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Bird Community Composition and Functional Guilds Response to Vegetation Structure in Southwest Ethiopia

Gelaye Gebremichael [1,2,*], Kitessa Hundera [1], Lindsay De Decker [2], Raf Aerts [3,4], Luc Lens [2] and Anagaw Atickem [5]

[1] College of Natural Sciences, Jimma University, Jimma P.O. Box 378, Ethiopia
[2] Terrestrial Ecology Unit (TEREC), Ghent University, K.L. Ledeganckstraat 35, 9000 Ghent, Belgium
[3] Division Forest, Nature and Landscape, University of Leuven, Celestijnenlaan 200E-2411, 3001 Leuven, Belgium
[4] Division Ecology, Evolution and Biodiversity Conservation, University of Leuven, Kasteelpark Arenberg 31-2435, 3001 Leuven, Belgium
[5] College of Natural Sciences, Addis Ababa University, Addis Ababa 999047, Ethiopia
* Correspondence: gelayegmd@gmail.com; Tel.: +251-913-271-987

Abstract: Shade coffee farms in southwest Ethiopia are known to host high levels of avian biodiversity. However, these farms vary in terms of forest management, which affects their understory, mid-story, crown cover, and canopy closure, and hence their structural complexity. Such differences in vegetation structure can potentially affect the survival of specialist bird species, and shade coffee farms may not equally contribute to avian biodiversity conservation. This study aimed to investigate how avian community composition, richness, and the relative abundance of different bird functional guilds relate to structural differences in vegetation shaped by forest management. Bird guild classification was based on bird species forest dependence, diet type, migration status, nest type, foraging, and nesting strata, and bird communities were surveyed using the Timed Species Counts (TSCs) method. Species turnover in bird communities was evaluated using detrended correspondence analysis and redundancy analysis, whereby multiple regression models were used to examine bird guild responses to vegetation structure. Total bird species richness and relative abundance did not respond to vegetation structure. However, the richness of forest specialists and understory foragers, and the relative abundance of mid-high foragers, all positively related to tree diameter at breast height (DBH) and crown cover, whereas the relative abundance of species with medium levels of forest dependency, mid-high/canopy foragers, and open-nesters were positively related to basal area and canopy cover. This study demonstrates that the relative value of shade coffee farms for avian biodiversity conservation depends on the type of forest management, and that bigger trees with larger crown cover provide a habitat of higher quality to habitat specialist birds.

Keywords: bird conservation; Ethiopia; forest management; shade coffee farm; vegetation structure

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1. Introduction

Tropical forest ecosystems cover a large geographical area worldwide and constitute a very rich ecosystem that provides a broad range of services to humankind [1]. Due to agricultural expansion and other anthropogenic factors, these resources have been degraded and are currently being lost at an alarming rate [2]. As the intensification of management can have negative impacts on the quality of the remaining forests [3,4], which is likely to affect the structure and composition of the biological communities that inhabit these forests, a better understanding of the responses of such communities to intensified forest management is vital for their effective conservation [5]. To this end, birds are a very suitable taxon because they are highly diverse and relatively easy to monitor without disturbance [6,7].

Forest management for shade coffee cultivation has been shown to reduce vegetation complexity by disturbing the understory, mid-story, crown cover, and canopy closure, which negatively affects the survival of bird species inhabiting these forests. For example, anthropogenic disturbance during the breeding season can affect the reproductive success of birds through increased visual cues to predators [8], and through increasing thermal and water stress [9]. Similarly, human interventions in vertical vegetation distribution may reduce birds' access to such vegetation layers and lower their nesting success [9]. Along these lines, in severely managed habitats, ground-breeding birds exhibit lower densities and fewer breeding pairs [10].

Avian species richness and community composition are affected by selective tree removal, but the strength of such effects often depends on the functional characteristics of the species [11–15]. For instance, the abundance of species foraging in the canopy and mixed strata tend to increase with increasing shade coffee management [16], whereas foragers in the middle and understory tend to decrease in abundance. Canopy foragers have been shown to increase with the presence of large trees, canopy cover, tree height, and the density of the understory vegetation [17].

While Ethiopian shade coffee is considered a bird-friendly product [18,19], intensification of shade coffee management is believed to have negative impacts on forest specialists and understory insectivores [18]. In the area where this study was conducted, such intensification is accompanied by a reduction of crown cover [20], which is believed to have immediate negative impacts on bird diversity by limiting the extent of available habitat, reducing forest structural complexity [21,22], and affecting microclimatic conditions [23]. As the extent (and even direction) of such effects is further believed to depend on species' functional traits such as body mass, forest habitat specialty, dietary guild and foraging strata [12], nesting strata [24], and migration status [16,25], studies at the functional guild level are needed to properly inform conservationists and managers.

Birds play important functional roles in ecosystems as pollinators, seed dispersers, predators, or ecosystem engineers, thereby establishing a direct link between biodiversity and ecosystem functions and services [26]. In Ethiopia, few studies have been conducted on the effects of shade coffee management on bird diversity [18,19,27,28], and most studies have so far focused on changes in community composition and distribution across different land-use types, leaving gaps in our knowledge of possible responses to more subtle changes within a particular land-use type. Here, we investigated how (i) bird community composition and (ii) richness and the relative abundance of different bird functional guilds (classified according to their forest dependence, diet type, migration status, nest type, foraging and nesting strata) respond to vegetation characteristics within a given landscape. We hope the results of this study will inform the management and conservation of bird communities of shade coffee farms in other global regions.

2. Materials and Methods

2.1. Study Area

The study was conducted in the semi-plantation coffee system of the Garuke, in southwest Ethiopia (7°4′40.96″ N and 36°44′17.12″ E; Figure 1). The Garuke landscape comprises a mosaic of agricultural lands, human settlements, wetlands, and differently-sized forest remnants lying on hill slopes, streams, and isolated farmlands. Management of these forest remnants differs in relation to the vegetation structure [29]. Shade coffee farms are typically established by modifying the original forest with coffee plantations in order to improve the productivity of the coffee plants by reducing tree and shrub density, which involves the slashing of undergrowth, planting of coffee seedlings, tree cutting, and coffee plant pruning. A total of 30 forest remnant patches within our study area were delineated from Google earth and imported to ArcMap 10.4.1 using KML to layer conversion tool. The patch sizes ranged from 1.1 ha to 24 ha, with a mean and standard deviation of 7.36 ha and 6.43 ha, respectively. For this study, 15 of the patches were selected randomly using the INDEX function in Excel.

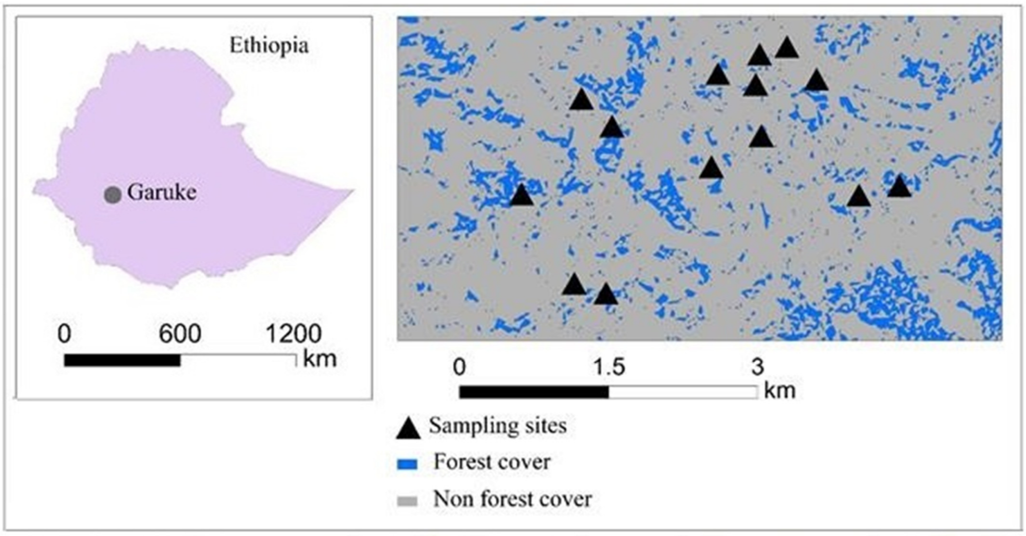

Figure 1. The location of the study area and sites where both vegetation and bird data were collected.

2.2. Bird Survey

Bird species were surveyed in fifteen forest patches in the Garuke area between February 2009 and October 2010. We recorded all bird species heard or seen to assess the response of bird community composition and functional guilds to vegetation structure. To reduce bias within and between observers, we provided a month-long training prior to the survey.

To estimate the relative abundance of each species, we applied the Timed Species Counts (TSC) method, which is an easy and useful method, particularly in tropical habitats [30,31]. Data were collected between 6:30 and 10:00 a.m. and between 3:30 and 5:30 p.m. by walking slowly through each study patch in a random way [30]. To establish a random entry point to each patch, a vertical line on the east side of the patch was developed using Catalog in ArcMap 10.4.1 about 200 m away from the boundary of the patch. The XY coordinates at the end of the vertical lines were developed using the "feature vertices to points" function of ArcMap 10.4.1. As X coordinates remain the same along the vertical line, random Y coordinates between the ends of the vertical line were generated using the RANDBETWEEN function in Excel to determine the entry points. During the surveys, the counting order of the patch was also randomized using the INDEX function in Excel. During each survey day, one to two TSCs were applied per patch.

All bird species were recorded in a fixed period (1 h) and were listed in the order in which they were seen (or heard). Each observation hour was therefore divided into six consecutive 10 min intervals [30], and each species was recorded only once per hour. As TSC is based on the assumption that more common species are recorded earlier than rarer ones within a 60 min interval [30–32], species seen or heard during the first 10 min interval received a score of "6", those recorded during the following interval received a score of "5", and so on. Species that were not recorded in a given TSCs obtained a score of "0" [32]. We did not count flyovers and did not include observations outside the plot boundaries, and counting was interrupted or completely stopped during heavy rains. We conducted a total of 135 TSCs, with the number of TSCs per plot ranging between 10 and 15. We calculated an index of the relative abundance of species as the mean of the scores from repeated TSCs per plot (hereafter referred to as 'relative abundance'). The index varied between a maximum value of six and a minimum value of 1/n, where n is the number of repeated TSCs surveys [30,32].

2.3. Functional Guilds

Bird species were classified on the basis of the following functional traits: diet type (insectivores, frugivores, granivores, nectarivores, herbivores, scavengers), foraging strata (ground, ground and understory, understory, understory and mid-high, canopy and mid-high, mixed), nesting height (ground: <1 m; understory: 1–3 m; sub-canopy/canopy: >3 m), nest type (open: uncovered; closed: covered), forest dependency (high, medium, low, not occurring in forests), and migratory status (migratory, resident). Data on diet and nest type were obtained from '*The Birds of Africa*' [33–36], while information on forest dependency was obtained from BirdLife International [37]. We have made some reclassifications to diet type. This was applied by pooling omnivores, carnivores, and vultures and designating them as "scavengers". Nest type and nesting strata were not assigned for brood parasites and migratory species. Bird taxonomy was based on the IOC World Bird List (V10.1) [38].

2.4. Vegetation Structure

Vegetation structure was assessed within thirty-six 400 m^2 vegetation plots (20×20), whereby the number of vegetation plots was proportional to the area of the forest patches. The plots were randomly placed along the TSC transects. Within each vegetation plot, the number of trees was counted and the diameter at breast height (DBH) was measured for all trees with DBH $\geq$ 5 cm, using diameter tape. Mean tree height and dominant tree height (i.e., the average height of the five tallest trees in the vegetation plot) were measured using clinometers. Basal area was calculated as the sum of the cross-sectional area measured at the breast height ($\geq$5 cm) of all trees in a stand, expressed as m^2 ha^{-1}. The percentage of the crown cover was calculated from vertical crown projections using SVS (Stand Visualization System, USDA Forest Service). Crown closure (%) was calculated from the four readings in the cardinal directions with a spherical densitometer. Data from vegetation plots were pooled to obtain forest patch level estimates.

2.5. Data Analysis

Bird community composition and its relationship with vegetation structure was analyzed using detrended correspondence analysis (DCA) and redundancy analysis (RDA). First, DCA analysis was performed to determine the extent of species turnover in the community, whereby a first axis length greater than four standard deviations represented a complete species turnover in community composition [39]. We then performed RDA analysis to explore patterns of community composition in relation to vegetation structure. DCA- and RDA-analysis was performed on a relative abundance matrix, whereby rare species were down-weighted. For RDA-analysis, all vegetation predictors were scaled and tested for significance (p < 0.05) using Monte-Carlo permutation tests. Prior to analysis, bird data were normalized by log transformation. DCA- and RDA-analysis was performed using the package "vegan" in R [40].

Given the observed multicollinearity among vegetation structures, we performed a principal components analysis (PCA) with varimax rotation to summarize the variation in vegetation structures and used the PCA-axes as independent variables. All vegetation variables were scaled and centered prior to PCA-analysis, while avian richness and the relative abundance of the different bird guilds were used as dependent variables. Hierarchical multiple regression analysis was used to explore relationships between vegetation structure (PC1, PC2, PC3), avian richness, and relative abundance. All models were adjusted for covariance. Each hierarchical model consisted of two blocks of independent variables (i.e., covariance or predictors), whereby covariance variable were included in the first block and predictor variables were included in the second one. Forest patch area was log-transformed to achieve linear relationships with avian richness, while untransformed values were used in the analyses of relative abundance. Variance inflation factors were inspected for all models. All statistical modelling was performed using SPSS version 28.

3. Results

A total of 122 bird species from 46 families were recorded in the study area (Table S1). Green-backed Camaroptera (*Camaroptera brachyuran*), Dideric Cuckoo (*Chrysococcyx caprius*), Western Olive Sunbird (*Cyanomitra olivace*), Senegal Coucal (*Centropus senegalensis*), and

Abyssinian Crimson-wing (*Cryptospiza salvadorii*) were the most common species. The number of recorded bird species per forest patch ranged from 16 to 102.

3.1. Habitat Characteristics

Variables related to vegetation structure showed strong variation among the different plots (Tables 1 and S2). The mean number of trees showed the highest level of variation, followed by mean tree basal area. Mean tree height showed the lowest level of variation, followed by mean maximum tree height.

Table 1. Mean and SD of shade coffee forest structural variables. DBH refers to diameter at breast height.

Variables	Number of Patches	Mean	SD
Mean number of trees	15	208.06	123.80
Mean DBH (cm)	15	50.99	15.02
Mean basal area (m^2 ha^{-1})	15	25.91	16.43
Mean crown closure (%)	15	59.34	8.54
Mean crown cover (%)	15	51.93	10.19
Mean tree height (m)	15	11.87	3.44
Mean maximum tree height (m)	15	18.14	3.85

3.2. Community Composition

The first DCA axis showed evidence of less than one complete species turnover (length of 1.05 standard deviations), indicating high species overlap among forest plots. RDA analysis showed that the relative abundance of bird communities significantly correlated with vegetation structure ($F = 1.445$, $p < 0.05$), more specifically with mean diameter at breast height ($F = 2.204$, $p < 0.01$) and mean crown closure ($F = 1.901$, $p < 0.0$, Figure 2).

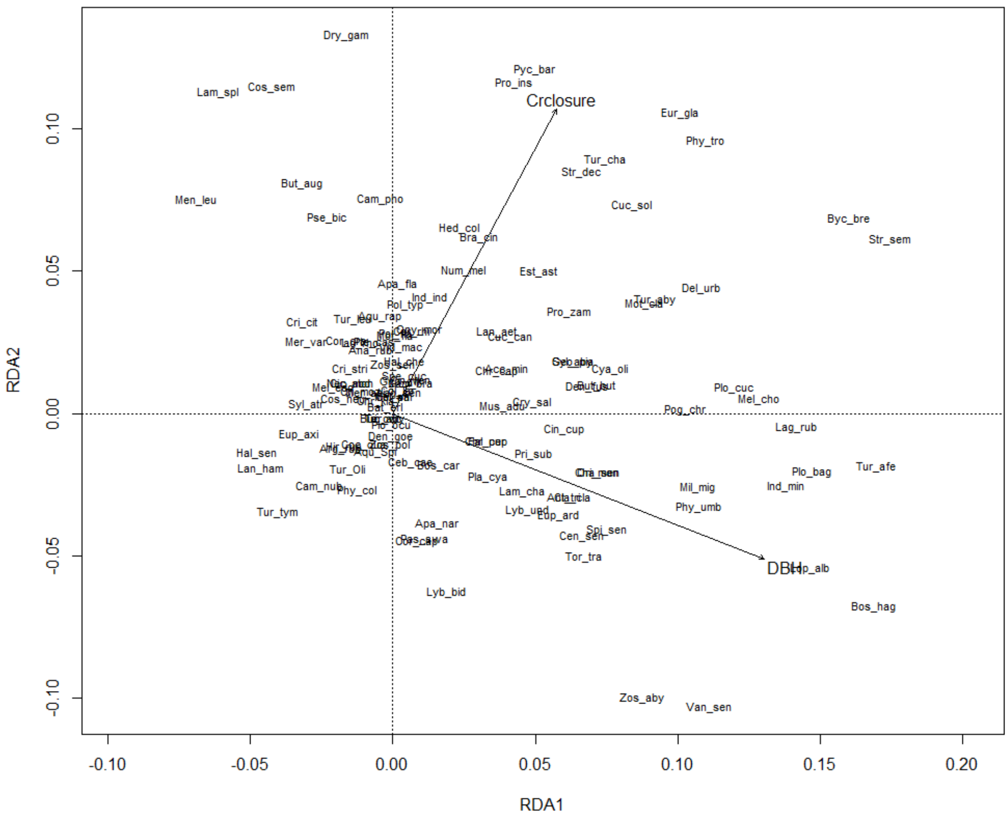

Figure 2. RDA ordination diagram on bird community and vegetation data. DBH refers to mean diameter at breast height; Crclosure refers to mean crown closure; bird species codes are provided in Table S1. Significant relationships with bird community composition are represented by arrows.

3.3. Vegetation Structure and Relationships with Bird Community

Most variation in vegetation structure was explained by the first three PCA axes, which together explained 84.41% of the variation (Table 2). PC1 explained 40.79% of the variation and was positively related to the mean maximum tree height and mean tree height, and negatively related to the mean number of trees (Table 2). PC2 explained 23.33% of the variation and was positively related to mean diameter at breast height and mean crown cover. PC3 explained 20.29% of the variation and was positively related to the mean basal area and mean crown closure.

Table 2. Principal Component Analysis loadings after varimax rotation and percentage variance explained by the first three components (PC1, PC2, and PC3) of vegetation structure. Bold values represent the highest loadings on the positive and negative sides of the respective PC axes.

Variables	PC 1	PC 2	PC 3
Mean number of trees	**−0.47892**	0.35909	0.23284
Mean DBH	0.10061	**0.72146**	−0.03815
Mean basal area	0.24164	0.22275	**0.55736**
Mean crown closure	0.041308	0.010143	**0.6977**
Mean crown cover	0.26944	**0.52895**	−0.35788
Mean tree height	**0.56589**	−0.14172	−0.04252
Mean maximum tree height	**0.55461**	−0.03097	0.13043
%variance explained	40.79	23.33	20.29

The level of richness of species with a high level of forest dependency and of understory foragers was positively related to PC2 (Table 3; Figure 3a,b). The relative abundance of species with a low level of forest dependency and of mid-high foragers was positively related to PC2 (Table 2; Figure 3e,f), while the relative abundance of species with a medium level of forest dependency was positively related to PC1 and PC3 (Table 2; Figure 3c,d). Finally, the relative abundance of mid-high/canopy foragers and open nesters was positively related to PC3 (Table 2; Figure 3g,h).

Table 3. Results of hierarchical multiple regression modelling, assessing the effects of vegetation structure of shade trees on the richness and relative abundance of bird functional guilds. Patch area is included as a covariate. Only significant models are shown (n = 12 from a total of 46 models). Labels: FD (forest dependency), Mh (mid-high), Mh/C (mid-high/canopy) and C/SC (canopy/sub-canopy). Relative Abu = relative abundance. Codes for the significant levels: *** p< 0.001, ** p< 0.01, * p < 0.05. Bold values represent the significant association.

	Intercept [SE]	PC1	PC2	PC3	Patch Area	R Square
Richness						
High FD	**3.62 (0.76)** **	0.15 (0.26)	**0.66 (0.18)** *	0.20 (0.32)	0.36 (0.76)	0.37
Un forager	**4.45 (0.36)** ***	−0.07 (0.12)	**0.59 (0.15)** **	−0.06 (0.16)	−1.06 (0.0.49)	0.69
Relative Abu						
High FD	**−0.303 (0.060)** ***				**0.013 (0.003)** *	0.054
Medium FD	0.119 (0.143)	**0.161 (0.067)** *	−0.035 (0.035)	**0.123 (0.035)** **	−0.264 (0.170)	0.044
Low FD	0.176 (0.135)	0.0154 (0.064)	**0.179 (0.049)** ***	0.149 (0.083)	−0.156 (0.098)	0.130
Mh forager	**−0.304 (0.063)** ***	0.005 (0.021)	**0.060 (0.026)** *	−0.001 (0.028)	**0.176 (0.0.081)** *	0.052
Mh/C forager	**0.626 (0.026)** ***	0.010 (0.008)	0.013 (0.010)	**0.028 (0.011)** *	0.067 (0.032)	0.610
Open-nester	**1.255 (0.154)** ***	−0.007 (0.051)	−0.043 (0.026)	**0.074 (0.018)** ***	**0.177 (0.017)** **	0.055
Closed nester	**0.254 (0.105)** *				**−0.488 (0.122)** ***	0.065
Granivorous	0.035 (0.135)				**−0.425 (0.203)** *	0.060
C/SC nester	**−0.153 (0.038)** ***	−0.015 (0.015)	0.029 (0.020)	0.034 (0.021)	**0.008 (0.004)** *	0.027
Migrant	**−0.333 (0.059)** ***				**0.0013 (0.006)** *	0.035

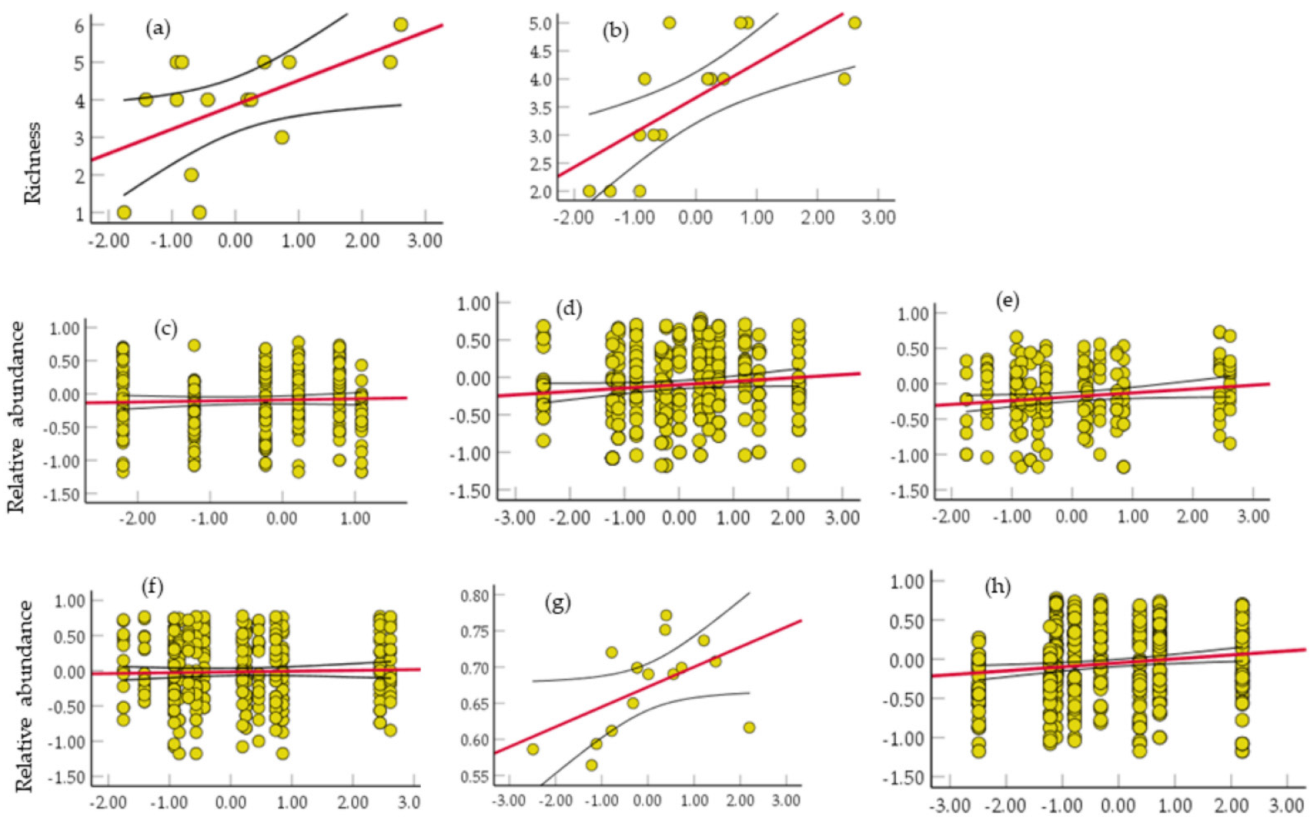

Figure 3. Relationships between avian species richness and the relative abundance of different functional bird guilds with principal components of vegetation structure. See text for details. Relationships between richness of (**a**) species with high-level forest dependency and PC2, and (**b**) understory species with PC2. Relationships between the relative abundance of (**c**) species with medium-level forest dependency and PC1, (**d**) species with medium-level forest dependence and PC3, (**e**) mid-high foragers and PC2, (**f**) species with low-level forest dependency and PC2, (**g**) mid-high/canopy foragers and PC3, and (**h**) open-nesters and PC3. Data points are displayed in yellow and 95% confidence intervals of significant regression lines (red) are shown.

4. Discussion

Although many studies have shown that Ethiopian shade coffee benefits bird biodiversity conservation [18,19,27,28], the importance of vegetation structure on shade coffee plantations for bird biodiversity remains poorly documented. This study revealed that the importance of shade coffee for bird biodiversity conservation is highly dependent on shade coffee management, and that not all shade coffee plantations contribute equally to bird biodiversity conservation. After controlling for area effects, the richness and relative abundance of bird functional guilds were found to show positive or null responses to the vegetation structure of shade coffee farms. Several other studies have shown that changes in forest vegetation structure affect the functional guilds of birds depending on the functional characteristics of the species [11–15,28].

4.1. Effects of Vegetation Structure on Bird Community Composition

We recorded 122 bird species, far exceeding the bird species counted in previous studies in the shade coffee farms of southwest Ethiopia [18,27,28], reaffirming the importance of shade coffee for biodiversity conservation. Nevertheless, most species with the highest relative abundance were generalists in terms of forest requirement: Green-backed Camaroptera, Dideric Cuckoo, Western Olive Sunbird, Senegal Coucal and Abyssinian Crimson-wing. The traditional shade coffee farms in our study area have an intermediate vegetation structure between primary forest and agricultural land, and thus attract species that are generalist in their habitat and have a moderate need for forest habitats.

Site-specific conditions are influenced by environmental parameters and human interventions and can affect species diversity and community composition [41,42]. Moreover, bird diversity and composition are influenced by local vegetation characteristics [41]. This study suggested that total bird species richness and relative abundance did not respond to the vegetation structure of Ethiopian shade coffee. The null response of bird species to vegetation structure is consistent with a study from Tanzania on bird species richness and abundance [43]. On the other hand, many other studies have documented a decrease in the overall richness and abundance of bird species with more intensive coffee management [25,44].

4.2. Functional Guild Richness and Relative Abundance in Relation to Vegetation Structure

Functional guild richness and relative abundance were differentially related to vegetation structure. The species richness of forest specialists and of understory foragers, and the relative abundance of mid-high foragers and of species with low levels of forest dependency, were positively related to DBH and crown cover. These findings suggest that, in shade coffee farms, sites that comprise high DBH and crown cover are the most important for the conservation of the aforementioned guilds. These bird guilds in particular may be adversely affected by current rapid changes in coffee farm management practices that are aimed to increase coffee yields through increased crown cover contraction [20] and decreased DBH [29].

A possible reason for birds' functional guilds being positively associated with increasing DBH and canopy cover may be that the likelihood of improved nesting, foraging, and shelter sites increases with increasing DBH and canopy cover. The presence of medium to large trees in the mid-layer of shade coffee farms may have a positive effect on the supply of food resources for birds that prefer to forage in the mid-layer. The common practice in our study area to slash the ground cover and manipulate understory, mid-story and crown cover/closure may hence adversely affect the availability of foraging, nesting, and shelter sites (see also [16]). The relative abundance of species with open nests, medium levels of forest dependency, and a preference to forage in the mid-high/canopy was positively related to the basal area and crown closure of forest trees. Nest type is important for egg and young survival, as open nests are more visible to predators than closed nests [45]. Consequently, larger basal areas and crown closure may hinder the visibility of eggs and young from open nests to predators, which may lead to greater nest success.

4.3. Conservation Implications

While shade coffee provides important habitat for bird communities in fragmented landscapes, coffee management practices may still have profound impacts on avian diversity. Earlier studies showed that managed forests with a higher shade cover and greater shade tree diversity hosted a higher richness and diversity of birds [42]. Our study shows that the species composition, species richness, and relative abundance of forest birds in shade coffee farms was relatively stable across forest plots that differ in management intensity. This suggests that traditionally-managed shade coffee farms continue to play a key role in the conservation of avian species in strongly degraded forest landscapes [16,19,27,46]. However, not all bird functional guilds seem to equally persist in shade coffee farms. Thus, our study highlights that shade coffee farms managed at low intensity, preserving forest structure complexity and plant species diversity, are needed to maintain bird diversity, while at the same time supporting local community livelihoods.

5. Conclusions

Traditional coffee farms in southwest Ethiopia host a diverse bird community. Bird community composition, richness, and abundance were relatively stable across patches that varied in intensity of shade coffee management, while the latter differentially affected the presence of different bird guilds. The conservation value of shade coffee forests for bird species foraging in the understory and mid-high, and for forest specialist, increased with increased DBH and crown cover, while for species with medium levels of forest dependency, for mid-high/canopy foragers and for open-nesters, the basal area and crown closure seemed the most important. Our findings hence highlight the importance of understanding the relationships between patch-level shade coffee management and bird diversity and point to the need to develop a standard for the vegetation structure of shade coffee plantations that can potentially support bird species adversely affected by current trends of shade coffee intensification.

Supplementary Materials: The following is available at https://www.mdpi.com/article/10.3390/f13122068/s1, Table S1: bird species functional attributes, species codes, species relative abundance per site and total relative abundance of a given species. Table S2: The Vegetation structure and number of plots sampled per patch.

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