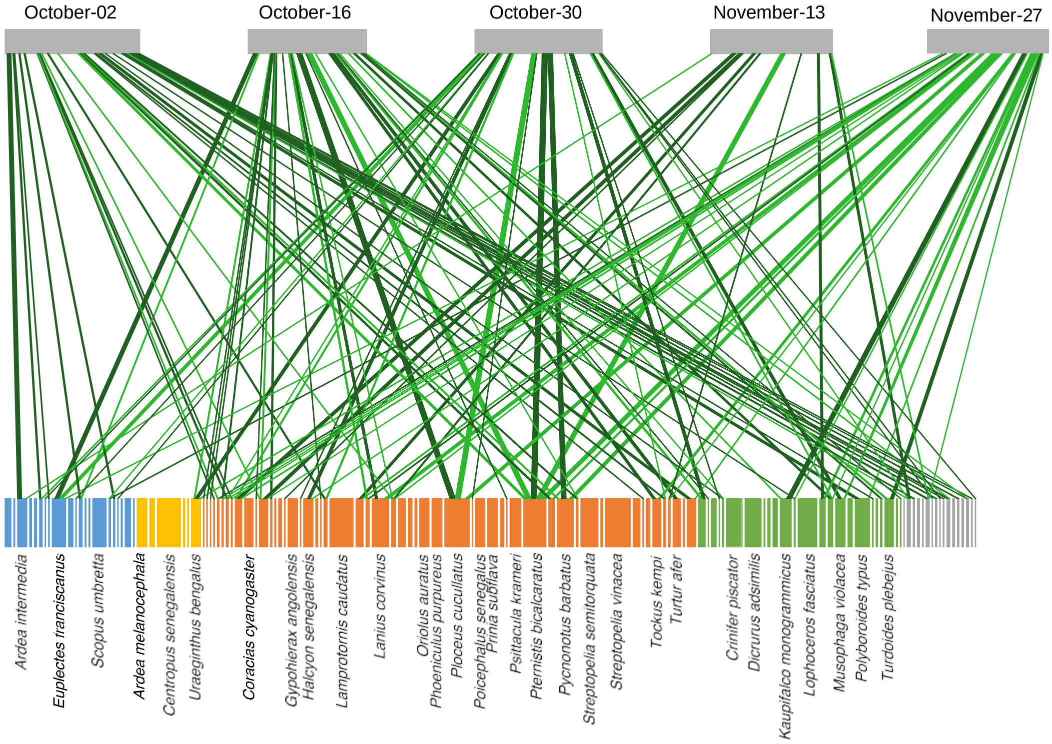

Figure 3.10 – Bigraph of the species and ecological guild distribution per fortnight sampled. Green links indicate species in different proportions (dark green – significant differences; light green – lower differences) over the five fortnights, obtained from the SIMPER analysis. The width of links is proportional to their frequency of occurrence. Species boxes are proportional to the sum of the frequency of occurrence of all interactions in that fortnight and across fortnights, respectively. Species box colour corresponds to the respective ecological guild (Blue – wetland species; yellow – grassland species; orange – shrubland species; green – woodland species; grey – no guild attributed, as it was not identified to the species level). Only the most frequent species (more than 30% of the average monthly frequency of occurrence in transects) have their name displayed.

Finally, to examine how vertical strata and habitat use of bird assemblages fluctuated over time, we visually represented the variation of these types of usage per fortnight (Figure 3.11). Overall, both patterns of richness and abundance were similar. Birds used rice fields and wooded edges significantly more than fallow fields. When there was an increase in the use of wooded edges, a decrease in the use of rice fields followed around the end of October. In the vegetative strata use, birds used the tree layer the most, followed by the shrub and herb layers. No variation in the shrub and herb layers use was observed through the sampled period. However, the use of the tree layer was higher in the first weeks of October and November.

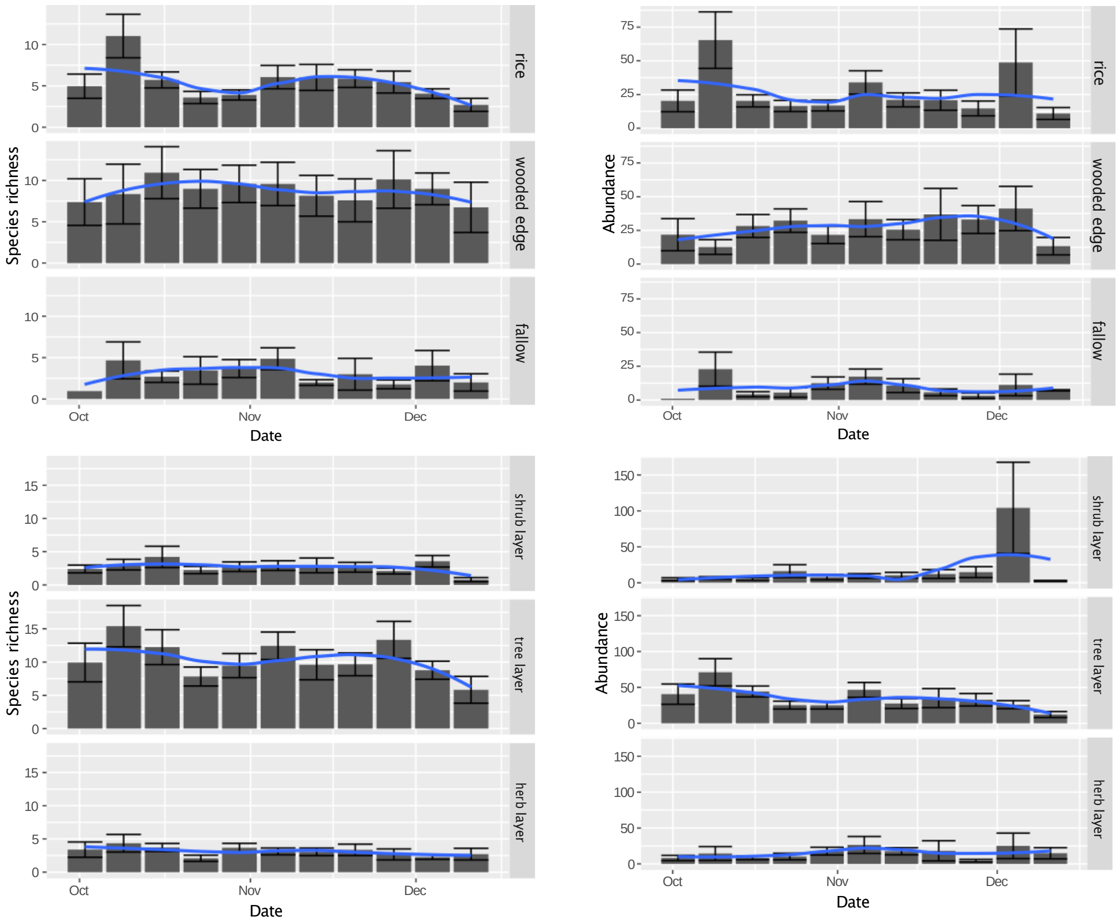

Figure 3.11 - Bar plots (average values with 95% confidence values) of species richness (left) and abundance (right) of the horizontal (above) and vertical (below) habitat use along the cultivation season sampled (joined with LOESS smoothing curve).

4. Discussion

This study identified species from all four ecological guilds considered, highlighting the co-existence of diverse bird species within this agricultural landscape. Passeriformes was the most detected order in this study since most species detected are adapted to dry regions. Contrastingly, Pelecaniformes are more adapted to wet environments, probably complementing the previous order on using landscapes and habitats. Coraciiformes are common in West Africa, highlighting the strong resident component of the bird assemblage of this region. Columbidae and Accipitridae, two of the most detected families, were consistent with their tendency to utilise habitats closer to human populations (Floigl et al., 2022). In terms of occurrence, common species are outnumbered by rare species, indicating species turnover in these bird assemblages due to fluctuations in habitat and landscape over time. Bird assemblage composition is collectively shaped by the various ecological guilds and by rare and common species.

4.1. Spatial variation

Regarding ecological guilds, wetland species were primarily detected in fallow fields, followed by rice fields. These species favour landscape types with higher water content, which aligns with our findings. The preference for fallow fields can be explained by their more diverse vegetation and associated biodiversity. In fact, fallow fields are rice fields that remain uncultivated for at least one season, stimulating the growth of native vegetation in the absence of rice production. The vegetation in fallow fields supports a rich farmland biodiversity - plants, invertebrates and frogs - (Koshida and Katayama, 2018) while providing food, shelter and nesting sites. Thus, agricultural landscapes containing wet fallow fields are likely a better suited for wetland species than landscapes with only cultivated rice. Grassland species were detected mostly in rice fields, followed by fallow fields. This was expected since these landscapes are characterised by farming in open habitats. The preference of this ecological guild for rice fields may be attributed to its greater adaptability to habitats with less diverse vegetation. Such adaptations allow these birds to find adequate breeding sites, shelter, or food sources in rice paddies. Both shrub and woodland species displayed an even distribution across all four landscape types, with a slightly lower occurrence in fallow fields and being more frequent in forest areas. Previous studies also showed that many of the species detected in forested areas are only found in croplands when there are surrounding uncultivated patches (Marigliano et al., 2010). In fact, most agroecosystems species may depend on uncultivated patches with natural environments, not typically found in intensive agriculture landscapes (Goijman et al., 2015).

Regarding the similarities of the bird assemblages between each landscape type, fallow fields shared a high number of bird species with rice fields, which may be explained by their similar vegetation structure and previous management. The resemblance between species composition in rice fields and forest areas can be attributed to the bird assemblages´ complementary utilisation of both landscape types (Guadagnin et al., 2012). The resemblance between forest areas and cashew orchards is probably due to being closed-wooded habitats. Although there is a significant overlap in species composition across different landscapes, certain species, often less common, show a stronger association with specific landscape types. This indicates a gradient of landscape type use and underscores the importance of maintaining habitat heterogeneity.

Several landscape descriptors have proved to be important drivers of bird species richness, such as vegetation cover (King et al., 2016), distance to the refuge (Guillemain et al., 2002), rice field size (Sebastián-González and Green, 2014) and landscape configuration (Pérez-García et al., 2014). Some of these descriptors also proved influential in our study. Density of vegetation cover negatively influenced the bird assemblage in the cashew orchards and positively in the forest areas. Both are wooded areas but differ in their plant diversity - cashew orchards are monocultures, have their undergrowth cleaned yearly and are thus less diverse. For this reason, this landscape type may not be so attractive for birds, contrasting with a higher microhabitat diversity in forested areas. As expected, the richness of grassland species declined in areas of dense vegetation cover. In contrast, shrubland species increased in these areas due to their preference for more closed habitats.

Species richness within rice fields declines with the increasing distance to the nearest forested area, confirming the importance of preserving native forested habitats near these farmed areas. Many studies showed a similar pattern, since forested areas close to rice cultures can act as refuge areas and allow birds to use both landscape types, obtaining the necessary nutrients for their day-to-day requirements with minimal expenditure of energy (Toral et al., 2011). Contrary to what was expected, species richness increased near human settlements, being shrub and woodland species significantly influenced by this factor. This result illustrates that while human disturbance can affect bird populations, certain bird species, including those dependent on denser environments, can coexist with human activities when they are of low impact (Tryjanowski et al., 2020).

Previous research has established the importance of rice field size in relation to birds' ecological needs. In our study, we observed that the width of rice fields had a limited impact on the species richness of bird assemblages within this landscape type, displaying a minor positive association but lacking a significant effect. This was likely because the sampled rice fields are confined to the narrow floodplains around local small rivers, resulting in their limited width. Further research is needed to definitively conclude whether bird assemblages are influenced by this variable.

4.2. Temporal variation

We observed notable fluctuations in species richness and abundance throughout the rice growing cycle, indicating a significant influx and departure of birds during this period. These fluctuations show that these assemblages are dynamic in time. Noticeable are the peaks of bird abundance and richness at the beginning of October and before the start of November, which correspond to the transition between rice stages. Several studies have shown that birds occupy rice fields in a predictable pattern, depending on habitat conditions (Erwin, 2002). Water availability is pivotal for rice germination and growth, starting with the first substantial rains. These rainfall-driven rice growth patterns also influence bird populations, confirming that bird assemblages respond to temporal changes in the rice field habitat (Santillan, 2018).

All ecological guilds display fluctuations in richness and abundance through time. Wetland species decreased and grassland species increased as the fields dried out. This indicates some turnover between these two guilds, a pattern also observed in other studies (Boyle et al., 2010; Williams and Middleton, 2008). The significant increase in grassland species' abundance occurs mostly due to the flocks of *P. cucullatus*, a species which is very common across Africa. Shrubland and woodland species presented similar patterns. Woodland species increased at the beginning of December when the rice grain was already ripe, and shrubland species abundance increased when the grain matured. Once again, this complementarity through time reveals the existence of ecological guild turnover. Other studies that assessed bird food availability in rice fields (Iwata and Fujioka, 2006) showed that the composition of bird assemblages varied with the type of food available in the fields, from aquatic insects in the first weeks of cultivation, to mature grain in the ripening phase (Mohd-Taib et al., 2018). This could be one reasonable explanation for our study case. Further studies would be necessary to validate this possibility.

The bird assemblage's composition turnover verified demonstrated bird assemblages stay stable during the periods of rice stage dominance and once more that bird assemblages vary with rice stages.

Wetland species presented significant differences between the first weeks of the cultivation season and the others, corroborating the hypothesis that habitat characteristics (in this case, water availability) influence assemblage composition. As stated earlier, most of these species showed a decrease over time. *E. franciscanus* decreased exponentially from the first to the last fortnight. The probable cause of this event was that this species was mainly detected in vegetation lines along dikes. This shows that human actions can directly impact bird assemblages in this area. Shrubland species were the strongest drivers of the bird assemblage change, being the most abundant and frequent guild in the area and for this habitat configuration was ideal for the species of this ecological guild. Some of the most frequent shrubland species show a gradual increase during the rice maturation period grains, followed by a decrease as grains desapear, probably due to an increase in food availability, for some of the species of this guild. For further conclusions, it will be necessary to study other aspects of this group ecology, namely their behaviour and diet. Woodland species showed a larger variation in the last two fortnights of October when the rice vegetative stage was at its highest. Once more, this phase corresponds to the period in which environmental conditions are not as adverse, with a green landscape and medium-water availability. This scenario encompasses the highest foraging suitability of rice fields for these animals. Furthermore, a significant proportion of the detected species consisted of migratory birds. During the study period, the area's configuration made the rice fields potentially appealing to these birds, allowing them to preferentially utilise the space (Longoni, 2010).

Various works highlighted the importance of the temporal variation in the use of horizontal habitat (Wood et al., 2010) and vertical vegetation strata (Núñez et al., 2019) within rice fields. Regarding the horizontal habitat use, an increase in wooded edge activity coincided with a decline in rice field use towards the end of October. This may be explained by species that use the rice fields to find better habitat conditions in the wooded edges when the rice fields dry out. At this scale, the distances between these two habitats are relatively short, allowing for greater flexibility and enabling a gradual transition from rice fields to wooded edges, which can vary in duration throughout the day. Even migrant individuals may try this strategy before returning to their migratory routes. The vertical utilization pattern, with increased tree usage both before panicle initiation and after grain ripening, indicates that bird communities in rice fields utilize the shrub strata during the grain season, likely to access food resources provided by the rice plantations more easily. This highlights the importance of habitat structural complexity (Frutos et al., 2016).

4.3. Limitations & future studies

In this study, we performed a comprehensive examination beyond cultivation management contributions, delving into multiple dimensions. Specifically, we investigated the impact of spatial and temporal heterogeneity in agricultural landscapes, particularly in rice fields, on bird communities. This aspect has received limited attention to date. Our investigation extended to habitat-level observations within rice fields and landscape-wide assessment in their vicinity. This multiscale approach provided fresh insights into the composition and variation of bird communities as holistic systems, encompassing activities not confined solely to the rice fields. We have shown that each ecological guild exhibited distinct associations with various landscape types and other factors that varied significantly between seasons. These findings underscore the complementary roles of spatial and temporal landscape configuration in bird assemblages throughout the rice cultivation season.

It should be noted that this study was conducted in a single annual cycle, showing lower representation than a study encompassing several years. It could have also been considered a larger number of sampling sites and a higher number of recordings for better representation and higher model reliability. All results concerning fallow fields should be cautiously regarded, as we had only a single sampling site in this habitat type.

In future studies, we recommend upscaling the survey to an all-year-round sampling, considering the ecological characteristics of each bird species and diet categories. In that way, along with the collection of food availability seasonal variation data, it will be possible to study a whole new dimension of the bird assemblages of this area. A more comprehensive characterisation of the sampling sites, such as measuring the water availability, would be necessary to further support our conclusions. In addition, it would be interesting to quantify landscape type changes that may have occurred in the last decades, determine patterns of change, and document the current condition since vegetation acts as an environmental indicator. We would also suggest expanding the analysis of each species and the comprehension of habitat use, recording the behaviour and movements of the individuals detected.

4.4. Implications for conservation

The avifauna of Guinea-Bissau include a total of 548 species (Tobias et al., 2021). This study area has then revealed itself as a rich habitat for 127 of those species. Bironqui and Demba So stand out as significant conservation sites among the studied villages. These sites are noteworthy for their high species diversity and abundant bird populations. Consequently, we recommend and anticipate the continuation of conservation efforts in these areas.

Even though these areas serve productive purposes, they can still play a vital role in bird conservation in tandem with the ecosystem services offered by biodiversity (Green and Elmberg, 2014; Sutton-Grier and Sandifer, 2019). From a broader perspective, Guinea-Bissau is located in a region of particular global importance for bird conservation since many species are migrants, in decline or depend on this area for at least a part of the year (Birdlife International, 2018). To promote greater diversity, preserving vital habitats and definition of sites for conservation is necessary. These locations require long-term monitoring and management and will gain global recognition due to international visibility and consequential priority in conservation.

Our results indicated that a diverse range of landscape types was necessary to satisfy the habitat requirements of the bird assemblage present in the area. To sustain such a rich diversity of bird species, it is crucial to preserve a balance between rice fields and their surrounding habitats (Beja et al., 2010). To reach this goal, it is necessary to establish appropriate methods for rice paddy ecosystem management on a landscape scale (Amano et al., 2008). Although this management may not be effective for species susceptible to external disturbances (Kim et al., 2009), wildlife benefits will likely emerge. To highlight the significance of rice fields as valuable habitats for birds, it will be necessary to draw the attention and support of a diverse range of stakeholders, including political entities, conservation practitioners, and local communities. Therefore, conservation efforts, strict regulation and awareness campaigns should be implemented to develop sustainable ecosystems that benefit humans and wildlife communities. A collaborative conservation effort with organisations like KAFO, a non-profit rural organisation that acts in the area (KAFO, 2022), is fundamental for effective awareness and monitoring programs. To develop holistic, sustainable management and conservation strategies, work in rice fields can start with simple bird surveys in other areas across Western Africa. Understanding the spatial and temporal dynamics of species assemblages in response to shifts in temperature and precipitation may also be helpful in species response projections to future climatic conditions (Santillan, 2018). Many studies that measured bird food composition and availability in these habitats registered arthropods in birds' diets (Iwata and Fujioka, 2006; Mohd-Taib et al., 2018; Acosta et al., 2010; Cruz-Garcia and Price, 2011). Thus, birds may be able to act as biological control agents for some agricultural pests, promoting a reduction in the use of agrochemicals during rice growth (Kim et al., 2009). The use of agrochemicals, aside from being expensive and harmful to humans and wildlife, affects the soil and water of ecosystems (Furihata et al., 2019). Promoting the adoption of nature-based pest control methods among farmers will raise local population awareness, enhance rice field productivity, and contribute to the conservation and prosperity of birds, other wildlife, and ecosystems (Khatiwada et al., 2016).

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6. Appendix

Table 2.1 - List of expected species in the region based on the habitat information available on Avibase (Tobias et al., 2021), reinforced by the information from the field guide " Birds of Western Africa" (2nd edition, 2014), and respective attributed ecological guild category. Lighter grey comprises species detected only on acoustic stations, medium grey detected only on transects and darker grey to species detected in both methods. Taxonomic nomenclature follows the Clements Checklist of August 2021.

Scientific Name	Common Name	Ordem	Família	Habitats Used (Birds of West Africa Guide)	Habitat in Avibase	Final Category
Microcarbo africanus	Long-tailed Cormorant	Suliformes	Phalacrocoracidae (Cormorants and Shags)	Open water species	Wetland	WL
Nycticorax nycticorax	Black-crowned Night Heron	Pelecaniformes	Ardeidae (Herons, Egrets, and Bitterns)	Woodland species		WDL
Ixobrychus sturmii	Dwarf Bittern	Pelecaniformes	Ardeidae (Herons, Egrets, and Bitterns)	Wet woodland species	Wetland	WL
Butorides striata	Green-backed Heron	Pelecaniformes	Ardeidae (Herons, Egrets, and Bitterns)	Wet woodland species	Wetland	WL
Ardeola ralloides	Squacco Heron	Pelecaniformes	Ardeidae (Herons, Egrets, and Bitterns)	Wetland species		WL
Bubulcus ibis	Cattle Egret	Pelecaniformes	Ardeidae (Herons, Egrets, and Bitterns)	GL/WL/WWL	Grassland	GL
Egretta ardesiaca	Black Heron	Pelecaniformes	Ardeidae (Herons, Egrets, and Bitterns)	WL/OW/WWL	Wetland	WL
Egretta gularis	Western Reef Egret	Pelecaniformes	Ardeidae (Herons, Egrets, and Bitterns)	OW/WWL	Coastal	WL
Egretta garzetta	Little Egret	Pelecaniformes	Ardeidae (Herons, Egrets, and Bitterns)	WL/OW/WWL	Wetland	WL
Ardea intermedia	Intermediate Egret	Pelecaniformes	Ardeidae (Herons, Egrets, and Bitterns)	WL/OW/WWL	Wetland	WL
Ardea alba	Great Egret	Pelecaniformes	Ardeidae (Herons, Egrets, and Bitterns)	WL/OW/WWL	Wetland	WL
Ardea cinerea	Grey Heron (cc Gray Heron)	Pelecaniformes	Ardeidae (Herons, Egrets, and Bitterns)	WL/OW/WWL	Wetland	WL
Ardea melanocephala	Black-headed Heron	Pelecaniformes	Ardeidae (Herons, Egrets, and Bitterns)	Grassland species		GL
Scopus umbretta	Hamerkop	Pelecaniformes	Scopidae (Hamerkop)	WL/OW/WWL	Wetland	WL
Dendrocygna viduata	White-faced Whistling Duck	Anseriformes	Anatidae (Ducks, Geese, and Waterfowl)	Open water species		WL
Plectropterus gambensis	Spur-winged Goose	Anseriformes	Anatidae (Ducks, Geese, and Waterfowl)	Wetland species		WL
Pandion haliaetus	Osprey	Accipitriformes	Pandionidae (Osprey)	OW/WWL	Marine	WL
Haliaeetus vocifer	African Fish Eagle	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	Open water species	Wetland	WL
Gypohierax angolensis	Palm-nut Vulture	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	OWL/GL/OWL	Forest	SL
Necrosyrtes monachus	Hooded Volture	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	Urban species	Shrubland	SL
Trigonoceps occipitalis	White-headed Vulture	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	Open woodland species		SL
Gyps africanus	White-backed Vulture	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	Open woodland species		SL
Gyps rueppelli	Ruppell's Vulture	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	Open woodland species		SL
Elanus caeruleus	Black-shouldered Kite	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	Grassland species		GL
Milvus migrans	Black Kite	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)		Woodland	WDL
Circus pygargus	Montagu's Harrier	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	Wetland species		WL
Circus macrourus	Pallid Harrier	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)		Grassland	GL
Circus aeruginosus	Eurasian Marsh Harrier	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	Wetland species		WL
Polyboroides typus	African Harrier Hawk	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	Woodland species		WDL
Circaetus beaudouini	Beaudouini's Snake Eagle	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	Open woodland species		SL
Circaetus cinereus	Brown Snake Eagle	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	Open woodland species		SL
Lophaetus occipitalis	Long-crested Eagle	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	OWL/GL	Forest	SL
Kaupifalco monogrammicus	Lizard Buzzard	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	WDL/GL	Woodland	WDL
Accipiter badius	Shikra	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	OWL/WDL/GL	Shrubland	SL
Accipiter erythropus	Red-thighed Sparrowhawk	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	WDL/OWL/WWL	Forest	SL
Accipiter melanoleucus	Black Sparrowhawk	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	Woodland species		WDL
Accipiter tachiro	African Goshawk	Accipitriformes	Accipitridae (Hawks, Eagles, and Kites)	OWL/WWL	Forest	WDL
Falco tinnunculus	Common Kestrel	Falconiformes	Falconidae (Falcons and Caracaras)	OWL/GL	Shrubland	SL
Falco ardosiaceus	Grey Krestel	Falconiformes	Falconidae (Falcons and Caracaras)	WDL/OWL/GL	Woodland	SL

Table 2.1 (continuation) - List of expected species in the region based on the habitat information available on Avibase (Tobias et al., 2021), reinforced by the information from the field guide " Birds of Western Africa" (2nd edition, 2014), and respective attributed ecological guild category. Lighter grey comprises species detected only on acoustic stations, medium grey detected only on transects and darker grey to species detected in both methods. Taxonomic nomenclature follows the Clements Checklist of August 2021.

Scientific Name	Common Name	Ordem	Família	Habitats Used (Birds of West Africa Guide)	Habitat in Avibase	Foraging Guild
Falco peregrinus	Peregrine Falcon	Falconiformes	Falconidae (Falcons and Caracaras)		Grassland	GL
Falco biarmicus	Lanner Falcon	Falconiformes	Falconidae (Falcons and Caracaras)		Shrubland	SL
Gelochelidon nilotica	Gull-billed Tem	Charadriiformes	Laridae (Gulls, Terns, and Skimmers)	Open water species	Coastal	WL
Pternistis bicalcaratus	Double-spurred Francolin	Galliformes	Phasianidae (Pheasants, Grouse, and Allies)	OWL/GL	Woodland	SL
Pternistis ahantensis	Ahanta Francolin	Galliformes	Phasianidae (Pheasants, Grouse, and Allies)	OWL/GL	Forest	SL
Ptilopachus petrosus	Stone Partridge	Galliformes	Odontophoridae (New World Quail)	WDL/GL	Rock	SL
Zapornia flavirostra	Black Crake	Gruiformes	Rallidae (Rails, Gallinules, and Coots)	WL/WWL	Wetland	WL
Gallinula chloropus	Common Moorhen	Charadriiformes	Jacanidae (Jacanas)	WL/WWL	Wetland	WL
Actophilornis africanus	African Jacana	Charadriiformes	Jacanidae (Jacanas)	Wetland species		WL
Himantopus himantopus	Black-winged Stilt	Charadriiformes	Recurvirostridae (Stilts and Avocets)	Wetland species		WL
Charadrius forbesi	Forbes' Plover	Charadriiformes	Charadriidae (Plovers and Lapwings)	Wetland species		WL
Vanellus spinosus	Spur-winged Lapwing	Charadriiformes	Charadriidae (Plovers and Lapwings)	Wetland species		WL
Vanellus senegallus	African Wattled Lapwing	Charadriiformes	Charadriidae (Plovers and Lapwings)	Wetland species		WL
Tringa totanus	Common Redshank	Charadriiformes	Scolopacidae (Sandpipers and Allies)	WL/OW/WWL	Wetland	WL
Tringa ochropus	Green Sandpiper	Charadriiformes	Scolopacidae (Sandpipers and Allies)	WL/OW/WWL	Wetland	WL
Tringa glareola	Wood Sandpiper	Charadriiformes	Scolopacidae (Sandpipers and Allies)	Wetland species		WL
Actitis hypoleucos	Common Sandpiper	Charadriiformes	Scolopacidae (Sandpipers and Allies)	Wetland species		WL
Gallinago gallinago	Common Snipe	Charadriiformes	Scolopacidae (Sandpipers and Allies)	OW/WWL	Wetland	WL
Treron calvus	African Green Pigeon	Columbiformes	Columbidae (Pigeons and Doves)	Open woodland species		SL
Columba guinea	Speckeled Pigeon	Columbiformes	Columbidae (Pigeons and Doves)	OWL/WDL/GL/U	Shrubland	SL
Streptopelia senegalensis	Laughing Dove	Columbiformes	Columbidae (Pigeons and Doves)	U/GL/OWL	Woodland	SL
Streptopelia semitorquata	Red-eyed Dove	Columbiformes	Columbidae (Pigeons and Doves)	OWL/WDL/WWL	Shrubland	SL
Streptopelia vinacea	Vinaceous Dove	Columbiformes	Columbidae (Pigeons and Doves)	OWL/WL/GL	Shrubland	SL
Turtur afer	Blue-spotted Wood Dove	Columbiformes	Columbidae (Pigeons and Doves)	OWL/GL/WWL	Shrubland	SL
Turtur abyssinicus	Black-billed Wood Dove	Columbiformes	Columbidae (Pigeons and Doves)	OWL/WDL/WWL	Shrubland	SL
Poicephalus senegalus	Senegal Parrot	Psittaciformes	Psittacidae (New World and African Parrots)	OWL/GL	Woodland	SL
Psittacula krameri	Rose-ringed Parakeet	Psittaciformes	Psittaculidae (Old World Parrots)	OWL/WWL	Forest	SL
Tauraco persa	Green Turaco	Musophagiformes	Musophagidae (Turacos)	Open woodland species		SL
Musophaga violacea	Violet Tauraco	Musophagiformes	Musophagidae (Turacos)	WWL/WDL	Forest	WDL
Crinifer piscator	Western Grey Plantain-eater	Musophagiformes	Musophagidae (Turacos)	WWL/OWL/GL	Woodland	WDL
Clamator levaillantii	Levaillant's Cuckoo	Cuculiformes	Cuculidae (Cuckoos)	WDL/WWL/OWL	Grassland	SL
Clamator glandarius	Great Spotted Cuckoo	Cuculiformes	Cuculidae (Cuckoos)	Open woodland species		SL
Cuculus gularis	African Cuckoo	Cuculiformes	Cuculidae (Cuckoos)	WDL/GL/WWL	Shrubland	WDL
Cuculus solitarius	Red-chested-Cuckoo	Cuculiformes	Cuculidae (Cuckoos)	WDL/WWL/OWL	Forest	WDL
Chrysococcyx klaas	Klaa's Cuckoo	Cuculiformes	Cuculidae (Cuckoos)	OWL/WWL/WDL/GL	Shrubland	SL
Chrysococcyx caprius	Didric Cuckoo	Cuculiformes	Cuculidae (Cuckoos)	Woodland species		WDL
Chrysococcyx cupreus	African Emerald Cuckoo	Cuculiformes	Cuculidae (Cuckoos)	Woodland species		WDL
Ceuthmochares aereus	Yellowbill	Cuculiformes	Cuculidae (Cuckoos)	Woodland species		WDL
Centropus senegalensis	Senegal Coucal	Cuculiformes	Cuculidae (Cuckoos)	Grassland species		GL

Table 2.1 (continuation) - List of expected species in the region based on the habitat information available on Avibase (Tobias et al., 2021), reinforced by the information from the field guide “ Birds of Western Africa” (2nd edition, 2014), and respective attributed ecological guild category. Lighter grey comprises species detected only on acoustic stations, medium grey detected only on transects and darker grey to species detected in both methods. Taxonomic nomenclature follows the Clements Checklist of August 2021.

Scientific Name	Common Name	Ordem	Família	Habitats Used (Birds of West Africa Guide)	Habitat in Avibase	Foraging Guild
Centropus leucogaster	Black-throated Coucal	Cuculiformes	Cuculidae (Cuckoos)	Open woodland species		SL
Cypsiurus parvus	African Palm Swift	Caprimulgiformes	Apodidae (Swifts)	Urban species	Shrubland	SL
Apus affinis	Little Swift	Caprimulgiformes	Apodidae (Swifts)	Urban species	Human Modified (sparse	SL
Apus apus	Common Swift	Caprimulgiformes	Apodidae (Swifts)		Human Modified (sparse	SL
Ispidina lecontei	African Pygmy Kingfisher	Coraciiformes	Alcedinidae (Kingfishers)	WDL/OWL	Forest	WDL
Halcyon leucocephala	Grey-headed Kingfisher	Coraciiformes	Alcedinidae (Kingfishers)	WDL/WWL/GL	Shrubland	SL
Halcyon senegalensis	Woodland Kingfisher	Coraciiformes	Alcedinidae (Kingfishers)	OWL/GL	Woodland	SL
Halcyon malimbica	Blue-breasted Kingfisher	Coraciiformes	Alcedinidae (Kingfishers)	WDL/WWL	Forest	WDL
Ceryle rudis	Pied Kingfisher	Coraciiformes	Alcedinidae (Kingfishers)	Open water species	Wetland	WL
Merops bulocki	Red-throated Bee-eater	Coraciiformes	Meropidae (Bee-eaters)	OWL/WWL	Shrubland	SL
Merops apiaster	European Bee-eater	Coraciiformes	Meropidae (Bee-eaters)		Woodland	WDL
Merops persicus	Blue-cheeked Bee-eater	Coraciiformes	Meropidae (Bee-eaters)		Desert	GL
Coracias naevius	Rufous-crowned Roller	Coraciiformes	Coraciidae (Rollers)	Woodland species		WDL
Coracias cyanogaster	Blue-bellied Roller	Coraciiformes	Coraciidae (Rollers)	OWL/WWL	Woodland	SL
Coracias abyssinicus	Abyssinian Roller	Coraciiformes	Coraciidae (Rollers)	OWL/GL	Shrubland	SL
Eurystomus glaucurus	Broad-billed Roller	Coraciiformes	Coraciidae (Rollers)	WDL/OWL/WWL/GL	Forest	WDL
Phoeniculus purpureus	Green Wood-Hoopoe	Bucerotiformes	Phoeniculidae (Woodhoopoes and Scimitarbills)	Open woodland species		SL
Tockus kempi	Western Red-billed Hornbill	Bucerotiformes	Bucerotidae (Hornbills)	OWL/WWL	Woodland	SL
Lophoceros nasutus	African Grey Hornbill	Bucerotiformes	Bucerotidae (Hornbills)	OWL/GL	Shrubland	SL
Lophoceros fasciatus	African Pied Hornbill	Bucerotiformes	Bucerotidae (Hornbills)	Woodland species		WDL
Lybius dubius	Bearded Barbet	Piciformes	Lybiidae (African Barbets)	WDL/WWL	Woodland	WDL
Indicator indicator	Greater Honeyguide	Piciformes	Indicatoridae (Honeyguides)	Woodland species		WDL
Campethera punctuligera	Fine-spotted Woodpecker	Piciformes	Picidae (Woodpeckers)	Open woodland species		SL
Chloropicus goertae	Grey Woodpecker	Piciformes	Picidae (Woodpeckers)	WDL/WWL	Woodland	SL
Galerida cristata	Crested Lark	Passeriformes	Alaudidae (Larks)	Grassland species		GL
Psalidoprocne obscura	Fanti Saw-wing	Passeriformes	Hirundinidae (Swallows)	WDL/GL/OWL	Forest	SL
Riparia riparia	Common Sand Martin	Passeriformes	Hirundinidae (Swallows)		Water	WL
Hirundo smithii	Wire-tailed Swallow	Passeriformes	Hirundinidae (Swallows)		Shrubland	SL
Motacilla flava	(cc Western) Yellow Wagtail	Passeriformes	Motacillidae (Wagtails and Pipits)	GL/WL/OWL	Grassland	GL
Coracina pectoralis	White-breasted Cuckooshrike	Passeriformes	Campephagidae (Cuckooshrikes)	Woodland species		WDL
Eurillas virens	Little Greenbul	Passeriformes	Pycnonotidae (Bulbuls)	Open woodland species		SL
Atimastillas flavicollis	Yellow-throated Leaflove	Passeriformes	Pycnonotidae (Bulbuls)	WWL/WDL	Shrubland	SL
Phyllastrephus scandens	Leaf-love	Passeriformes	Pycnonotidae (Bulbuls)	WWL/OWL	Forest	WDL
Pycnonotus barbatus	Common Bulbul	Passeriformes	Pycnonotidae (Bulbuls)	Open woodland species		SL
Turdus pelios	African Thrush	Passeriformes	Turdidae (Thrushes and Allies)	OWL/WWL	Woodland	SL
Cossypha niveicapilla	Snowy-crowned Robin Chat	Passeriformes	Muscicapidae (Old World Flycatchers)	OWL/GL/WWL	Woodland	SL
Cossypha albicapillus	White-crowned Robin Chat	Passeriformes	Muscicapidae (Old World Flycatchers)	WWL/OWL	Woodland	WDL

Table 2.1 (continuation) - List of expected species in the region based on the habitat information available on Avibase (Tobias et al., 2021), reinforced by the information from the field guide “ Birds of Western Africa” (2nd edition, 2014), and respective attributed ecological guild category. Lighter grey comprises species detected only on acoustic stations, medium grey detected only on transects and darker grey to species detected in both methods. Taxonomic nomenclature follows the Clements Checklist of August 2021.

Scientific Name	Common Name	Ordem	Família	Habitats Used (Birds of West Africa Guide)	Habitat in Avibase	Foraging Guild
Cisticola cantans	Singing Cisticola	Passeriformes	Cisticolidae (Cisticolas and Allies)	Woodland species		WDL
Cisticola lateralis	Whistling Cisticola	Passeriformes	Cisticolidae (Cisticolas and Allies)	WDL/GL/OWL	Shrubland	SL
Prinia subflava	Tawny-flanked Prinia	Passeriformes	Cisticolidae (Cisticolas and Allies)	GL/OWL	Shrubland	SL
Prinia fluviatilis	River Prinia	Passeriformes	Cisticolidae (Cisticolas and Allies)	Wet woodland species	Wetland	WL
Camaroptera brachyura	Green-backed Camaroptera	Passeriformes	Cisticolidae (Cisticolas and Allies)	Woodland species		WDL
Hypergerus atriceps	Oriole Warbler	Passeriformes	Cisticolidae (Cisticolas and Allies)	WWL/WDL	Forest	WDL
Eremomela pusilla	Senegal Eremomela	Passeriformes	Cisticolidae (Cisticolas and Allies)	Woodland species		WDL
Hylia prasina	Green Hylia	Passeriformes	Macrosphenidae (African Warblers)	Woodland species		WDL
Melocichla mentalis	African Moustached Warbler	Passeriformes	Macrosphenidae (African Warblers)	Open woodland species		SL
Acrocephalus scirpaceus	European Reed Warbler	Passeriformes	Acrocephalidae (Reed Warblers and Allies)	Woodland species		WDL
Locustella naevia	Common Grasshopper Warbler	Passeriformes	Locustellidae (Grassbirds and Allies)	Woodland species		WDL
Iduna opaca	Western Olivaceous Warbler	Passeriformes	Acrocephalidae (Reed Warblers and Allies)	WWL/OWL/GL	Shrubland	SL
Hippolais polyglotta	Melodious Warbler	Passeriformes	Acrocephalidae (Reed Warblers and Allies)	Woodland species		WDL
Hippolais icterina	Icterine Warbler	Passeriformes	Acrocephalidae (Reed Warblers and Allies)	Open woodland species		SL
Phylloscopus trochilus	Willow Warbler	Passeriformes	Phylloscopidae (Leaf Warblers)	Woodland species		WDL
Phylloscopus collybita	Common Chiffchaff	Passeriformes	Phylloscopidae (Leaf Warblers)	Open woodland species		SL
Sylvietta brachyura	Northern Crombec	Passeriformes	Macrosphenidae (African Warblers)	Woodland species		WDL
Hyliota flavigaster	Yellow-bellied Hyliota	Passeriformes	Hyliotidae (Hyliotas)	Open woodland species		SL
Sylvia atricapilla	(cc Eurasian) Blackcap	Passeriformes	Sylviidae (Sylviid Warblers, Parrotbills, and Allies)	Open woodland species		SL
Sylvia borin	Garden Warbler	Passeriformes	Sylviidae (Sylviid Warblers, Parrotbills, and Allies)	Woodland species		WDL
Curruca cantillans	(cc Eastern) Subalpine Warbler	Passeriformes	Sylviidae (Sylviid Warblers, Parrotbills, and Allies)	Woodland species		WDL
Fraseria cinerascens	White-browed Forest Flycatcher	Passeriformes	Muscicapidae (Old World Flycatchers)	WDL/WWL	Forest	WDL
Melaenornis edolioides	Northern Black Flycatcher	Passeriformes	Muscicapidae (Old World Flycatchers)	WDL/WWL	Woodland	WDL
Ficedula hypoleuca	(cc European) Pied Flycatcher	Passeriformes	Muscicapidae (Old World Flycatchers)	Open woodland species		SL
Terpsiphone viridis	African Paradise Flycatcher	Passeriformes	Monarchidae (Monarch Flycatchers)	WDL/WWL/GL	Woodland	WDL
Terpsiphone rufiventer	Red-bellied Flycatcher	Passeriformes	Monarchidae (Monarch Flycatchers)	OWL/WWL	Forest	SL
Platysteira cyanea	Common Wattle-eye	Passeriformes	Platysteiridae (Wattle-eyes and Batises)	WDL/WWL/GL	Forest	WDL
Turdoides plebejus	Brown Babbler	Passeriformes	Leiothrichidae (Laughingthrushes and Allies)	WDL/WWL/GL	Woodland	WDL
Turdoides reinwardtii	Blackcap Babbler	Passeriformes	Leiothrichidae (Laughingthrushes and Allies)	WDL/WWL	Woodland	WDL
Hedydipna platura	Pygmy Sunbird	Passeriformes	Nectariniidae (Sunbirds and Spiderhunters)	Open woodland species		SL
Anthreptes longuemarei	Western Violet-backed Sunbird	Passeriformes	Nectariniidae (Sunbirds and Spiderhunters)	OWL/WWL	Woodland	SL
Cyanomitra verticalis	Green-headed Sunbird	Passeriformes	Nectariniidae (Sunbirds and Spiderhunters)	OWL/WWL	Woodland	SL
Chalcomitra senegalensis	Scarlet-chested Sunbird	Passeriformes	Nectariniidae (Sunbirds and Spiderhunters)	OWL/WWL	Shrubland	SL
Cinnyris cupreus	Copper Sunbird	Passeriformes	Nectariniidae (Sunbirds and Spiderhunters)	OWL/WWL	Shrubland	SL
Cinnyris venustus	Variable Sunbird	Passeriformes	Nectariniidae (Sunbirds and Spiderhunters)	WWL/OWL	Woodland	SL
Cinnyris pulchellus	Beautiful Sunbird	Passeriformes	Nectariniidae (Sunbirds and Spiderhunters)	OWL/WWL	Woodland	SL
Cinnyris coccinigastrus	Splendid Sunbird	Passeriformes	Nectariniidae (Sunbirds and Spiderhunters)	OWL/WWL	Shrubland	SL

Table 2.1 (continuation) - List of expected species in the region based on the habitat information available on Avibase (Tobias et al., 2021), reinforced by the information from the field guide " Birds of Western Africa" (2nd edition, 2014), and respective attributed ecological guild category. Lighter grey comprises species detected only on acoustic stations, medium grey detected only on transects and darker grey to species detected in both methods. Taxonomic nomenclature follows the Clements Checklist of August 2021.

Scientific Name	Common Name	Ordem	Família	Habitats Used (Birds of West Africa Guide)	Habitat in Avibase	Foraging Guild
Lanius senator	Woodchat Shrike	Passeriformes	Laniidae (Shrikes)		Shrubland	SL
Lanius corvinus	Yellow-billed Shrike	Passeriformes	Laniidae (Shrikes)	OWL/GL	Shrubland	SL
Malaconotus blanchoti	(cc Gray)Grey-headed Shrike	Passeriformes	Malaconotidae (Bushshrikes and Allies)	OWL/WWL	Woodland	SL
Telophorus sulfureopectus	Sulphur-breasted Bush-Shrike	Passeriformes	Malaconotidae (Bushshrikes and Allies)	OWL/WWL	Woodland	SL
Dryoscopus gambensis	Northern Puffback	Passeriformes	Malaconotidae (Bushshrikes and Allies)	WWL/OWL	Woodland	SL
Laniarius turatii	Turati's Boubou	Passeriformes	Malaconotidae (Bushshrikes and Allies)	Open woodland species		SL
Laniarius barbarus	Yellow-crowned Gonolek	Passeriformes	Malaconotidae (Bushshrikes and Allies)	WDL/WWL	Woodland	WDL
Tchagra senegalus	Black-crowned Tchagra	Passeriformes	Malaconotidae (Bushshrikes and Allies)	OWL/GL	Shrubland	SL
Nilaus afer	Brubru	Passeriformes	Malaconotidae (Bushshrikes and Allies)	Open woodland species		SL
Prionops plumatus	White Helmetshrike	Passeriformes	Vangidae (Vangas, Helmetshrikes, and Allies)	Open woodland species		SL
Oriolus auratus	African Golden Orieole	Passeriformes	Oriolidae (Old World Orioles)	Open woodland species		SL
Dicrurus adsimilis	Fork-tailed Drongo	Passeriformes	Dicruridae (Drongos)	Woodland species		WDL
Ptilostomus afer	Piapiac	Passeriformes	Corvidae (Crows, Jays, and Magpies)	Open woodland species		SL
Corvus albus	Pied Crow	Passeriformes	Corvidae (Crows, Jays, and Magpies)	Urban species	Shrubland	SL
Lamprotornis purpureus	Purple Glossy Starling	Passeriformes	Sturnidae (Starlings)	Open woodland species		SL
Lamprotornis caudatus	Long-tailed Glossy Starling	Passeriformes	Sturnidae (Starlings)	OWL/WWL/WDL/GL	Woodland	SL
Lamprotornis splendidus	Splendid Glossy Starling	Passeriformes	Sturnidae (Starlings)	WDL/WWL	Forest	WDL
Buphagus africanus	Yellow-billed Oxpecker	Passeriformes	Buphagidae (Oxpeckers)	Open woodland species		SL
Passer griseus	Northern Grey-headed Sparrow	Passeriformes	Passeridae (Old World Sparrows)	OWL/WDL/U	Shrubland	SL
Gymnoris dentata	Bush Petronia	Passeriformes	Passeridae (Old World Sparrows)	OWL/GL	Desert	GL
Plocepasser superciliosus	Chestnut-crowned Sparrow-weaver	Passeriformes	Ploceidae (Weavers and Allies)	Open woodland species		SL
Ploceus nigricollis	Black-necked Weaver	Passeriformes	Ploceidae (Weavers and Allies)	Open woodland species		SL
Ploceus cucullatus	Village Weaver	Passeriformes	Ploceidae (Weavers and Allies)	OWL/GL	Woodland	SL
Quelea erythrops	Red-headed Quelea	Passeriformes	Ploceidae (Weavers and Allies)	Wetland species		WL
Euplectes franciscanus	Northern Red Bishop	Passeriformes	Ploceidae (Weavers and Allies)	Wetland species		WL
Euplectes hordeaceus	Black-winged Bishop	Passeriformes	Ploceidae (Weavers and Allies)	OWL/GL	Grassland	SL
Euplectes macroura	Yellow-mantled Widowbird	Passeriformes	Ploceidae (Weavers and Allies)	WL/GL	Grassland	GL
Euplectes afer	Yellow-crowned Bishop	Passeriformes	Ploceidae (Weavers and Allies)	WL/WWL	Wetland	WL
Estrilda melpoda	Orange-cheeked Waxbill	Passeriformes	Estrildidae (Waxbills and Allies)	Open woodland species		SL
Estrilda troglodytes	Black-rumped Waxbill	Passeriformes	Estrildidae (Waxbills and Allies)	Open woodland species		SL
Glaucestrilda caerulescens	Lavender Waxbill	Passeriformes	Estrildidae (Waxbills and Allies)	GL/OWL	Shrubland	GL
Uraeginthus bengalus	Red-cheeked Cordonbleu	Passeriformes	Estrildidae (Waxbills and Allies)	GL/OWL	Shrubland	GL
Pytilia phoenicoptera	Red-winged Pytilia	Passeriformes	Estrildidae (Waxbills and Allies)	OWL	Woodland	SL
Lagonosticta senegala	Red-billed Firefinch	Passeriformes	Estrildidae (Waxbills and Allies)	U/GL/OWL	Woodland	SL
Lagonosticta rubricata	Blue-billed Firefinch	Passeriformes	Estrildidae (Waxbills and Allies)	WDL/OWL	Woodland	WDL
Spermestes cucullata	Bronze Mannikin	Passeriformes	Estrildidae (Waxbills and Allies)	Open woodland species		SL
Vidua macroura	Pin-tailed Whydah	Passeriformes	Viduidae (Indigobirds)	OWL/GL	Shrubland	SL
Vidua chalybeata	Village indigobird	Passeriformes	Viduidae (Indigobirds)	Urban species	Shrubland	SL
Vidua camerunensis	Camaroon Indigobird	Passeriformes	Viduidae (Indigobirds)		Woodland	WDL
Crithagra mozambica	Yellow-fronted Canary	Passeriformes	Fringillidae (Finches, Euphonias, and Allies)	OWL/U	Shrubland	SL

Table 3.1 – Eigenvalues (and % of total co-inertia) for the first two axes of the PCA and the influence of values from each component.

	Axis 1	Axis 2
Variance-covariance		
Eigenvalues	0,317	0,099
(%)	66,569	20,748
Correlation		
Eigenvalues	2,011	1,375
(%)	40,227	27,506

	PC 1	PC 2	PC 3	PC 4	PC 5
ricefield_leng	0.0139	-0.0883	-0.252	0.264	0.927
den_vegcov	0.0451	-0.0702	0.792	0.604	0.037
dis_forested	-0.177	0.977	0.029	0.083	0.080
dis_village	0.747	0.126	-0.381	0.474	-0.238
dis_road	0.639	0.131	0.403	-0.579	0.277