

Season- and guild-modulated habitat use by mammals across a forest-cashew-rice mosaic in Northern Guinea-Bissau (West Africa)



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Abstract:

Driven by the growing world population and increased food demand, the conversion of natural habitats into agricultural lands is occurring at an unprecedented rate. This is in turn the leading driver of the current biodiversity crisis, particularly in tropical forest areas characterised by prominent species diversity. Due to an accelerating cash-crop expansion, the once forest-savannah landscape of Northern Guinea-Bissau is now notably occupied by cashew orchards, in addition to scattered forest patches and floodable rice paddies. So far, it remains unknown how these kinds of human-modified landscapes can sustain mammal species over contrasting seasons, and how the habitat use varies across feeding guilds. To address this gap, this study aimed to understand how medium-sized mammals make use of mosaic-like landscapes in Northern Guinea-Bissau by considering the interactive effects of (1) habitat type: forest patch, cashew orchard and rice paddy and (2) season: before (June-July 2022) and after (October-November 2022) the peak of the rainy season. To do so, in each of the two seasons we conducted a 30-day consecutive camera-trap survey across seven landscapes, each of which comprised the three habitat types, amounting to 21 sampling sites. I evaluated mammal species richness, abundance (number of records) and composition across habitat types and seasons at the assemblage-level and discussed the species-specific habitat dependency. I further analysed species abundance across four feeding guilds: carnivores, insectivores, herbivores and omnivores. Based on a sampling effort of 1200 camera-trap days

and 940 records, I identified 21 mammal species from 10 families and five orders. At the assemblage-level, species richness and abundance were similar between habitat types, but higher after the peak of the rainy season, except for rice paddies. Forest and cashew habitats shared similar species composition, which differed from rice paddies. Habitat-dependent species were found in each of the habitat types. At the feeding guild-level, in both seasonally periods carnivores and insectivores were less abundant in cashew orchards, while omnivores were more abundant. The results demonstrate that habitat conversion is likely to disrupt the functional structure of mammal assemblages. Maintaining heterogeneous landscapes, including both forested and open-area habitats, is crucial to maximize the integrity of mammal assemblages in Northern Guinea-Bissau. These findings can be used as baseline information in effective conservation measures in Guinea-Bissau and other tropical regions undergoing rapid conversion for cashew cultivation.

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1. Introduction

1.1. Land-use change worldwide

Land-use change is the leading driver of the current biodiversity crisis (Caro *et al.* 2022). Generally driven by the growing world population, native habitats are being degraded and converted into agricultural lands at an unprecedented rate in part to meet the increasing food demand (Hansen *et al.* 2020). Even though the tropics comprise the most biodiverse biomes on Earth (Dirzo *et al.* 2014), they are experiencing the highest native habitat loss rate, along with the fastest agriculture expansion and intensification (Myers *et al.* 2000; Barlow *et al.* 2007). Indeed, between 1990 and 2020, more than 90% of the world's native habitat loss occurred in tropical regions (Ometto *et al.* 2022). This trend is further expected to continue in the decades ahead (Ometto *et al.* 2022) as the world demand for agricultural products is projected to increase between 70-100% by 2050 (FAO 2019; Tilman *et al.* 2011). Although the increase in agricultural production is expected to come at a higher biodiversity cost for tropical developing countries, most of this agriculture is not dedicated to staple food production, but to commodities which are primarily consumed in the Global North (Zabel *et al.* 2019).

1.2. Biodiversity responses to land-use change

Land-use change generally affects biodiversity by increasing species' local extinction risk, thereby decreasing overall species richness and abundance, changing species composition (Newbold *et al.* 2015; Ferreira *et al.* 2017; Ramahlo *et al.* 2022) and distribution (Andrade-Núñez & Mitchell Aide 2010) and altering phylogenetic diversity (Li *et al.* 2020). These impacts cascade onto ecosystem functioning, impairing ecosystem services and, consequently, human well-being (Newbold *et al.* 2019).

Gibson *et al.* (2011) and Newbold *et al.* (2019) show that the impact of land use change on biodiversity varies geographically, with tropical biomes being particularly sensitive. This is partly due to the overall high biodiversity levels, to the small range sizes that species have and to the high proportion of species that are habitat or dietary specialists, in comparison to other biomes. Biodiversity persistence in human-modified landscapes also depends on the degree of the overall habitat change (Arroyo-Rodríguez *et al.* 2020; Almeida-Maués *et al.* 2022), including the type of the crop (e.g., Fitzherbert *et al.* 2008; De Beenhouwer *et al.* 2013; Bernard *et al.* 2014; Warren-Thomas *et al.* 2015). Species responses

to land-use change further depend on their intrinsic ecological traits (Newbold *et al.* 2019). For instance, specialist species are typically more prone to undergo local extinction in the aftermath of land-use change. Conversely, generalist species and those adapted to human-induced disturbances are less likely to be affected, sometimes even being favoured (Andrade-Núñez & Mitchell Aide, 2010; Ramesh & Downs, 2015; Vasconcelos *et al.* 2015). In addition, by sharing similar trophic requirements, species of the same feeding-guild tend to interact with the environment in an analogous way, being also expected to respond in a similar way to land-use change (Newbold *et al.* 2019). In this context, herbivores are generally negatively affected by land use change because of the large decrease in the amount of plant biomass, although the responses depend on the size of the animal, being the biggest species the ones that show higher abundance reductions (Newbold *et al.* 2019). Due to lower availability of key resources such as fruits, frugivores are also detrimentally impacted by land use change (Newbold *et al.* 2019). Finally, carnivores typically have larger area requirements and occur in lower densities (Ehlers Smith *et al.* 2020), so this guild tends to be the most sensitive one and thus is likely experiencing the most pronounced abundance decline (Newbold *et al.* 2019; Ehlers Smith *et al.* 2020). Conversely, as omnivores exploit a wider range of resources, land-use change is expected to have a less detrimental impact on this guild (Newbold *et al.* 2019).

Terrestrial mammal species comprise a variety of feeding guilds, including carnivores, insectivores, herbivores, omnivores and frugivores, which fulfill a wide range of essential ecological roles such as predation, herbivory, seed dispersal, nutrient cycling, ecosystem engineering and pest control (Lacher *et al.* 2019). The decline of certain feeding groups can imply substantial restructuring of ecological communities and in turn alter the services they provide to humans (Ramesh & Downs, 2015; Lacher *et al.* 2019; Newbold *et al.* 2019). Furthermore, mammals are a fundamental component of local diets (Fa *et al.* 2002). Notwithstanding its importance, according to the IUCN Red List, which is the most comprehensive global assessment of species extinction risk, 40% of the world's mammal species are affected by habitat loss and degradation and 28% are classified as threatened with extinction (IUCN 2023). Additionally, most of these species are found in tropical regions (Dirzo *et al.* 2014). However, there is a lack of studies focused on tropical mammals that take feeding guilds into account.

1.3. Cashew expansion

Small-scale agriculture is a good alternative to intensive industrial agricultural land-uses, as the former are typically less disturbing and have higher biodiversity value (Barlow *et al.* 2007; Mendenhall *et al.* 2014). In fact, tree plantations managed within a mosaic of forested habitats can sustain a wide range of biodiversity, including primary forest species, thereby playing a supplementary role in species conservation (Lyra-Jorge *et al.* 2010; Brady *et al.* 2011; Fahrig *et al.* 2011; Vasconcelos *et al.* 2015; Rege *et al.* 2020). However, syntheses analysing the configuration requirements of such mosaics to support biodiversity lack sufficient understanding from tropical regions (Arroyo-Rodríguez *et al.* 2020).

Cashew (*Anacardium occidentale*) is an evergreen tropical fruit tree native to Brazil (Johnson, 1973) currently cultivated in most tropical regions worldwide (FAO 2019), being West Africa is the most recent and rapidly growing one (Monteiro *et al.* 2017). Compared to alternative crops, cashew is drought resistant, has a low susceptibility to yearly rainfall variation and demands less human labour, which converts it into a significant commodity (Catarino *et al.* 2015). However, as cashew is typically planted in monocultures, cashew orchards have no tree diversity in the canopy layer and periodically undergo removal of the understory. This habitat type is thus structurally much simpler than forests (Temudo & Abrantes, 2014; Catarino *et al.* 2015; Komanduri *et al.* 2023), and it is therefore expected to sustain lower biodiversity (Estrada-Carmona *et al.* 2022). A systematic literature review from studies in India, Guinea-Bissau and Nigeria reported a reduction from four to 84% in species richness for fungi, plants, butterflies, birds and terrestrial mammals in cashew orchards compared to baseline habitats, such as forest (Rege & Lee 2023). Additionally, studies based on butterflies, anurans and mammals suggest that even though cashew orchards located near forests can provide habitat for a subset of forest-dwelling species, cashew expansion may lead to reduced abundance of specialist species and consequent shifts in overall species composition (Vasconcelos *et al.* 2015; Rege *et al.* 2020; Komanduri *et al.* 2023). To date, despite cashew has become an emerging cash-crop of global significance, there is an overall limited understanding on its role to sustain biodiversity (Rege & Lee 2023).

1.4. Case study of Guinea-Bissau

Guinea-Bissau is a small West African country (36,130 km²) that in 2022 had a population of 2,105,566 inhabitants, with an annual growth of 2.2% (The World Bank 2023). The population is mainly rural and comprises a large diversity of ethno-linguistic groups, being

Fula, Mandinga and Balanta the main ones (Temudo & Abrantes 2014). Most of the population of Guinea-Bissau are food insecure (Jalloh *et al.* 2012), and agriculture is currently the main pillar of the country's economy (Temudo *et al.* 2015).

Guinea-Bissau has two seasonally contrasting time periods that shape the country's ecosystems: before and after the peak of the rainy season (Catarino *et al.* 2015). While before the rain is an especially challenging period for animals to find trophic and water resources, after the peak of the rainy season comprises a somehow more favourable period for species to thrive (Stoner & Timm 2011). Notwithstanding, human-induced changes in vegetation cover are known to change rainfall regimes by enhancing temperatures and reducing rainfall across tropical regions, thereby leading to longer and stronger dry seasons (Malhi *et al.* 2014). In particular, West Africa stands out to be a highly seasonal region that has experienced significant decreased in rainfall magnitude and duration (Feng *et al.* 2013).

Native vegetation in Guinea-Bissau is characterised by a mosaic of forests and savannahs (Temudo 2009). During colonial times (XV - XXth centuries) shifting cultivation of peanuts and cereals was the main driver of deforestation (Temudo *et al.* 2015). Rice is currently the major cereal produced and consumed in Guinea-Bissau, as it is the staple food (FAO 2019), as well as an essential part of its local life and culture (Van Gent *et al.* 1993). As rice paddies are generally flooded during part of the year, those are subject to greater seasonal changes in their use (Jalloh *et al.* 2012). During the flooding period, generally after the start of the rainy season, rice paddies comprise productive habitats known to withstand reasonably levels of species diversity that provide key ecosystem services (Jalloh *et al.* 2012; Ribeiro *et al.*, 2017).

In the XIXth century, the cashew tree was introduced in the country by the Portuguese (Temudo & Abrantes, 2014; Vasconcelos *et al.* 2015) as a long-term fallow tree to prevent erosion and to recover the fertility of poor soils (Catarino *et al.* 2015). At first, cashew orchards were mainly planted in the savannahs, but on the 1980's cashew became an intensively cultivated cash-crop and started to be mostly cultivated in once forested areas (Temudo 2009). Since then, in response to the high international demand for cashew, traditional food crops (such as rice), forests and savannahs have been continuously cleared and replaced by cashew monocultures at an unprecedented rate (Monteiro *et al.* 2017). Guinea-Bissau is currently the second highest producer of cashew in West Africa, annually exporting around 160.000 tons of cashew nuts, and this cash-crop currently constitutes the only revenue source for smallholder farmers (Havik *et al.* 2018). In fact, the large-scale expansion of cashew has led to changes in the country landscapes and livelihoods by

transforming the country agro-economy, cultivation strategies and value chains, thus becoming a threat to food security and sustainable farming practices (Temudo & Abrantes 2014; Havik *et al.* 2018). Mostly due to cashew expansion, remaining forests are becoming scarcer, especially in the Northern part of the country (Temudo & Abrantes 2014). Even though to date the total area occupied by cashew has only been quantified across the Cantanhez National Park (Pereira *et al.* 2022), it is undoubtedly that it corresponds to most of the agricultural land in the country (Monteiro *et al.* 2017), and it is expected to expand further (Catarino *et al.* 2015). These changes in land-use have consequently affected the habitat availability for biodiversity (Temudo & Abrantes 2014).

The mammal species inhabiting the Northern part of Guinea-Bissau have not been yet documented. Furthermore, how mammals seasonally cope with such changes remains largely unknown. In this context, understanding the use of a forest-cashew-rice mosaic-like landscape by mammals could help informing conservation actions to enhance long-term wildlife persistence. Indeed, understanding how different mammal feeding-guilds seasonally respond to land-use change may further allow to unveil the consequences of biodiversity change for ecosystem functioning.

1.5. Aim and study questions

This study is part of the wider project *TROPIBIO* (CIBIO, Vairão, Portugal) addressing biodiversity patterns on other taxa in the same study area in Guinea-Bissau. In my study, I aimed to unveil patterns of habitat use by medium-sized mammals across a forest-rice-cashew mosaic in Northern Guinea-Bissau. To account for the strong seasonality that characterises this region, I considered the two contrasting time periods: before and after the peak of the rainy season. To do so, I answered the following questions: (1) is species richness, abundance (considering the number of camera-trapping records as a proxy) and composition, (2) as well as the abundance of each of four feeding guilds – carnivores, insectivores, herbivores and omnivores – affected by the habitat type?; and, (3) how do these diversity metrics at both assemblage and feeding guild-levels vary between before and after the peak of the rainy season?

I hypothesized that (1) at the assemblage-level, species richness and abundance is the lowest in the cashew orchards, and species composition differs across the three habitat types; and (2) at the feeding guild-level, although abundance of either of the guilds is the lowest in the cashew orchards, that is particularly notorious for carnivores, while omnivores comprise

the least affected guild; (3) at either the assemblage or the guild-levels, overall mammal diversity increases after the peak of the rainy season across all the habitat types, and particularly within the rice paddies, and consequently species composition also changes. I further discuss the results based on the forest dependency of each species and the observed diversity of mammal species in the light of that expected for the study area.

2. Materials and methods

2.1. Study area

The study was conducted in the Oio region in Northern Guinea-Bissau (12°15'28" – 12°24'49" North and 15°10'13" – 15°14'16" West), in West Africa (Fig. 1). The region has a sub-humid tropical climate with two well-defined seasons: a rainy season (from June to October), and a dry season (from November to May) (Catarino *et al.* 2008). Temperatures range between 23°C and 34°C in the rainy season, and between 17°C to 37°C in the dry season, with a coinciding mean annual temperature of 27.9°C in both seasons (The World Bank 2023). The mean annual precipitation is 1487 mm, with 98% of this rainfall concentrated in the rainy season (The World Bank 2023). The topography is flat throughout the country, with particularly low altitudes territory allowing flooding of extensive areas during the rainy season (Catarino *et al.* 2008). Due to the above-mentioned land use changes, the vegetation in the North of the country is currently composed of forest patches dispersed in an agricultural matrix mostly comprised by cashew orchards and rice paddies (Temudo & Abrantes 2014).

Here, I surveyed mammal assemblages across seven landscapes, with one site of each habitat types (forest patch, cashew orchard and rice paddy (locally referred to as *bolanha*)) at each landscape (Fig. 1). All sampling sites were surveyed across two seasonally contrasting periods: *before the peak of the rainy season* (BR), between June and July, and *after the peak of the rainy season* (AR) between October and November. Detailed information on each sampling site can be found in Table A1.

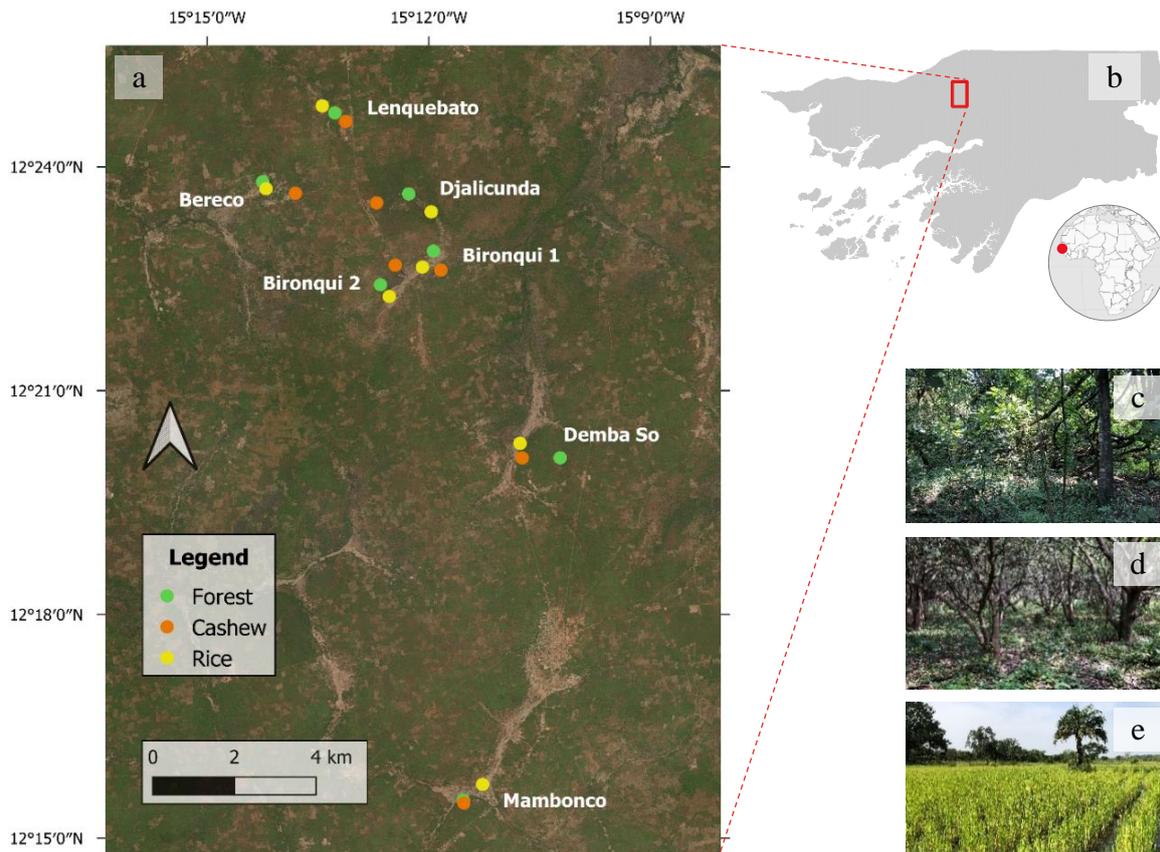


Figure 1. Location of the sampling sites (a) within the study area, and (b) in the context of Guinea-Bissau and Africa. Photos illustrate each of the habitat types sampled in this study: (c) forest patches, (d) cashew orchards and (e) rice paddies. In (a), solid dots correspond to each of the 21 sampling sites, colour-coded according to the habitat type (i.e., forest patches in *green*, cashew orchards in *orange* and rice paddies in *yellow*), geographically nested within seven landscapes. Photo credits: Francisco Silva.

2.2. Habitat types

To characterise each of the habitat types, F. Silva did a visual characterization of each sampling site in each of the two seasons addressed in this thesis. From the centre of each sampling site and within five-meter radius, F. Silva estimated the percentage of bare ground, leaf litter, percentage of canopy cover and number of trees (values for each metric at each of the sampling sites can be found in Table A2). I used the number of trees to estimate the density of trees per hectare. This data was not included in further analysis but is presented here to provide an idea of how the habitats differ amongst each other, also facilitating the later discussion of the results.

Forests patches

Forest patches are open forests that have higher vertical complexity than the other two sampled habitats. Forest patches differ in structure amongst each other most probably because of their different management system. While five of them correspond to community-managed forests implemented by KAFO, the one located near Demba So village comprises a sacred forest, and the one located near Bereco village has no status. Tree density ranges between 892 and 1911 trees per ha and all sampled sites include the presence of fan palm (*Borassus aethiopum*), which is a valuable multipurpose palm for local people (Catarino *et al.* 2008). Mid-canopy cover is high (>60%) and upper-canopy cover is relatively low (5 – 30%). The forest ground is rarely bare, with grass and shrub covering between 0 to 50%, while the leaf litter cover greatly varies among sites (0 – 90%). Overall, forests patches do not show much seasonal variation in their characteristics, apart from an increase in tall grass, which is >2 m-height AR-period.

Cashew orchards

Cashew orchards correspond to organic monocultures (Catarino *et al.* 2015) that have replaced native forests (Temudo & Abrantes 2014). Even though the exact age of the cashew orchards could not be determined, given that all of them are already producing fruits, we can infer that they are a minimum of eight years old (Catarino *et al.* 2015). The density of cashew trees ranges from 1656 to 3949 trees per ha. Cashew orchards have a dense mid-canopy cover (~90%) but lack upper canopy, while bare ground and shrub cover is minimal. Instead, cashew orchards exhibit an understory layer of short and tall grass that is cleared around twice a year to facilitate the process of cashew nut harvesting (Sousa *et al.* 2015), which takes place between June and July. Leaf litter cover is generally higher BR (25 – 50%) than AR (0 – 45%).

Rice paddies

Rice paddies are rainfed and, while flooded in the rainy season, are crossed by water channels. The planting of the rice starts in June and the harvests takes place between November and December. In contrast to cashew orchards, rice paddies are more labour intensive in terms of planting, harvesting and irrigation (Havik *et al.* 2018). Overall, rice paddies lack any mid or upper-canopy cover and therefore leaf litter, although in two sites, Len and Bir1, sparse trees are found (tree density ranging between 0 and 255 trees per hectare). Rice paddies are the habitat type showing the highest variability across seasonally

periods. In the BR-period, the ground is covered by herbaceous plants and patches of bare ground. When the rice paddies are flooded in the AR-period, the vegetation consists of tall grass of mainly rice (*Oryza glaberrima*), which covers between 30 and 90% of the ground.

2.3. Mammal surveys

Mammal data was collected along a 6-month camera-trapping survey carried out between the 13th of June and the 13th of December in 2022. This time period covered most of both cashew and rice annual cycles (FAO 2019) (Table A3). Camera-trapping surveys are a widely used non-invasive and reliable method that allows species identification, thus providing data on species occupancy and habitat use (Ramesh & Downs, 2015). Furthermore, camera-traps are an optimized conservation tool used to monitor medium and large-sized species (Cordier *et al.* 2022). Therefore, in this study, the use of camera trap surveys was the most accurate and cost-efficient method to monitor medium-sized mammals. I considered medium-sized mammals to all the mammals recorded in the camera-traps, although there is quite a variation in size, ranging from 250g (red-legged sun squirrel *Heliosciurus gambianus*) to 150kg (warthog *Phacochoerus africanus*) (Kingdon 2015).

Because of medical reasons, I had to cancel visiting the field. However, I designed the set-up of the data collection and field assistants and colleagues working for the larger project deployed one digital camera (Browning Dark Ops model BTC-6HD-MXP or Browning Patriot model BTC-PATRIOT-FHD) in each of the 21 sampling sites (Fig. 1). They configured each camera to obtain a sequence of five photographs with a 15-second interval. Deployed cameras were unbaited, placed on a tree trunk between 30 and 40 cm above ground and spaced a minimum of 300 meters apart in adjacent sampling sites (except for the sites of Mam-F and Mam-C, which were spaced by 66m due to limitations in space). Cameras were operating 24 hours a day and the field assistants and colleagues checked them approximately every two weeks to cut any grass affecting camera visibility and to replace batteries or the SD card, if necessary. Mammal surveys were conducted together with KAFO NGO (Federação Camponesa / Centro Camponês de Djalicunda).

2.4. Species identification

I manually examined all the recorded photographs extracted from the 6-month camera trap survey using TimeLapse Software (Greenberg *et al.* 2019; Greenberg 2023). For each sampling site, I identified all mammal photos to the species level based on The Kingdon Field

Guide to African Mammals (Kingdon 2015) and, when needed, through the assistance of an expert in the mammal fauna of the region, Luís Palma. I also recorded the date, time and number of individuals of each photograph. Additionally, to allow further studies aiming at understanding the activity patterns of mammals and how those are affected by human and domestic animals' presence, I also noted the start and end time of each group of consecutive photographs with people and/or domestic animals. To minimise considering the same individual in consecutive records, I treated photographs from the same species taken within an interval of 30 minutes as a single detection event (Gessner *et al.* 2014). Exceptions to this include instances where different individuals could be clearly distinguished by age, sex or distinctive morphological characteristics. Only a small amount of 33 pictures (1.2%) could not be identified at species level and thus were not included in further analysis.

Due to theft and malfunctioning of some cameras for some period of time, data for the whole 6-months survey was not available in all of the sites. Considering the high seasonality of the study area, I then subsampled the data to assess seasonal differences. To do so, I selected a subset of 30 consecutive camera-trap days in each of the two previously mentioned seasonally periods (BR and AR). In the BR-period I excluded two sites (Bir2-R and Dem-F) from the analysis as they did not count on 30 consecutive days of data, thus accounting for a total of 1200 camera trap days. The data for the 6-month survey is not to be used in this thesis, but it is expected to be used in further studies (Table A3).

2.5. Research ethics

All sampling activities, including deploying the camera-traps, had the permission of each of the local communities. All the communication between the research team and the local communities was mediated by members of the local NGO KAFO, which permanently works with the local communities involved in this study. As camera-traps are usually unable to differentiate between animals and humans, the movement of people was also recorded. The utility of human photographs can raise concern, as while they can be used to detect illegal activities, the fundamental right of human privacy must always be taken into consideration (Sharma *et al.* 2020). In this study, all photographs were kept within the purpose of the project. In addition to the scientific output, I designed a photo catalogue of the recorded mammal species to be delivered to the local communities of the study area (Fig. A1).

2.6. Data analyses

In summary, I evaluated the effects of (1) habitat type (forest patch, cashew orchard and rice paddy) and (2) season (BR and AR) on mammal species richness, abundance, and composition across the 21 sampling sites nested within the seven landscapes. I then repeated the analysis considering the abundance of each of the following mammal feeding-guilds: carnivores, insectivores, herbivores, and omnivores. I conducted all the statistical analyses using R version 4.1.2 (R Core Team 2021) and the R package *ggplot2* (Wickham 2016) was used for graphical visualization.

2.6.1. Sampling sufficiency

To visually analyse the adequacy of mammal surveys, for each season, I computed a rarefaction curve for each sampling site, for each of the habitat type and for the overall study area. To do so, I used the *rarecurve* function of the *vegan* R-package (Oksanen *et al.* 2020). Although rarefaction curves did not reach an asymptote in all instances (Fig. A2), I still considered my comparison based on the same sampling effort per site appropriate for the purposes of this study.

2.6.2. Assemblage-level patterns

In separate models, I used *species richness* and *abundance* as the response variables and *habitat type* (forest patch, cashew orchard and rice paddy) and *season* (BR and AR) as explanatory variables. As species richness was following a normal distribution, I fitted a Linear Model (LM). I considered the number of species records as a proxy of species abundance (e.g., Jenks *et al.* 2011; Gessner *et al.* 2014), and fitted a Generalized Linear Model (GLM) with Negative Binomial distribution (*glmer.nb* function). As the effects of habitat type on mammal richness and abundance likely depend on the season, I fitted another LM and GLM model with Negative Binomial distribution for species richness and abundance, respectively, incorporating an interaction term between the two predictors. Furthermore, to account for the spatially nested sampling design, I included the *landscape identity* as a random effect by further fitting a Linear Mixed Model (LMM) for species richness and a Generalized Linear Mixed Model (GLMM) with Negative Binomial distribution for species abundance. I then used the Akaike Information Criterion corrected for small sample size (AICc) to identify the best-fit model (Johnson & Omland 2004). Considering the low AIC values, the models that received the strongest support and that I therefore selected where the

LM with interaction between habitat and season for species richness and the GLMM with interaction between habitat and season for species abundance. In the abundance model, I excluded one sampling site from the analysis (Ber-F) as it was considered an outlier for having a surprisingly high abundance, probably due to the placement of the camera trap nearby a nest from the ground squirrel *Xerus erythropus*. I fitted the models using the *lme4* R-package (Bates *et al.* 2015).

To examine the species composition patterns, I first calculated the matrix of distances using the Bray-Curtis dissimilarity index and then used the *metaMDS* function of the *vegan* R-package (Oksanen *et al.* 2020) to perform a Non-Metric Multidimensional Scaling (NMDS) ordination analysis with two dimensions (stress = 0.17) considering species abundance. To evaluate the differences in species composition between habitat types and seasons, I applied a Permutational Multivariate Analysis of Variance (PERMANOVA) with 1000 permutations using the *adonis* function from the *vegan* package in R (Oksanen *et al.* 2020). I then computed pairwise differences using the *pairwise.perm.manova* function of the same package and 999 permutations.

2.6.3. Feeding guild-level patterns

At the feeding guild-level, I grouped species records into four feeding guilds – carnivores, insectivores, herbivores, and omnivores – to have an improved insight of their likely different responses across habitat types and seasons. Species classification was based on their diet as extracted from both the PanTHERIA (Jones *et al.* 2009) and Elton databases (Wilman *et al.* 2014) (Table A4). For each feeding guild, I fitted GLM and GLMM models including and excluding the random term *landscape identity* and the interaction term between *habitat* and *season*. I chose the models with the lowest AICc values, thus fitting GLMMs with Negative Binomial distribution with interaction between habitat and season in the models of herbivores and omnivores, and with Poisson distribution (*log-link* function) for the carnivores and insectivores. In the model regarding omnivore abundance, I deleted three outliers from the analyses (Ber-F BR, and Ber-F and Bir1-C AR), as they had particularly high abundance values, which could be due to the placement of the camera trap in close proximity to a nest from *X. erythropus*.

2.6.4. Habitat dependency

To visualise the degree of dependency of species on each of the habitat types, I calculated and plotted the corresponding proportion of records, BR and AR, using the *geombar* function of the *ggplot2* package (Wickham 2016). I further counted the number of species that had at least 50% of the records in one habitat type, and considered them as habitat-dependent species.

3. Results

During the six-month period, from a total of 2,685 independent records, I identified 22 mammal species belonging to 10 families and five orders (Table A3). From the subsampled two 30-consecutive day periods (BR and AR) combined, I obtained 940 independent records of 21 mammal species from the same families and orders as in the total dataset. Out of these species, seven were classified as carnivores (11.1% of the records), three as insectivores (7.0%), four as herbivores (8.7%) and seven as omnivores (73.2%, Table A4). On average (\pm SD), 9.9 ± 2.5 species were recorded in forest patches (44.6% of the records), 8.9 ± 2.3 species in cashew orchards (35.4%), and 7.4 ± 4.3 species in rice paddies (20.0%). The most recorded species was the ground squirrel *Xerus erythropus* (25.6% of all records), followed by the giant pouched rat *Cricetomys gambianus* (19.9%), and the common patas monkey *Erythrocebus patas* (10.9%) (Table A4). Conversely, the least recorded species was the common warthog *Phacochoerus africanus*, with only two records, followed by the hausa genet *Genetta thierryi* and the gambian mongoose *Mungos gambianus*, with three records each of them. A total of 449 records (48%) were obtained in the BR-period and 491 records (52%) in the AR-period. One species was exclusively recorded in the BR-period (common genet *Genetta genetta*) and four species in the AR one (*M. gambianus*, Senegal Galago *Galago senegalensis*, marsh cane rat *Thryonomys swinderianus* and *P. africanus*).

3.1. Assemblage-level patterns

While in the BR-period species richness was similar across habitat types, in the AR-period it was higher both for forests patches ($\beta_{forest} = 3.667$, $P = 0.009$) and cashew orchards ($\beta_{cashew} = 3.819$, $P = 0.007$) compared to rice paddies. The AR-period had a positive effect on species richness in forest patches ($\beta_{forest*AR} = 3.833$, $P = 0.050$) and cashew orchards ($\beta_{cashew*AR} = 5.286$, $P = 0.008$) compared to rice paddies. Yet, the only seasonal difference within the same

habitat was observed for cashew orchards, with species richness being higher in the AR-period ($\beta_{AR} = 3.286$, $P = 0.014$) than in the BR one. (Fig. 2a, Table A5).

Likewise, while in the BR-period species abundance was similar across habitat types, in the AR-period it was higher in both forest patches ($\beta_{forest} = 1.293$, $P < 0.001$) and cashew orchards compared to rice paddies ($\beta_{cashew} = 1.314$, $P < 0.001$). Similar than for species richness, species abundance was positively affected by the AR-period at forest patches ($\beta_{forest*AR} = 0.989$, $P = 0.050$) and cashew orchards ($\beta_{cashew*AR} = 1.615$, $P = 0.001$) compared to rice paddies. Seasonal differences within the same habitat type were noted for both cashew orchards and rice paddies, with the species abundance correspondingly increasing ($\beta_{AR} = 0.657$, $P = 0.049$) and decreasing ($\beta_{AR} = -0.956$, $P = 0.010$) in the AR-period (Fig. 2b, Table A6).

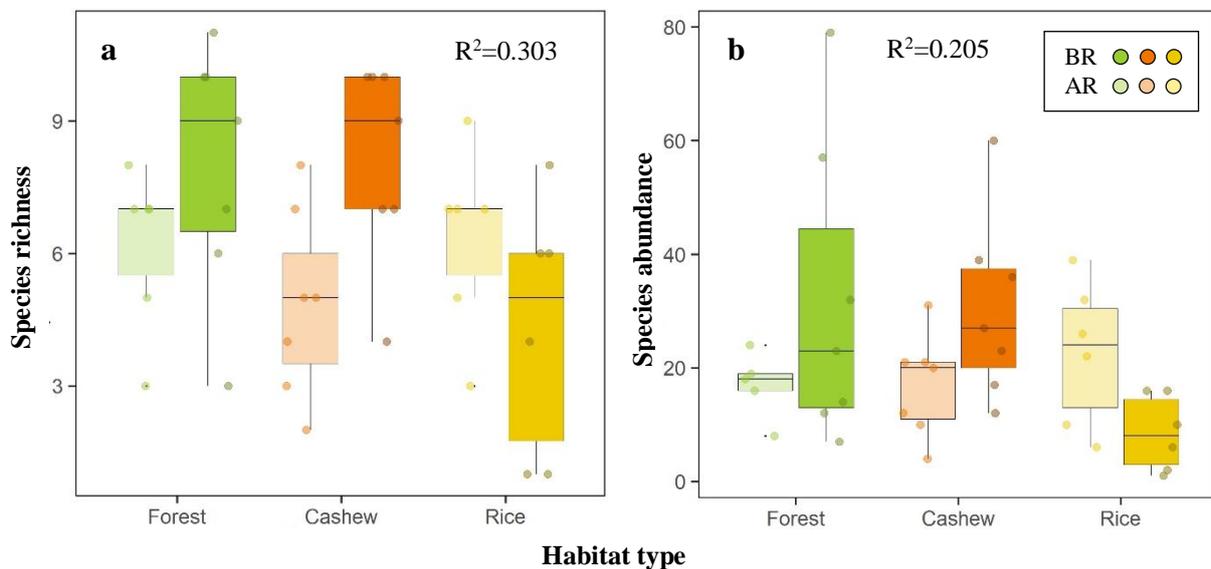


Figure 2. (a) Observed species richness and (b) abundance given by the number of records of mammals across forest patches (green), cashew orchards (orange) and rice paddies (yellow), before (BR, lighter colours) and after (AR, darker colours) the peak of the rainy season. This corresponded to 19 sampling sites BR and 21 AR nested in seven landscapes in Northern Guinea-Bissau. Each dot is an observed species richness / abundance, and the horizontal black line of the box shows the median. In the BR-period two sampling sites (Bir2-R and Dem-F) were excluded from the analyses as they did not count with 30 consecutive days of data.

In both sampling seasons, species composition showed differences among habitat types (PERMANOVA: BR $R^2 = 0.185$, $P = 0.049$, $d.f. = 2$; AR $R^2 = 0.203$, $P = 0.011$, $d.f. = 2$). Pairwise comparisons showed that mammal assemblages in cashew orchards were different from rice paddies both in the BR ($P = 0.036$) and AR ($P = 0.003$) periods. The assemblages in forest patches did not show differences with either cashew orchards or rice paddies for any of the studied periods. Yet, during the AR-period, the species composition of the cashew orchards seemed to be a subset of that in forest patches (Fig. 3a-b, Table A7).

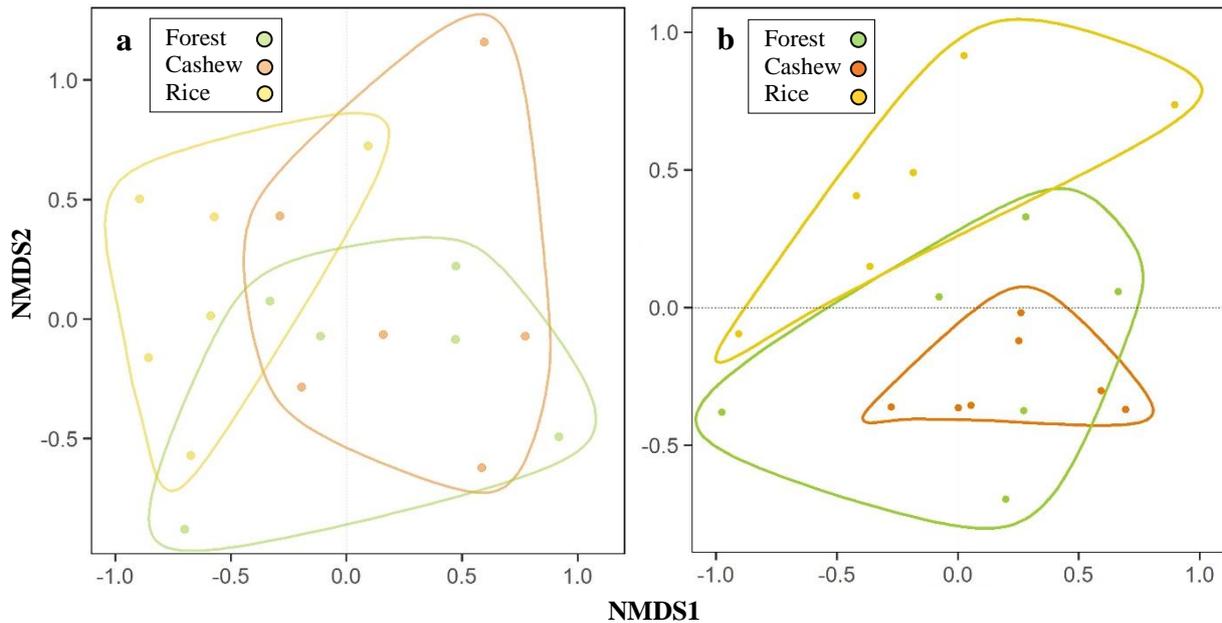


Figure 3. Non-metric dimensional scaling (NMDS) showing species composition across forest patches (green), cashew orchards (orange) and rice paddies (yellow), (a) before (BR) and (b) after (AR) the peak of the rainy season. This corresponded to 19 sampling sites BR and 21 sampling sites AR nested in seven landscapes in Northern Guinea-Bissau. Coloured points denote sampling sites. Two sampling sites (Bir2-R-BR and Dem-F-BR) were excluded from the analyses as they did not count on 30 consecutive days of data.

3.2. Feeding guild-level patterns

In the BR-period, carnivores were more abundant in forest patches ($\beta_{forest} = 0.802$, $P = 0.044$) than in rice paddies and, close to significance, than in cashew orchards ($\beta_{forest} = 0.654$, $P = 0.061$). In the AR-period, carnivores were more abundant in both forest patches ($\beta_{forest} = 1.068$, $P = 0.008$) and cashew orchards ($\beta_{cashew} = 0.836$, $P = 0.042$) compared to rice paddies (Fig. 4a, Table A8).

During the BR-period, insectivores were more abundant in rice paddies than in cashew orchards ($\beta_{cashew} = -1.889$, $P = 0.003$). During the AR-period, the abundance of insectivores tended to be higher in forest patches than in rice paddies ($\beta_{forest} = 0.884$, $P = 0.060$). Seasonal

differences within the same habitat type were observed in both cashew orchards and rice paddies, with insectivore abundance correspondingly increasing ($\beta_{AR} = 1.540$, $P = 0.014$), and decreasing ($\beta_{AR} = -0.981$, $P = 0.038$) in the AR-period. The species abundance of insectivores was positively affected by the AR-period at forest patches ($\beta_{forest*after\ rain} = 1.688$, $P = 0.008$) and cashew orchards ($\beta_{cashew*AR} = 2.521$, $P = 0.001$), compared to rice paddies (Fig. 4b, Table A8).

During the BR-period, herbivores were more abundant in forests patches than in cashew orchards ($\beta_{forest} = 0.955$, $P = 0.050$). However, in the AR-period herbivores were more abundant in both forests patches ($\beta_{forest} = 1.792$, $P = 0.005$) and cashew orchards ($\beta_{cashew} = 2.060$, $P < 0.001$) compared to rice paddies. Seasonal differences within the same habitat type were seen in cashew orchards, with species abundance being higher in the AR-period ($\beta_{AR} = 1.334$, $P = 0.003$). The AR-period had a stronger positive effect in cashew orchards compared to both forests ($\beta_{cashew*AR} = 1.223$, $P = 0.040$) and rice paddies ($\beta_{cashew*AR} = 2.305$, $P = 0.006$) (Fig. 4c, Table A8).

Finally, in the AR-period, omnivores abundance was higher in forests patches and cashew orchards compared to rice paddies ($\beta_{forest} = 0.929$, $P = 0.009$; $\beta_{cashew} = 1.156$, $P = 0.001$). Seasonal differences within the same habitat type were noted in rice paddies, which exhibited higher species abundance in the BR-period ($\beta_{BR} = 1.046$, $P = 0.003$). Similarly to insectivores, the effect of the rain had a positive effect on the species abundance of omnivores in forest patches ($\beta_{forest*AR} = 1.276$, $P = 0.010$) and cashew orchards ($\beta_{cashew*AR} = 1.293$, $P = 0.006$) compared to rice paddies (Fig. 4d, Table A8).

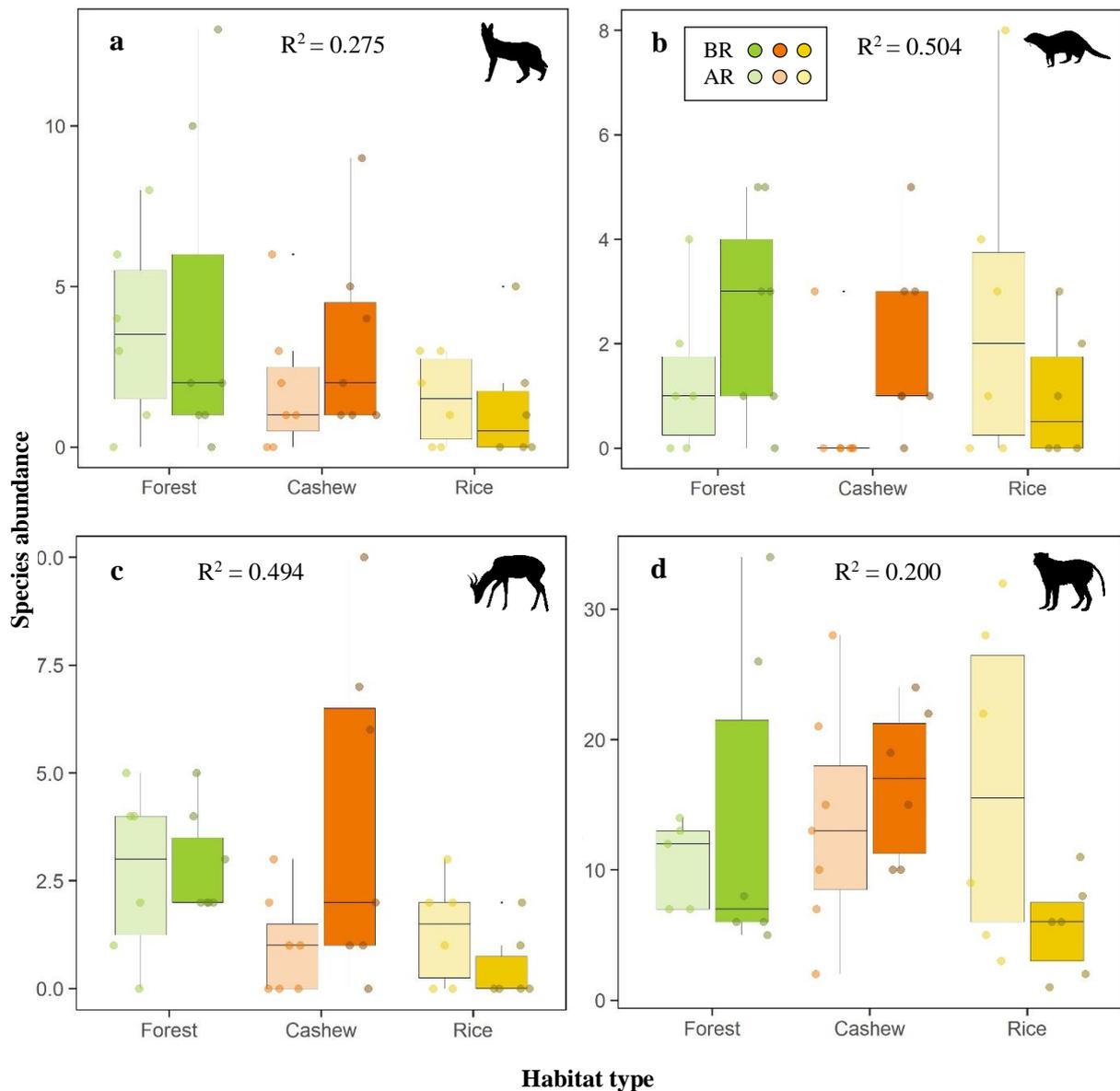


Figure 4. Observed species abundance of mammals given the number of records in 4 feeding guilds (a) carnivores, (b) insectivores, (c) herbivores and (d) omnivores across forest patches (green), cashew orchards (orange) and rice paddies (yellow), before (lighter colours) and after (darker colours) the peak of the rainy season. This corresponded to 19 sampling sites BR and 21 sampling sites AR nested in seven landscapes in Northern Guinea-Bissau. Each dot is an observed species abundance, and the horizontal black line of the box shows the median. In the omnivores, three outliers were excluded from the analyses (Ber-F-BR, Ber-F-AR, Bir1-C-AR).

3.3. Habitat dependency

In the BR-period, out of 17 recorded species, two (11.8%; serval *Leptailurus serval* and the banded mongoose *Mungos mungo*) were exclusively recorded in forest patches, two (11.8%; common genet *Genetta genetta* and hausa genet *Genetta thierryi*) in cashew orchards and one (5.8%; Slender mongoose *Herpestes sanguineus*) in rice paddies. Around half (i.e., nine) of the species recorded occurred in all the three habitat types (Fig. 5a, Table A9). In the AR-period, out of 20 recorded species, three (15.0%; Senegal galago *Galago senegalensis*, *G. thierryi* and warthog *Phacochoerus africanus*) were found exclusively in the forest, one (5.0%; Marsh mongoose *Atilax paludinosus*) in cashew orchards, any was exclusively of rice paddies and ten (50%) were found in all the three habitat types (Fig. 5b, Table A9). In the BR-period, seven species (41%) had at least 50% of the records in forest patches, and this further increased in the AR-period with nine species (45%). However, just 17% (BR) and 15% (AR) of the species had more than half of their records in cashew orchards, and 29% (BR) and 5% (AR) in rice paddies (Fig. 5a-b, Table A9).

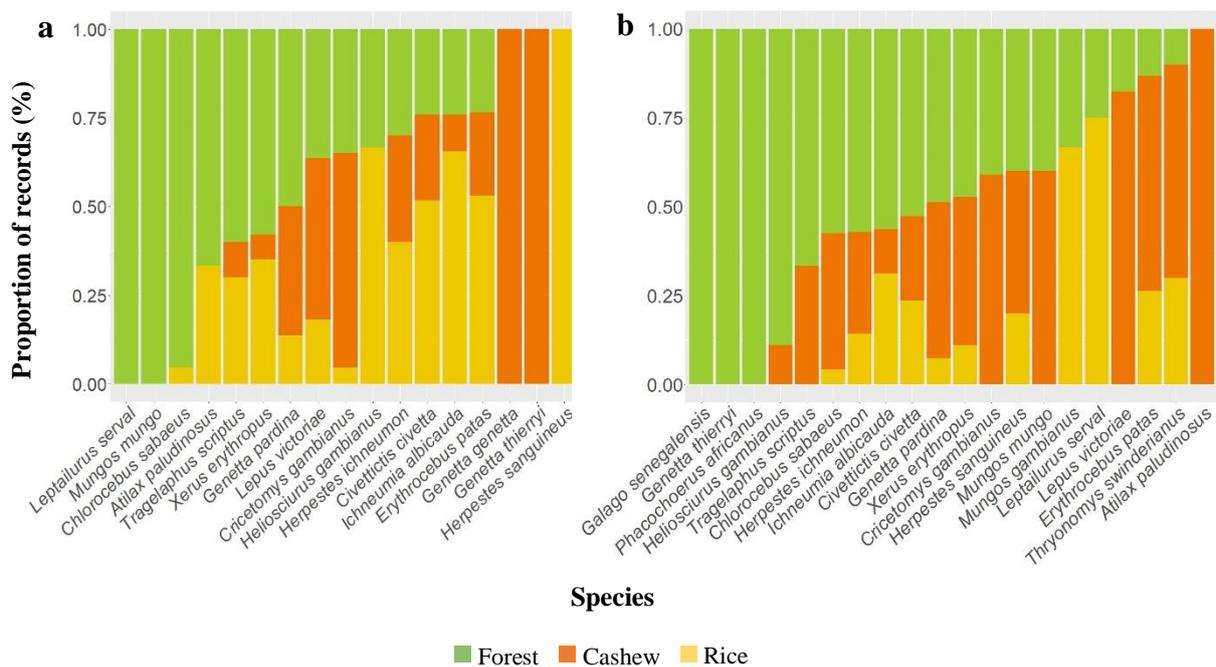


Figure 5. Proportion of mammal species records in forest patches (green), cashew orchards (orange) and rice paddies (yellow) (a) before the peak of the rainy season (BR) and (b) after the peak of the rainy season (AR) in Northern Guinea-Bissau. The plot includes (a) 17 species with 449 records BR and (b) 20 species with 491 records AR. The species are displayed by forest dependency rank.

4. Discussion

In this study, I provide an assessment of the habitat use by medium-sized mammals across a forest-cashew-rice mosaic in Guinea-Bissau. Overall, mammal diversity was shaped by the synergistic effects of habitat type and season. At assemblage-level, forest patches and cashew orchards did not show significant differences in species richness, abundance nor composition in none of the two seasonally periods. However, the abundance within each of the feeding guild as well as the proportion of species records accounting for habitat dependency were evidence that forests patches harboured a higher diversity of feeding and habitat specialists. While carnivores, insectivores and herbivores were negatively affected by the cashew, omnivores were benefited from this cash crop. Overall, the peak of the rainy season appears to magnify the differences between habitats.

4.1. Assemblage-level responses

Surprisingly, in the BR-period the three habitat types were similar in terms of both species richness and abundance. However, during the AR-period, rice paddies showed a marked reduction in both species richness and abundance, making them significantly different than forest patches and cashew orchards. The similarity between forest patches and cashew orchards may be explained by their more similar structure (Pereira *et al.* 2022) compared to that of rice paddies and by the heterogenic mosaic-like structure of the landscape and consequent rescue effect, as cashew orchards were located in proximity to forests (Daily *et al.* 2003). This is consistent with results from Rege *et al.* (2020), which show that most of the mammal species that make use of forest are also present in cashew orchards, suggesting that cashew orchards could act as a supplementary habitat along forest patches. Furthermore, agricultural landscapes with less intensive management and higher tree cover have higher species richness and share a more similar composition with adjacent forests than those more intensively managed with open tree canopies (Bhagwat *et al.* 2008). This might be the case here, as the surveyed cashew orchards comprise organic monocultures with closed canopies. Here it is also worth noting that the cameras in forest patches were facing the ground, and thus its position may have not been appropriate to record arboreal species, which may have been underestimated (e.g., Senegal Galago *Galago senegalensis* and red-legged sun squirrel *Heliosciurus gambianus*).

In line with expectations, forest and cashew orchards showed similar season-modulated responses, exhibiting higher species richness and abundance in the AR-period. This higher mammal diversity and intensity of habitat use in the AR-period is likely to be due to the higher food availability such as plants and fruits in that period (Ehlers Smith *et al.* 2018; Ramahlo *et al.* 2022). Contrary to expectations, rice paddies followed the opposite trend, having lower species richness and abundance AR. This might be at least in part due to the lower detection probability by the cameras during the AR-period. That period corresponded to the rice season, in which the visibility of the cameras was much reduced by the growth of the rice. This can be seen in the rarefaction curve of Fig. A2b, where the BR-period the curve for rice paddies reaches a better asymptote than the one for the AR-period. For that reason, the study findings within rice paddies are limited in that regard and its interpretation required caution.

In both seasonally periods, forest patches showed a similar composition to that of cashew orchards and rice paddies and, additionally, in the AR-period, the composition of cashew orchards was a subset of that of forest patches. This can be due to previously mentioned similar structure of cashew orchards to forest patches (Pereira *et al.* 2022). This is supported by the findings from Bhagwat *et al.* (2008), which also show similarity in species composition in agricultural plantations in relation to neighbouring forest reserves. Additionally, Rege *et al.* (2020) found that 82% of mammals in the forests of Western Ghats, in India, make use of cashew orchards.

4.2. Feeding guild-level responses

Mammal responses to habitat type differed across feeding guilds. In both seasonally periods, carnivores were the feeding guild having higher proportion of species occurring in forests patches, in comparison to the other two habitat types. Carnivores tend to be particularly vulnerable in fragmented landscapes because of their relatively large home range sizes, low population density, sensitivity to edge effects and direct persecution by humans (Crooks 2002). Thus, as hypothesized, carnivores are the feeding guild reacting more strongly to cashew expansion. This goes in line with a study on habitat use of small carnivores in the Arusha National Park (Tanzania) which shows that carnivores select natural habitat types, such as forests, and are absent or avoid human transformed habitats (Martinoli *et al.* 2006). Cashew orchards did not provide suitable habitat for insectivores in the BR-period, while in the AR-period several insectivores made use of this habitat type. This may be associated to

the increased number of insects with rainfall (Wolda 1978). In the BR-period, herbivores were more abundant in forest patches, which can be explained by the higher amount of plant biomass in natural habitats than in land used by humans (Newbold *et al.* 2019). The high abundance of herbivores in cashew orchards in the AR-period may be due to an increase of undergrowth vegetation with rainfall (Sousa *et al.* 2015).

Conversely, omnivores were the only feeding guild exhibiting higher species abundance on cashew orchards than in the other two habitat types. This can be attributed to the omnivore broader resource utilization compared to the other feeding guilds (Newbold *et al.* 2019). For example, the giant pouched rat *Cricetomys gambianus* is a generalist species in both habitat and diet (Kingdon 2015) that was heavily recorded in cashew orchards, accounting for 30% of the total recorded mammal species in this habitat type. This suggests that generalist species may not be affected and may even be benefitted in human-transformed habitat types (Andrade-Núñez & Mitchell Aide 2010). These findings align with Rege & Lee (2023) and Vasconcelos *et al.* (2015), who also found that cashew orchards host more generalist species than forests.

Considering that cashew orchards seem to provide favourable habitats for omnivores, our results support previous studies suggesting that ecological communities will be restructured due to land use change (Barnes *et al.* 2014, 2017). This, in turn, may alter the structure, functionality and resilience of ecosystems, having severe implications to human well-being (Newbold *et al.* 2019).

4.3. Habitat dependency

More than 40% of the recorded species had at least half of their records in forest patches, independent of the season. However, here it is important to mention that, as shown in table A4, the number of records for the hausa genet *Genetta thierryi*, the common genet *Genetta genetta*, the Senegal galago *Galago senegalensis*, the warthog *Phacochoerus africanus* and the slender mongoose *Herpestes sanguineus* was remarkably low and thus may not be fully indicative of their dependence to a certain habitat. Furthermore, the relatively low number of records for *G. senegalensis* can be explained by the already mentioned placement of the cameras, which did not fully cover all the arboreal habitats. However, considering the arboreal dependence of this species, it would not be surprising to find it exclusively in forests (Kingdon 2015).

This suggests that while cashew supports part of the overall species of the landscape, it does not sustain arboreal ones, such as *G. senegalensis*, which is exclusive from the forest. The high-dependency of certain mammal species to forest habitats may indicate that a continuing conversion of forests into cashew monocultures could have negative consequences for mammal diversity (Rege *et al.* 2020), thus highlighting the irreplaceable value of remnant forests within an agricultural mosaic (Barlow *et al.* 2007). However, the fact that some species also seem to be cashew and rice dependent, may be evidence of the importance of preserving an heterogeneous mosaic of different habitat types.

4.4. Observed vs expected mammal species

Very few studies on terrestrial mammals have been done in Guinea-Bissau. While one was carried out more than 30 years ago (Benôit, 1989), more recent ones have mainly focused on Cantanhez National Park, Bijagós and the Boé region (e.g., Gippoliti & Dell’Omo 2003; Rainho & Palmeirim 2017; Ghiurghi & Bout 2018; Westra *et al.* 2022). Thus, there exists a very limited number of studies carried out in Northern Guinea-Bissau, especially focusing on medium-sized mammals (Gippoliti & Dell’Omo 2003; Reiner *et al.* 2015). Considering the differences in native habitat loss and degradation across Guinea-Bissau, comparing the species diversity of the area of study with other regions of the country could be spurious. Therefore, due to the scantiness of background information on the mammal biodiversity of Northern Guinea-Bissau, it is challenging to be definite about the medium-sized mammal species that should be present in the landscape. However, although according to the rarefaction curve the overall mammal community was well sampled at the study area level (Fig. A2c), considering the very few available literature there are other mammal species that would be expected to be found in the landscape.

For instance, while megafauna (e.g., the savannah elephant *Loxodonta Africana*, the lion *Panthera leo*, the leopard *Panthera pardus* and the African buffalo *Syncerus caffer*) is still found in the Southern part of Guinea-Bissau, it is no longer present in the Northern part of the country (Ghiurghi & Bout 2018). This may be explained by the size-selection defaunation gradient, which causes large mammals to usually be the first being extirpated of their natural ranges (Dirzo *et al.* 2014). During colonial times many species were probably filtered by the dramatic changes in land-use that took place in this part of the country, and thus some of the most sensitive species may have been reduced in abundance, while others

became extinct (Balmford 1996). Therefore, it is not surprising that megafauna no longer remains in this region.

Surprisingly, two species of duikers - the maxwell's duiker *Philantomba maxwelli* and the red-flanked duiker *Cephalophus rufilatus* - documented to be common and widespread in West Africa and catalogued as Least Concern by the IUCN Red List (IUCN 2023), were not recorded in this study. Even though these species are among the most hunted ungulates, they are known to show considerable resilience to intensive hunting pressure compared to other antelopes, as long as enough suitable habitat remains (Kingdon 2015). In spite of this, their populations are declining as much of their original habitat is being modified and destroyed by ever-expanding agriculture, high forest fragmentation and overhunting pressure for bushmeat (IUCN 2023). Other expected species of duikers that were not found in the landscape include the bay duiker *Cephalophus dorsalis*, the yellow-backed duiker *Cephalophus silvicultor*, the bohor reedbuck *Redunca redunca*, and the bush duiker *Sylvicapra grimmia* (IUCN 2023; Kingdon 2015).

Additionally, I also expected to record two species of common and widespread squirrels (the red-legged sun squirrel *Heliosciurus rufobrachium* and the fire-footed rope squirrel *Funisciurus pyrhopus*), two species of monkey (Campbell's monkey *Cercopithecus campbelli* and the western red colobus *Piliocolobus badius*) and a widespread carnivore (the tree civet *Nandinia binotata*) (IUCN 2023; Kingdon 2015). As the habitat of these species is partially arboreal, their absence in our study may be explained by the previously mentioned imperfect detection of arboreal mammals. However, I would also expect to have found *N. binotata* in cashew orchards and rice paddies, as this species is known to thrive in cultivation mosaics, especially in forest edges (IUCN 2023; Kingdon 2015). The colobus *P. badius* is currently catalogued as endangered by the IUCN Red List (IUCN 2023). Even though in the past this species was widely distributed throughout Guinea-Bissau, including isolated populations in the north of the country (Gippoliti & Dell'Omo 2003), its range is rapidly declining due to increased cultivation and forest loss and fragmentation (Kingdon 2015). This may explain the absence in much of its historical range, including the current human-modified landscapes of Northern Guinea-Bissau. Even though the mona monkey *C. campbelli* also used to be widespread in the country, it is currently declining in many parts of its range due to deforestation (Gippoliti & Dell'Omo, 2003).

Finally, other potential species that are less likely to occur in the study area due to their presumed relative low abundance include the side-striped jackal *Canis adustus*, the wildcat *Felis sylvestris lybica*, and the aardvark *Orycteropus afer* (Reiner *et al.* 2015), even

though according to Ghiurghi and Bout (2018) they are of very difficult observation in the country.

4.5. Study limitations

Apart from the previously mentioned constraints of this study, further limitations include the varying but relatively small size of the sampling sites and the close proximity to each other. Additionally, the age of the cashew orchards, which was unknown, as well as the overall habitat characteristics, which were recorded but not included into the analyses, are also determiners of the biodiversity present in the landscape (Rege & Lee 2023). Therefore, further studies that would complement the knowledge of the current one could (1) consider the habitat configuration of each sampling site (size, shape and isolation), and assess the necessary forest patch characteristics to preserve mammals across fragmented human-modified landscapes, (2) include habitat metrics as well as the age of cashew orchards into the analyses, (3) evaluate the connectivity between remnant forests and (4) analyse temporal activity patterns of mammals when coexisting with humans and domestic animal. Additionally, for further studies, I suggest increasing the number of camera traps in each sampling site and to locate them facing different directions, thus maximizing the species recorded.

4.6. Conservation implications

The persistence of mammal species in the long run in Guinea-Bissau relies on their ability to adapt and thrive in the forest-cashew-rice landscapes, as well as on the capacity of human communities to coexist with them (Gardner *et al.* 2009). Even though at the assemblage-level diversity metrics do not suggest detrimental impacts of cashew orchards to mammals, forest dependency and feeding-guild analyses are evidence that cashew expansion may alter the functional structure of mammal communities. In this context, given that numerous species appear to be forest dependent, maintaining forest patches within the heterogeneous mosaic landscapes in Northern Guinea-Bissau should be a priority to maximise the integrity of mammal assemblages. This key management measure goes in line with other studies that have analysed the effects of cashew on other taxa and locations (Vasconcelos *et al.* 2015; Komanduri *et al.* 2023; Rege *et al.* 2020). One way to achieve that would be through the effective implementation of community-managed forests, thus safeguarding the remaining forest patches in the country while promoting the collective well-being and empowerment of the communities that rely on them (Palmeirim *et al.* 2023).

Taking into account that the diversity of mammals depends on rain for food and water resources and therefore varied along the year (Ramahlo *et al.* 2022), mammal assemblages could be adversely affected by the potential reductions of rainfall due to land-use change (Feng *et al.* 2013; Malhi *et al.* 2014; Ehlers Smith *et al.* 2018). Seasonal changes may force mammals to adapt by carrying out physiological adaptations, such as reproductive delay and water conservation, and behavioural adaptations, such as dietary flexibility and short and long-distance migrations to areas containing more resources (Stoner & Timm 2011). Additionally, limited food resources due to longer and stronger droughts may lead to more inter- and intraspecific competitive interactions (Ramahlo *et al.* 2022).

The results from this study must be used as baseline information in effective conservation measures in Guinea-Bissau and overall West Africa. Additionally, these findings from Northern Guinea-Bissau have broader relevance for mammal conservation in other tropical regions undergoing rapid conversion for cashew cultivation. This study highlights that understanding the habitat use by mammals in human-modified landscapes requires integrating the effects of both habitat type and season. Furthermore, given the differential responses when assessing the assemblage-level or feeding-guild patterns, this study shows the importance of considering several diversity metrics and levels. Finally, considering that the effects of land-use change differ among taxa and geographical area (Rege & Lee 2023), conducting similar studies across other groups of organisms and regions would allow for a more comprehensive understanding of the impacts that cashew expansion has on biodiversity.

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Appendices

Table A1. Description of each sampling site in terms of habitat, landscape, geographic coordinates, start and end date of camera trapping survey and sampling effort used to survey medium-sized mammals in Northern Guinea-Bissau in the BR and AR periods.

| Sampling site | Habitat | Landscape | Coordinates | | BR | | AR | | Sampling effort (days) |
|---------------|---------|------------|-------------|-----------|-----------|---------|-----------|---------|------------------------|
| | | | Latitude | Longitude | Start day | End day | Start day | End day | |
| Len-F | Forest | Lenquebato | 12.41206 | -15.22121 | 18 Jun | 17 Jul | 20 Oct | 24Nov | 60 |
| Ber-F | Forest | Bereco | 12.39667 | -15.23751 | 18 Jun | 17 Jul | 20 Oct | 18 Nov | 60 |
| Dja-F | Forest | Djalicunda | 12.39397 | -15.20454 | 18 Jun | 17 Jul | 20 Oct | 18 Nov | 60 |
| Bir1-F | Forest | Bironqui 1 | 12.381194 | -15.19894 | 18 Jun | 17 Jul | 20 Oct | 18 Nov | 60 |
| Bir2-F | Forest | Bironqui 2 | 12.373671 | -15.21091 | 29 Jun | 28 Jul | 29 Oct | 30 Nov | 60 |
| Dem-F | Forest | Demba So | 12.33501 | -15.17038 | - | - | 20 Oct | 18 Nov | 30 |
| Mam-F | Forest | Mambonco | 12.25847 | -15.19224 | 27 Jun | 26 Jul | 20 Oct | 18 Nov | 60 |
| Len-C | Cashew | Lenquebato | 12.41014 | -15.21877 | 30 Jun | 29 Jul | 20 Oct | 18 Nov | 60 |
| Ber-C | Cashew | Bereco | 12.39413 | -15.23009 | 18 Jun | 17 Jul | 20 Oct | 18 Nov | 60 |
| Dja-C | Cashew | Djalicunda | 12.391966 | -15.21177 | 18 Jun | 17 Jul | 20 Oct | 18 Nov | 60 |
| Bir1-C | Cashew | Bironqui 1 | 12.376938 | -15.19726 | 18 Jun | 17 Jul | 20 Oct | 18 Nov | 60 |
| Bir2-C | Cashew | Bironqui 2 | 12.37804 | -15.20756 | 29 Jun | 28 Jul | 20 Oct | 18 Nov | 60 |
| Dem-C | Cashew | Demba So | 12.33496 | -15.17894 | 16 Jun | 15 Jul | 20 Oct | 22 Nov | 60 |
| Mam-C | Cashew | Mambonco | 12.25789 | -15.19212 | 29 Jun | 26 Jul | 20 Oct | 18 Nov | 60 |
| Len-R | Rice | Lenquebato | 12.41363 | -15.22404 | 18 Jun | 17 Jul | 20 Oct | 18 Nov | 60 |
| Ber-R | Rice | Bereco | 12.39513 | -15.23672 | 18 Jun | 17 Jul | 20 Oct | 18 Nov | 60 |
| Dja-R | Rice | Djalicunda | 12.38996 | -15.19947 | 13 Jun | 30 Jul | 20 Oct | 18 Nov | 60 |
| Bir1-R | Rice | Bironqui 1 | 12.377628 | -15.20145 | 18 Jun | 17 Jul | 20 Oct | 18 Nov | 60 |
| Bir2-R | Rice | Bironqui 2 | 12.37106 | -15.20893 | - | - | 20 Oct | 18 Nov | 30 |
| Dem-R | Rice | Demba So | 12.33822 | -15.17941 | 16 Jun | 15 Jul | 20 Oct | 18 Nov | 60 |
| Mam-R | Rice | Mambonco | 12.262003 | -15.18786 | 27 Jun | 26 Jul | 20 Oct | 18 Nov | 60 |

Table A2. Characteristics of each habitat type and sampling site recorded by F. Silva from the center of each sampling site and within five-meter radius in July (AR) and October (BR).

| | Len | | Ber | | Dja | | Bir1 | | Bir2 | | Dem | | Mam | | Mean | | SD | | |
|---------------|------------------------|----|-----|----|-----|----|------|----|------|----|-----|----|-----|----|------|------|------|------|------|
| | BR | AR | BR | AR | BR | AR | BR | AR | BR | AR | BR | AR | BR | AR | BR | AR | BR | AR | |
| Forest | Bare ground (%) | 5 | 25 | 0 | 40 | 0 | 5 | 35 | 50 | 5 | 10 | 0 | 0 | 0 | 5 | 6.4 | 19.3 | 11.9 | 16.9 |
| | Leaf litter (%) | 20 | 20 | 30 | 10 | 5 | 5 | 5 | 0 | 5 | 5 | 90 | 90 | 90 | 80 | 52.9 | 30.0 | 35.6 | 33.1 |
| | Grass cover (%) | 8 | 30 | 5 | 5 | 10 | 30 | 45 | 10 | 50 | 40 | 5 | 5 | 0 | 5 | 17.6 | 17.9 | 19.2 | 13.0 |
| | Tall grass cover (%) | 8 | 15 | 40 | 5 | 10 | 20 | 10 | 20 | 10 | 40 | 5 | 5 | 5 | 5 | 12.6 | 15.7 | 11.4 | 11.0 |
| | Shrub cover (%) | 8 | 10 | 25 | 40 | 10 | 40 | 5 | 20 | 30 | 5 | 0 | 0 | 5 | 5 | 11.9 | 17.1 | 10.4 | 14.5 |
| | Mid-canopy cover (%) | 70 | 90 | 60 | 95 | 65 | 70 | 85 | 90 | 20 | 70 | 95 | 95 | 60 | 95 | 65.0 | 86.4 | 22.0 | 9.9 |
| | Upper canopy cover (%) | 5 | 5 | 5 | 5 | 20 | 15 | 0 | 0 | 10 | 10 | 10 | 5 | 30 | 5 | 11.4 | 6.4 | 9.5 | 4.1 |
| | Number of trees | 12 | 12 | 12 | 12 | 15 | 15 | 13 | 13 | 12 | 12 | 11 | 11 | 15 | 15 | 12.3 | 12.3 | 4.2 | 4.2 |
| Cashew | Bare ground (%) | 0 | 5 | 0 | 5 | 0 | 0 | 0 | 5 | 0 | 20 | 0 | 10 | 0 | 0 | 0 | 6.4 | 0 | 6.4 |
| | Leaf litter (%) | 50 | 20 | 45 | 0 | 45 | 25 | 40 | 45 | 40 | 20 | 50 | 5 | 25 | 5 | 42.1 | 17.1 | 8.6 | 14.4 |
| | Grass cover (%) | 45 | 70 | 40 | 85 | 50 | 65 | 50 | 45 | 50 | 50 | 45 | 60 | 40 | 50 | 45.7 | 60.7 | 4.5 | 12.9 |
| | Tall grass cover (%) | 5 | 5 | 10 | 5 | 5 | 10 | 10 | 5 | 10 | 10 | 5 | 20 | 30 | 30 | 10.7 | 12.1 | 8.9 | 8.8 |
| | Shrub cover (%) | 0 | 0 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 15 | 1.4 | 3.6 | 2.4 | 5.2 |
| | Mid-canopy cover (%) | 95 | 95 | 90 | 85 | 80 | 90 | 95 | 100 | 85 | 90 | 90 | 65 | 65 | 90 | 85.7 | 87.9 | 10.6 | 10.3 |
| | Upper canopy cover (%) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Number of trees | 31 | 31 | 16 | 16 | 13 | 13 | 14 | 14 | 20 | 20 | 24 | 24 | 15 | 15 | 18.0 | 18.0 | 4.1 | 4.1 |
| Rice | Bare ground (%) | 5 | 5 | 10 | 5 | 5 | 5 | 15 | 0 | 5 | 5 | 5 | 0 | 5 | 0 | 7.1 | 2.9 | 3.6 | 2.5 |
| | Leaf litter (%) | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.0 | 1.7 | 0.0 |
| | Grass cover (%) | 10 | 5 | 80 | 60 | 75 | 0 | 65 | 0 | 90 | 5 | 45 | 0 | 90 | 5 | 65 | 10.7 | 26.7 | 20.3 |
| | Tall grass cover (%) | 5 | 50 | 5 | 5 | 15 | 30 | 15 | 70 | 0 | 60 | 45 | 80 | 5 | 90 | 24.3 | 55.0 | 28.3 | 27.4 |
| | Shrub cover (%) | 0 | 0 | 0 | 0 | 5 | 0 | 5 | 0 | 5 | 0 | 5 | 5 | 0 | 5 | 2.9 | 1.4 | 2.5 | 2.3 |
| | Mid-canopy cover (%) | 5 | 0 | 0 | 5 | 5 | 0 | 5 | 5 | 55 | 0 | 5 | 0 | 0 | 0 | 3.6 | 1.4 | 2.3 | 2.3 |
| | Upper canopy cover (%) | 0 | 5 | 5 | 0 | 0 | 0 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 1.4 | 1.4 | 2.3 | 2.3 |
| | Number of trees | 2 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0.9 | 0.9 | 0.6 | 0.6 |

Table A3. Number of records per mammal species using camera trap surveys in each of the habitat type - forest patch, cashew orchard and rice paddy - across the 21 sampling sites nested in seven landscapes. Data corresponds to 3193 camera trap days between June and December.

| Species | F | C | R | Forest | | | | | | | Cashew | | | | | | | Rice | | | | | | |
|--------------------------------|------------|-------------|-------------|------------|------------|------------|------------|-----------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|-----------|------------|
| | | | | Len | Ber | Dja | Bir1 | Bir2 | Dem | Mam | Len | Ber | Dja | Bir1 | Bir2 | Dem | Mam | Len | Ber | Dja | Bir1 | Bir2 | Dem | Mam |
| <i>Atilax paludinosus</i> | 6 | 3 | 1 | 1 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| <i>Chlorocebus sabaeus</i> | 102 | 32 | 19 | 0 | 35 | 62 | 0 | 3 | 0 | 2 | 0 | 2 | 1 | 17 | 2 | 0 | 10 | 0 | 18 | 0 | 1 | 0 | 0 | 0 |
| <i>Civettictis civetta</i> | 60 | 31 | 82 | 7 | 15 | 9 | 9 | 2 | 13 | 5 | 7 | 2 | 14 | 5 | 2 | 1 | 0 | 18 | 12 | 12 | 25 | 0 | 10 | 5 |
| <i>Cricetomys gambianus</i> | 229 | 302 | 30 | 20 | 132 | 40 | 13 | 2 | 12 | 10 | 58 | 87 | 25 | 47 | 42 | 38 | 5 | 4 | 0 | 21 | 1 | 0 | 3 | 1 |
| <i>Erythrocebus patas</i> | 40 | 89 | 184 | 11 | 0 | 4 | 17 | 8 | 0 | 0 | 17 | 8 | 3 | 26 | 33 | 0 | 2 | 5 | 7 | 31 | 129 | 5 | 1 | 6 |
| <i>Galago senegalensis</i> | 9 | 0 | 0 | 0 | 1 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Genetta genetta</i> | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Genetta pardina</i> | 61 | 73 | 28 | 4 | 20 | 22 | 7 | 6 | 0 | 2 | 7 | 12 | 10 | 26 | 12 | 4 | 2 | 1 | 1 | 15 | 5 | 0 | 5 | 1 |
| <i>Genetta thierryi</i> | 3 | 1 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Heliosciurus gambianus</i> | 28 | 3 | 10 | 0 | 10 | 6 | 9 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 6 | 0 | 3 | 0 | 0 | 1 | 0 |
| <i>Herpestes ichneumon</i> | 15 | 14 | 10 | 2 | 6 | 0 | 3 | 4 | 0 | 0 | 2 | 3 | 1 | 4 | 4 | 0 | 0 | 1 | 0 | 3 | 4 | 0 | 2 | 0 |
| <i>Herpestes sanguineus</i> | 9 | 15 | 4 | 0 | 5 | 1 | 0 | 0 | 3 | 0 | 0 | 7 | 0 | 0 | 1 | 7 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 1 |
| <i>Hystrix cristata</i> | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Ichneumia albicauda</i> | 50 | 46 | 55 | 3 | 23 | 9 | 5 | 8 | 1 | 1 | 6 | 3 | 28 | 3 | 4 | 2 | 0 | 9 | 5 | 24 | 9 | 0 | 2 | 6 |
| <i>Leptailurus serval</i> | 8 | 0 | 11 | 1 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 3 | 0 | 0 | 1 | 1 |
| <i>Lepus victoriae</i> | 32 | 65 | 5 | 0 | 28 | 0 | 1 | 2 | 0 | 1 | 33 | 23 | 1 | 6 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| <i>Mungos gambianus</i> | 3 | 4 | 6 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 0 | 1 | 2 | 0 |
| <i>Mungos mungo</i> | 24 | 34 | 2 | 4 | 0 | 5 | 5 | 3 | 3 | 4 | 5 | 5 | 0 | 8 | 13 | 1 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| <i>Phacochoerus africanus</i> | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Thryonomys swinderianus</i> | 1 | 11 | 5 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 7 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 3 | 0 |
| <i>Tragelaphus scriptus</i> | 67 | 33 | 19 | 7 | 2 | 37 | 4 | 6 | 2 | 9 | 6 | 2 | 10 | 5 | 4 | 1 | 5 | 2 | 5 | 8 | 0 | 1 | 0 | 3 |
| <i>Xerus erythropus</i> | 382 | 178 | 142 | 34 | 310 | 7 | 9 | 8 | 12 | 2 | 17 | 34 | 20 | 33 | 32 | 39 | 3 | 66 | 2 | 21 | 7 | 0 | 38 | 8 |
| Total species records | 614 | 936 | 1135 | 118 | 52 | 149 | 181 | 7 | 72 | 35 | 160 | 196 | 115 | 184 | 151 | 99 | 31 | 96 | 591 | 205 | 100 | 56 | 49 | 38 |
| Camera trap days | 996 | 1107 | 1090 | 168 | 170 | 166 | 130 | 77 | 112 | 173 | 168 | 184 | 176 | 180 | 175 | 111 | 113 | 174 | 183 | 184 | 184 | 130 | 95 | 140 |

Figure A1. Sample of four out of the 24 pages of the photo catalogue that illustrates the 22 mammal species recorded with camera-trapping across forest patches, cashew orchards and rice paddies between the 13th of June and the 13th of December in Northern Guinea-Bissau.

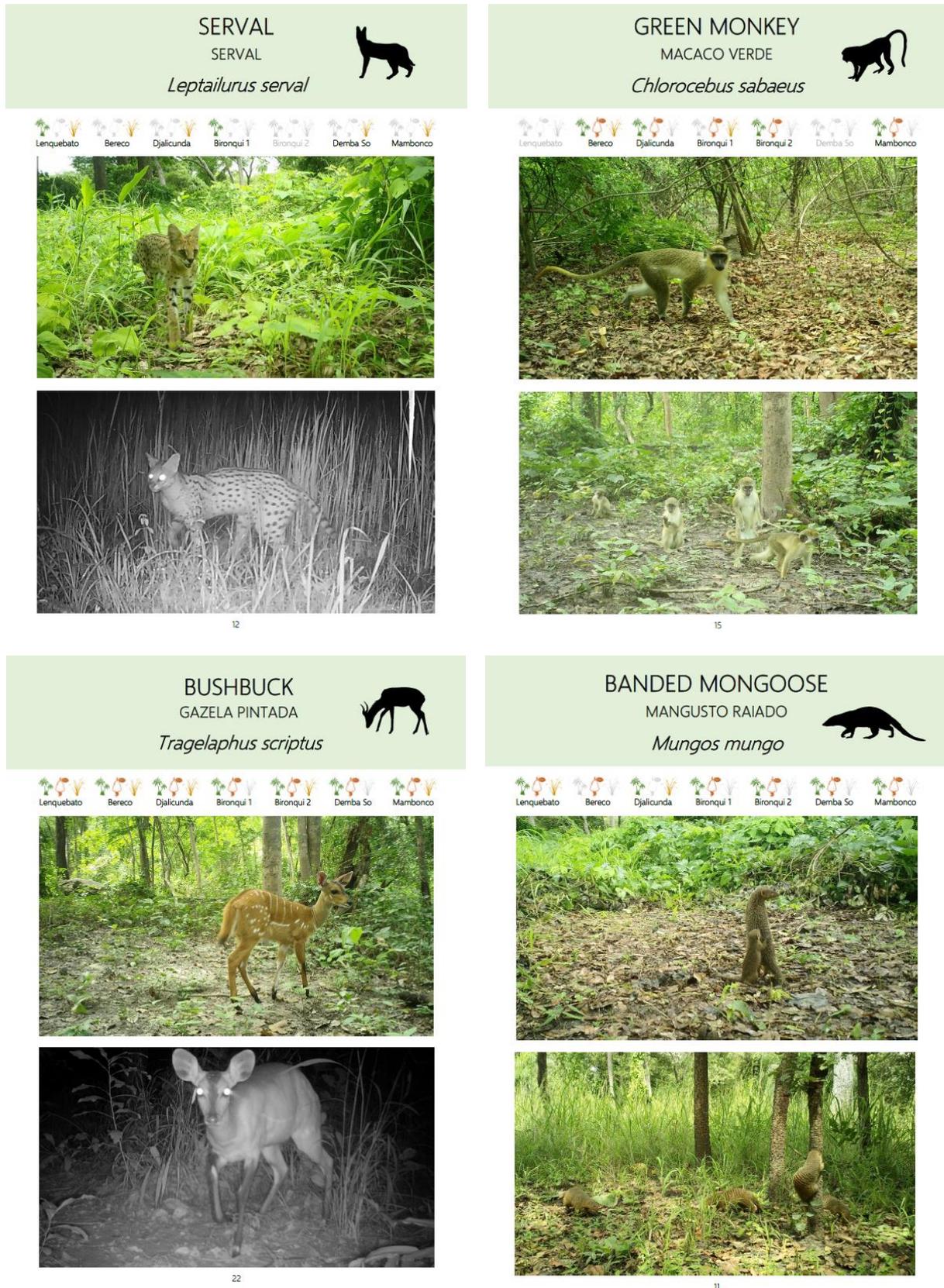


Figure A2. Rarefaction curves based on the number of species across forest patches, cashew orchards and rice paddies in (a) each of the sampling sites, (b) in each of the habitat type and (c) in the overall study area in the BR and AR periods in Northern Guinea-Bissau.

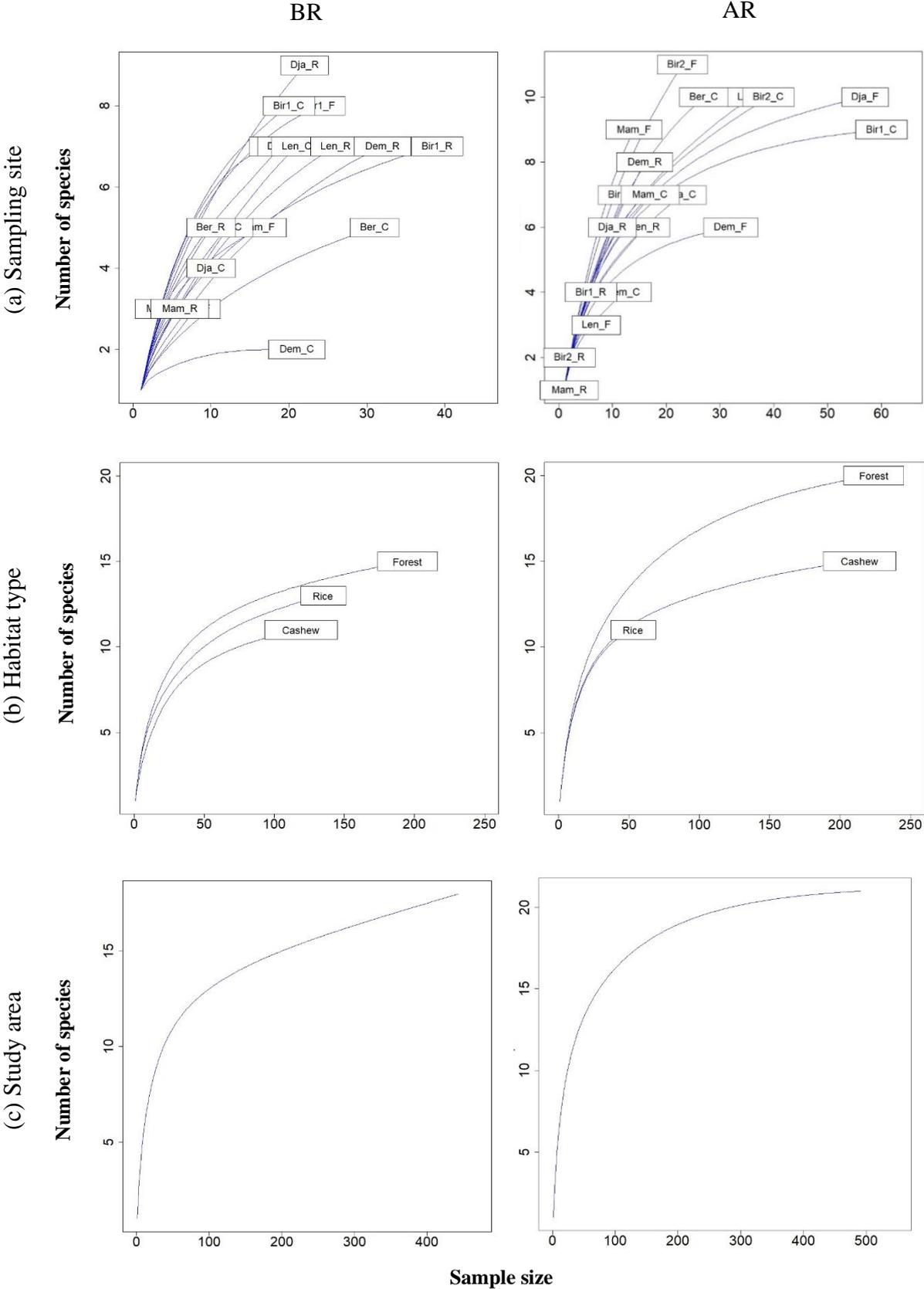


Table A4. Number of records per mammal species in each of the habitat type - forest patch, cashew orchard and rice paddy - during 30 in the BR-period and 30 days in the AR-period in Northern Guinea-Bissau. Feeding guild abbreviations: CA= Carnivore, IN = Insectivore, HE = Herbivore, OM = Omnivore.

| ORDER/Family | Scientific name | Common name | Feeding guild | Forest | | Cashew | | Rice | |
|-------------------------|--------------------------------|-------------------------|---------------|------------|------------|------------|------------|------------|-----------|
| | | | | BR | AR | BR | AR | BR | AR |
| CARNIVORA | | | | | | | | | |
| Felidae | <i>Leptailurus serval</i> | Serval | CA | 6 | 1 | 0 | 0 | 0 | 3 |
| Herpestidae | <i>Atilax paludinosus</i> | Marsh Mongoose | CA | 2 | 0 | 0 | 1 | 1 | 0 |
| | <i>Herpestes ichneumon</i> | Ichneumon Mongoose | CA | 3 | 4 | 3 | 2 | 4 | 1 |
| | <i>Herpestes sanguineus</i> | Slender Mongoose | CA | 0 | 2 | 0 | 2 | 1 | 1 |
| | <i>Ichneumia albicauda</i> | White-tailed Mongoose | IN | 7 | 9 | 3 | 2 | 19 | 5 |
| | <i>Mungos gambianus</i> | Gambian Mongoose | IN | 0 | 1 | 0 | 0 | 0 | 2 |
| | <i>Mungos mungo</i> | Banded Mongoose | IN | 1 | 8 | 0 | 12 | 0 | 0 |
| Viverridae | <i>Civettictis civetta</i> | African Civet | OM | 7 | 20 | 7 | 9 | 15 | 9 |
| | <i>Genetta genetta</i> | Common Genet | CA | 0 | 0 | 1 | 0 | 0 | 0 |
| | <i>Genetta pardina</i> | Pardine Genet | CA | 11 | 20 | 8 | 18 | 3 | 3 |
| | <i>Genetta thierryi</i> | Hausa Genet | CA | 0 | 2 | 1 | 0 | 0 | 0 |
| LAGOMORPHA | | | | | | | | | |
| Leporidae | <i>Lepus victoriae</i> | African Savanna Hare | HE | 4 | 3 | 5 | 14 | 2 | 0 |
| PRIMATES | | | | | | | | | |
| Cercopithecinae | <i>Chlorocebus sabaeus</i> | Green Monkey | OM | 21 | 27 | 0 | 18 | 1 | 2 |
| | <i>Erythrocebus patas</i> | Patas Monkey | OM | 15 | 5 | 15 | 23 | 34 | 10 |
| Galagidae | <i>Galago senegalensis</i> | Northern Lesser Galago | OM | 0 | 5 | 0 | 0 | 0 | 0 |
| RODENTIA | | | | | | | | | |
| Heterocephalidae | <i>Heliosciurus gambianus</i> | Gambian Sun Squirrel | OM | 2 | 8 | 0 | 1 | 4 | 0 |
| | <i>Xerus erythropus</i> | Striped Ground Squirrel | OM | 66 | 60 | 8 | 53 | 40 | 14 |
| Nesomyidae | <i>Cricetomys gambianus</i> | Gambian Pouched Rat | OM | 38 | 32 | 66 | 46 | 5 | 0 |
| Thryonomyidae | <i>Thryonomys swinderianus</i> | Marsh Cane Rat | HE | 0 | 1 | 0 | 6 | 0 | 3 |
| UNGULATA | | | | | | | | | |
| Bovidae | <i>Tragelaphus scriptus</i> | Bushbuck | HE | 12 | 14 | 2 | 7 | 6 | 0 |
| Suidae | <i>Phacochoerus africanus</i> | Common warthog | HE | 0 | 2 | 0 | 0 | 0 | 0 |
| TOTAL | | | | 189 | 224 | 119 | 214 | 135 | 53 |

Table A5. Summary of the Linear Model (LM) explaining mammal richness across forest patches, cashew orchards and rice paddies in the BR and AR periods in Northern Guinea-Bissau. The interaction between habitat and season was considered. Significant values ($P \leq 0.05$) are highlighted in bold. Estimate: predicted effect of the explanatory variable; Std. Error: standard error for the estimate; z-value; p-value: statistical significance of the estimate.

| Reference (Habitat) | Reference (Season) | Coefficients | Estimate | Standard error | z value | p value |
|----------------------------|---------------------------|---------------------|-----------------|-----------------------|----------------|-------------------|
| Forest | BR | (Intercept) | 6.167 | 0.967 | 6.376 | <0.0001 |
| Forest | BR | Cashew | 1.310 | 1.318 | 0.994 | 0.328 |
| Forest | BR | Rice | -0.167 | 1.368 | -0.122 | 0.904 |
| Forest | BR | Cashew*AR | -1.452 | 1.828 | -0.795 | 0.433 |
| Forest | AR | (Intercept) | 8.000 | 0.895 | 8.934 | <0.0001 |
| Forest | AR | Cashew | 0.143 | 1.266 | 0.113 | 0.911 |
| Forest | AR | BR | -1.833 | 1.318 | -1.391 | 0.174 |
| Cashew | BR | (Intercept) | 4.857 | 0.895 | 5.420 | <0.0001 |
| Cashew | BR | Rice | 1.476 | 1.318 | 1.120 | 0.271 |
| Cashew | BR | AR | 3.286 | 1.266 | 2.595 | 0.014 |
| Rice | BR | (Intercept) | 6.333 | 0.967 | 6.550 | <0.0001 |
| Rice | BR | AR | -2.000 | 1.368 | -1.462 | 0.153 |
| Rice | BR | Cashew*AR | 5.286 | 1.864 | 2.836 | 0.008 |
| Rice | BR | Forest*AR | 3.833 | 1.900 | 2.018 | 0.050 |
| Rice | AR | (Intercept) | 4.333 | 0.967 | 4.480 | <0.0001 |
| Rice | AR | Cashew | 3.810 | 1.318 | 2.890 | 0.007 |
| Rice | AR | Forest | 3.667 | 1.318 | 2.782 | 0.009 |

Table A6. Summary of the Generalized Linear Mixed Model (GLMM) fitted with a Negative Binomial distribution explaining mammal abundance across forest patches, cashew orchards and rice paddies in the BR and AR periods in Northern Guinea-Bissau. The interaction between habitat and season was considered. Significant values ($P \leq 0.05$) are highlighted in bold. Estimate: predicted effect of the explanatory variable; Std. Error: standard error for the estimate; z-value; p-value: statistical significance of the estimate.

| Reference (Habitat) | Reference (Season) | Coefficients | Estimate | Standard error | z value | p value |
|---------------------|--------------------|--------------|----------|----------------|---------|-------------------|
| Forest | BR | (Intercept) | 3.361 | 0.283 | 11.875 | <0.0001 |
| Forest | BR | Rice | -0.303 | 0.365 | -0.832 | 0.406 |
| Forest | BR | Cashew | -0.605 | 0.348 | -1.737 | 0.082 |
| Forest | BR | AR | 0.030 | 0.342 | 0.089 | 0.929 |
| Forest | BR | Cashew*AR | 0.626 | 0.477 | 1.314 | 0.189 |
| Forest | AR | (Intercept) | 3.392 | 0.260 | 13.020 | <0.0001 |
| Forest | AR | Cashew | 0.021 | 0.331 | 0.064 | 0.949 |
| Cashew | BR | (Intercept) | 2.756 | 0.266 | 10.349 | <0.0001 |
| Cashew | BR | AR | 0.657 | 0.334 | 1.967 | 0.049 |
| Rice | BR | (Intercept) | 3.058 | 0.282 | 10.852 | <0.0001 |
| Rice | BR | Cashew | -0.302 | 0.349 | -0.865 | 0.387 |
| Rice | BR | AR | -0.959 | 0.374 | -2.565 | 0.010 |
| Rice | BR | Cashew*AR | 1.615 | 0.502 | 3.217 | 0.001 |
| Rice | BR | Forest*AR | 0.989 | 0.505 | 1.959 | 0.050 |
| Rice | AR | (Intercept) | 2.099 | 0.304 | 6.908 | <0.0001 |
| Rice | AR | Cashew | 1.314 | 0.366 | 3.588 | <0.001 |
| Rice | AR | Forest | 1.293 | 0.366 | 3.535 | <0.001 |

Table A7. Results of Permutational Multivariate Analysis of Variance (PERMANOVA) analysis and pairwise comparisons showing the effect of habitat type -forest patch, cashew orchard and rice paddy- on species composition BR and AR. Significant values ($P \leq 0.05$) are highlighted in bold.

| Season | Source of variation | Df | Sum of Sqs | R2 | F-value | P-value |
|-----------|---------------------|----|------------|-------|---------|--------------|
| BR | | | | | | |
| | Habitat | 2 | 0.842 | 0.185 | 1.821 | 0.049 |
| | Residual | 16 | 3.600 | 0.815 | - | - |
| | Total | 18 | 4.542 | 1.000 | - | - |
| | Forest vs Cashew | - | - | - | - | 0.549 |
| | Forest vs Rice | - | - | - | - | 0.189 |
| | Cashew vs Rice | - | - | - | - | 0.036 |
| AR | | | | | | |
| | Habitat | 2 | 1.219 | 0.203 | 2.164 | 0.011 |
| | Residual | 17 | 4.789 | 0.797 | - | - |
| | Total | 19 | 6.007 | 1.000 | - | - |
| | Forest vs Cashew | - | - | - | - | 0.307 |
| | Forest vs Rice | - | - | - | - | 0.344 |
| | Cashew vs Rice | - | - | - | - | 0.003 |

Table A8. Summary of the Generalized Linear Mixed Models (GLMMs) explaining species abundance in four feeding guilds (a) carnivores, (b) insectivores, (c) herbivores and (d) across forest patches, cashew orchards and rice paddies BR and AR. Significant values ($P \leq 0.05$) are highlighted in bold. Carnivores and Herbivores models were fitted with a Poisson distribution, and insectivores and omnivores models were fitted with negative binomial distribution. Estimate: predicted effect of the explanatory variable; Std. Error: standard error for the estimate; z-value; p-value: statistical significance of the estimate.

| Reference (Habitat) | Reference (Season) | Coefficients | Estimate | Standard error | z value | p value |
|---------------------|--------------------|--------------|----------|----------------|---------|-------------------|
| CARNIVORES | | | | | | |
| Forest | BR | (Intercept) | 1.218 | 0.253 | 4.809 | <0.0001 |
| Forest | BR | AR | 0.149 | 0.283 | 0.526 | 0.599 |
| Forest | BR | Cashew*AR | 0.422 | 0.446 | 0.946 | 0.344 |
| Forest | BR | Rice*AR | -0.266 | 0.560 | -0.476 | 0.634 |
| Forest | AR | (Intercept) | 1.367 | 0.227 | 6.030 | <0.0001 |
| Forest | AR | Cashew | -0.232 | 0.278 | -0.835 | 0.403 |
| Cashew | BR | (Intercept) | 0.565 | 0.305 | 1.849 | 0.065 |
| Cashew | BR | Forest | 0.654 | 0.349 | 1.873 | 0.061 |
| Cashew | BR | Rice | -0.148 | 0.434 | -0.341 | 0.733 |
| Cashew | BR | AR | 0.571 | 0.345 | 1.655 | 0.098 |
| Cashew | BR | Rice*AR | -0.688 | 0.593 | -1.160 | 0.246 |
| Rice | BR | (Intercept) | 0.417 | 0.356 | 1.170 | 0.242 |
| Rice | BR | Forest | 0.802 | 0.399 | 2.010 | 0.044 |
| Rice | BR | AR | -0.118 | 0.483 | -0.244 | 0.807 |
| Rice | AR | (Intercept) | 0.299 | 0.375 | 0.797 | 0.425 |
| Rice | AR | Cashew | 0.836 | 0.411 | 2.036 | 0.042 |
| Rice | AR | Forest | 1.068 | 0.400 | 2.671 | 0.008 |
| INSECTIVORES | | | | | | |
| Forest | BR | (Intercept) | 0.117 | 0.409 | 0.287 | 0.774 |
| Forest | BR | Cashew | -1.085 | 0.670 | -1.621 | 0.105 |
| Forest | BR | Rice | 0.804 | 0.436 | 1.845 | 0.065 |
| Forest | BR | AR | 0.707 | 0.421 | 1.678 | 0.093 |
| Forest | BR | Cashew*AR | 0.834 | 0.757 | 1.102 | 0.270 |
| Forest | AR | (Intercept) | 0.824 | 0.309 | 2.667 | 0.008 |
| Forest | AR | Cashew | -0.251 | 0.352 | -0.714 | 0.475 |
| Cashew | BR | (Intercept) | -0.968 | 0.605 | -1.599 | 0.110 |
| Cashew | BR | AR | 1.540 | 0.628 | 2.452 | 0.014 |
| Cashew | AR | (Intercept) | 0.573 | 0.333 | 1.720 | 0.086 |
| Cashew | AR | Rice | -0.632 | 0.486 | -1.301 | 0.193 |
| Rice | BR | (Intercept) | 0.921 | 0.320 | 2.880 | 0.004 |
| Rice | BR | Cashew | -1.889 | 0.625 | -3.024 | 0.003 |

| | | | | | | |
|-------------------|----|-------------|--------|-------|--------|------------------|
| Rice | BR | AR | -0.981 | 0.473 | -2.074 | 0.038 |
| Rice | BR | Cashew*AR | 2.521 | 0.786 | 3.206 | 0.001 |
| Rice | BR | Forest*AR | 1.688 | 0.633 | 2.665 | 0.008 |
| Rice | AR | (Intercept) | -0.060 | 0.452 | -0.132 | 0.895 |
| Rice | AR | Forest | 0.884 | 0.470 | 1.880 | 0.060 |
| HERBIVORES | | | | | | |
| Forest | BR | (Intercept) | 0.884 | 0.322 | 2.742 | 0.006 |
| Forest | BR | Rice | -0.711 | 0.472 | -1.507 | 0.132 |
| Forest | BR | AR | 0.111 | 0.380 | 0.292 | 0.770 |
| Forest | BR | Cashew*AR | 1.223 | 0.594 | 2.061 | 0.039 |
| Forest | BR | Rice*AR | -1.082 | 0.796 | -1.358 | 0.175 |
| Forest | AR | (Intercept) | 0.995 | 0.291 | 3.416 | <0.001 |
| Forest | AR | Cashew | 0.268 | 0.340 | 0.788 | 0.431 |
| Cashew | BR | (Intercept) | -0.072 | 0.423 | -0.170 | 0.865 |
| Cashew | BR | Rice | 0.245 | 0.547 | 0.447 | 0.655 |
| Cashew | BR | Forest | 0.955 | 0.487 | 1.964 | 0.050 |
| Cashew | BR | AR | 1.334 | 0.456 | 2.928 | 0.003 |
| Rice | BR | (Intercept) | 0.173 | 0.410 | 0.422 | 0.673 |
| Rice | BR | AR | -0.970 | 0.700 | -1.386 | 0.166 |
| Rice | BR | Cashew*AR | 2.305 | 0.836 | 2.758 | 0.006 |
| Rice | AR | (Intercept) | -0.798 | 0.613 | -1.302 | 0.193 |
| Rice | AR | Cashew | 2.060 | 0.634 | 3.251 | 0.001 |
| Rice | AR | Forest | 1.792 | 0.644 | 2.782 | 0.005 |
| OMNIVORES | | | | | | |
| Forest | BR | (Intercept) | 2.366 | 0.282 | 8.388 | <0.001 |
| Forest | BR | Cashew | 0.209 | 0.345 | 0.607 | 0.544 |
| Forest | BR | Rice | 0.347 | 0.354 | 0.980 | 0.327 |
| Forest | BR | AR | 0.230 | 0.353 | 0.653 | 0.514 |
| Forest | BR | Cashew*AR | 0.018 | 0.476 | 0.037 | 0.971 |
| Forest | AR | (Intercept) | 2.596 | 0.256 | 10.149 | <0.001 |
| Forest | AR | Cashew | 0.227 | 0.329 | 0.691 | 0.490 |
| Cashew | BR | (Intercept) | 2.575 | 0.238 | 10.837 | <0.001 |
| Cashew | BR | Rice | 0.137 | 0.315 | 0.436 | 0.663 |
| Cashew | BR | AR | 0.248 | 0.315 | 0.788 | 0.431 |
| Rice | BR | (Intercept) | 2.713 | 0.256 | 10.612 | <0.001 |
| Rice | BR | Cashew*AR | 1.293 | 0.466 | 2.773 | 0.006 |
| Rice | BR | Forest*AR | 1.276 | 0.496 | 2.572 | 0.010 |
| Rice | AR | (Intercept) | 1.667 | 0.288 | 5.787 | <0.001 |
| Rice | AR | Cashew | 1.156 | 0.357 | 3.243 | 0.001 |
| Rice | AR | Forest | 0.929 | 0.354 | 2.624 | 0.009 |
| Rice | AR | BR | 1.046 | 0.348 | 3.002 | 0.003 |

Table A9. Proportion of mammal species records across habitat types in the BR and AR periods in Northern Guinea-Bissau.

| ORDER/Family | Scientific name | Common name | Forest | | Cashew | | Rice | |
|-------------------------|--------------------------------|-------------------------|--------|------|--------|------|------|------|
| | | | BR | AR | BR | AR | BR | AR |
| CARNIVORA | | | | | | | | |
| Felidae | <i>Leptailurus serval</i> | Serval | 100 | 25.0 | 0 | 0 | 0 | 75.0 |
| Herpestidae | <i>Atilax paludinosus</i> | Marsh Mongoose | 66.7 | 0 | 0 | 100 | 33.3 | 0 |
| | <i>Herpestes ichneumon</i> | Ichneumon Mongoose | 30 | 57.1 | 30 | 28.6 | 40 | 14.3 |
| | <i>Herpestes sanguineus</i> | Slender Mongoose | 0 | 40.0 | 0 | 40.0 | 100 | 20.0 |
| | <i>Ichneumia albicauda</i> | White-tailed Mongoose | 24.1 | 56.3 | 10.3 | 12.5 | 65.5 | 31.3 |
| | <i>Mungos gambianus</i> | Gambian Mongoose | 0 | 33.3 | 0 | 0 | 0 | 66.7 |
| | <i>Mungos mungo</i> | Banded Mongoose | 100 | 40 | 0 | 60 | 0 | 0 |
| Viverridae | <i>Civettictis civetta</i> | African Civet | 24.1 | 52.6 | 24.1 | 23.7 | 51.7 | 23.7 |
| | <i>Genetta genetta</i> | Common Genet | 0 | 0 | 100 | 0 | 0 | 0 |
| | <i>Genetta pardina</i> | Pardine Genet | 50 | 48.8 | 36.4 | 43.9 | 13.6 | 7.3 |
| | <i>Genetta thierryi</i> | Hausa Genet | 0 | 100 | 100 | 0 | 0 | 0 |
| LAGOMORPHA | | | | | | | | |
| Leporidae | <i>Lepus victoriae</i> | African Savanna Hare | 36.4 | 17.6 | 45.4 | 82.4 | 18.2 | 0 |
| PRIMATES | | | | | | | | |
| Cercopithecinae | <i>Chlorocebus sabaues</i> | Green Monkey | 95.5 | 57.4 | 0 | 38.3 | 4.5 | 4.3 |
| | <i>Erythrocebus patas</i> | Patas Monkey | 23.4 | 13.2 | 23.4 | 60.5 | 53.1 | 26.3 |
| Galagidae | <i>Galago senegalensis</i> | Northern Lesser Galago | 0 | 100 | 0 | 0 | 0 | 0 |
| RODENTIA | | | | | | | | |
| Heterocephalidae | <i>Heliosciurus gambianus</i> | Gambian Sun Squirrel | 33.3 | 88.9 | 0 | 11.1 | 66.7 | 0 |
| | <i>Xerus erythropus</i> | Striped Ground Squirrel | 57.9 | 47.2 | 7 | 41.7 | 35.1 | 11.0 |
| Nesomyidae | <i>Cricetomys gambianus</i> | Gambian Pouched Rat | 34.9 | 41.0 | 60.6 | 59.0 | 4.6 | 0 |
| Thryonomyidae | <i>Thryonomys swinderianus</i> | Marsh Cane Rat | 0 | 10 | 0 | 60 | 0 | 30 |
| UNGULATA | | | | | | | | |
| Bovidae | <i>Tragelaphus scriptus</i> | Bushbuck | 60 | 66.7 | 10 | 33.3 | 30 | 0 |
| Suidae | <i>Phacochoerus africanus</i> | Common warthog | 0 | 100 | 0 | 0 | 0 | 0 |