BIRD ABUNDANCE AND DIVERSITY IN SHADE COFFEE AND NATURAL FOREST KENYA

By

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ABSTRACT

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Frank Juma Ong'ondo

Coffee, one of the major traded commodities in the world, has captured attention of both the international business class and conservation community due to its value as a beverage and for the habitat it can provide for wildlife. Previous work in Central Kenya has demonstrated that when cultivated with shade trees, coffee farms can host high levels of bird diversity. However, questions of how the bird community in shade coffee farms compares to those in natural forest remained unanswered. Using three visits to each of 160-point count locations in natural forest (80) and shade coffee sites (80) in Central Kenya, I estimated bird abundance and species richness in natural forest and shade coffee. Specifically, I predicted higher abundance and diversity of granivores, forest visitors, forest generalists and no forest association in shade coffee than in natural forest, and higher abundance and diversity of insectivores, frugivores and forest specialists in natural forest than in shade coffee farms. Compared to natural forest, shade coffee had higher bird abundance and species diversity of all feeding guilds except frugivores, which were mostly detected in natural forest. Forest specialists and forest generalists were more abundant and with higher species richness in natural forest than in shade coffee. My study accentuates the value of remnant native trees within coffee plantations for the persistence and conservation of avian communities, while also clarifying that some groups of birds are reliant on natural forests and unlikely to be conserved in shade coffee farms. These findings contribute to a growing understanding of the value and limitations of shade coffee for avian conservation, which land managers can use in their management plans while promoting conservation efforts.

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May Most High God see you all.

This work is dedicated to my grandmother Silper Oduka, 104 years.

"I am seeing you going far and beyond, keep going and love what you are doing"

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

Birds of tropical forests are among the most threatened species on Earth (Sekercioglu et al. 2004, Sekercioglu 2012). Tropical forests cover just 10% of the Earth's surface but contain almost two-thirds of its biodiversity (Giam 2017), and deforestation rates continue throughout the tropics (Geist and Lambin 2002, Pouliot et al. 2012, Zulu and Richardson 2013). The abundance and diversity of birds is a function of habitat and landscape characteristics (Bawa et al. 2004, Wenny et al. 2011), which are impacted by the conversion of complex tropical forests to simplified agriculture habitats (Donald 2004). This disturbance destroys microhabitats that indirectly result in the disappearance or reduction in abundance of specialized species (Zurita et al. 2006, Mahiga et al. 2019). Work in the Neotropics has shown that forest specialists (particularly forest raptors, understory insectivores, and large frugivores) tend to suffer from any conversion of primary forest (Turner 1996, Donald 2004, Powell et al. 2015), but very little of this work has occurred in Africa.

Variation within forest habitats creates a range of food resources, nesting sites, and cover (Perfecto et al. 1996, Otieno et al. 2011). In turn, birds have adapted habitat preferences and feeding habits that affect their response to forest disturbance. Forest specialists are found in the interior of forests and are most likely to disappear when the forest is modified (Bennun et al. 1996). Forest specialists are particularly responsive to the loss of canopy cover (Reidy et al. 2014), which can diminish the availability of tree cavities for woodpeckers and other cavity-nesters (Bütler et al. 2013) and alter understory microhabitats important for maintaining bird abundance and diversity (Villard and Foppen 2018). Because of these complex attributes and the rarity of undisturbed forest on the landscape, forests harbour many endangered and specialised species (Bennun et al. 1996, Waceke 2014). However, forest habitat does not provide the proper feeding and nest building resources for other bird species that are better adapted to open country habitats, such as grasslands and shrubby fields. These species, called forest visitors, are expected to only use forests occasionally and mainly along their edges (Ndang'ang'a et al. 2013). Other bird species, called forest generalists, are capable of occupying forest habitats as well as more disturbed habitats, and are expected to show intermediate forests association between forests specialists and visitors. These forests association categories also correspond with diet (Carrara et al. 2015, Carlo and Morales 2016), as forest specialists tend to include more insectivores and frugivores, whereas forest visitors include many granivores (Sekercioglu et al. 2004, Bregman et al. 2014, Morante-Filho et al. 2015).

Forested habitats are severely threatened in Kenya (Langat et al. 2016). In the past two and half decades, Kenya lost an average of 12,050 ha of forest per year (Mongabay 2019). Kenya's forests host 4.0% of the known world biodiversity (Mongabay 2019). Despite their faunal endemism, Kenyan forests have received insufficient conservation attention. Kenyan forests are affected by climate change and human population growth (Cuni-Sanchez et al. 2019). To sustain the latter, there is an urgent need for food and bioenergy, prompting increased forest loss for agricultural expansion, which is a premier threat to forest biodiversity worldwide (Lambin and Meyfroidt 2011)

Coffee, one of the major export and cash crops of the tropics, has great influence on biodiversity (Jha et al. 2014). On one hand, deforestation for coffee cultivation is a major threat to forest biodiversity. But coffee can be cultivated in a variety of ways (Jha et al. 2014), and where the coffee shrubs are grown beneath 'shade trees', coffee systems can also provide some habitat for birds species associated with trees and more forested habitats (Perfecto et al. 1996). Coffee plantations provide ground cover that offers suitable habitat for some birds (Komar 2006). They can provide breeding sites and hiding places for skulking birds as well as feeding ground for birds such as thrushes (Tejeda-Cruz and Sutherland 2004, Philpott et al. 2008). Migratory birds also use shade coffee farms as a corridor when moving between temperate and tropical regions (Buechley et al. 2015, Estrada-Carmona et al. 2019). Native shade trees can provide insect resources and microhabitats that are suitable for some forest associated birds (Narango et al. 2018, Rodrigues et al. 2018, Kammerichs-Berke et al. in press). Coffee trees themselves also produce flowers that attract insectivorous and omnivorous bird species (Perfecto et al. 1996). Landscapes with shade coffee may also sustain connectivity and mobility of forest-dependent species moving and feeding from one forest fragment to another (Estrada-Carmona et al. 2019). Nonetheless, several authors have noted that shade coffee may not provide resources necessary for the most forest-reliant species (Tejeda-Cruz and Sutherland 2004, Komar 2006), and comparisons of bird communities between coffee and intact forests are needed (Mendenhall et al. 2016). Despite the apparent importance of trees in coffee to birds, and the importance of forests to Kenyan avifauna, relatively little work on this topic has been conducted in Kenya, and to date no studies have compared the avifauna in shade coffee and natural forests in Kenya. Therefore, this calls for understanding how Kenyan shade coffee farms can contribute to bird conservation, especially for forest associated species.

The contribution of agricultural landscapes to the conservation of biodiversity has only been recognized recently (Kremen and Merenlender 2018), although their value for forest specialists remain unresolved (Tejeda-Cruz and Sutherland 2004, Jha et al. 2014). This understanding increases the need for a land use planning strategy that incorporates the management and diversification of the anthropogenic matrix in which natural areas are embedded (Bawa et al. 2004). Many scientific studies focus on overall bird species richness (Sekercioglu 2002, Mulwa et al. 2012, Smith et al. 2015), but the review above demonstrates the importance of examining the species composition of bird communities in forests and coffee farms, especially with respect to forest specialization and feeding guilds. Working in Kenyan and Ethiopian coffee farms, respectively, Smith et al. (2015) and Buechley et al. (2015) found bird community patterns that differed from those reported from Neotropical coffee farms, further underscoring the need to better understand Afromontane bird communities in agro-ecological matrices. There is therefore an urgent need to understand how the landscape mosaic (Mahiga et al. 2019), under influence of human impacts, shapes the avian community composition.

The aim of my study was to investigate how bird abundance and diversity varies between shade coffee farms and natural forests of central Kenyan highlands. Specifically, I examined two hypotheses based on research previously conducted in the Neotropics. The *forest specialization hypothesis* posits that while shade coffee farms harbour many habitat generalists and species able to use both forest and more open habitats, they are not able to support many forest specialists (Tejeda-Cruz and Sutherlan 2005, Reidy et al. 2014). Similarly, the *dietary guild hypothesis* posits that shade coffee farms are well-suited for granivorous birds, but they are not as good as forests at supporting insectivores and frugivores (Komar 2006, Şekercioğlu, 2012). To examine these hypotheses, I test the following predictions.

a) Natural forest has higher species richness and abundance of forest specialists, insectivores and frugivores than does shade coffee.

b) Shade coffee has higher species richness and abundance of forest visitors, forest generalists, those species with no forest association at all, and granivores than does natural forest.

MATERIALS AND METHODS

Study Area

The study was conducted within and around shade coffee plantations and natural forest sites in the vicinity of Nairobi, Kenya. The region experiences both wet (April-June and October-December) and dry seasons (August–October and January-early March). The coffee and forest sites receive 865-962 mm of rainfall and occur at similar elevations 1500-1850m asl.

Shade coffee plantation study sites were on Sasini Coffee Plantation Company in Kiambu County of Central Kenya, in the heart of one of the country's six major areas producing Arabica coffee, *Coffea arabica* (Gakinya 2014, Smith et al. 2015). The Sasini Coffee Company plantations were founded in 1952 (Gakinya 2014). Sasini Coffee Company adopted two distinct management levels of coffee production: coffee grown under sun and shade coffee. All study sites were in shade coffee. The area receives on average 962 mm of rainfall annually, has an average temperature of 18.8°C, and the plantations lie along an altitudinal gradient of 1500-1800 m asl. The plantations lie in an agriculturally fertile area in Kiambu County and are surrounded by other agricultural habitats, such as tea plantations, maize plantations, vegetables, Irish potatoes, and dairy farming. Sasini Coffee Company has a total of 911 ha under coffee cultivation with eight plantations in Central Kenya. I selected 8 sites (2 sites per coffee estate x 4 coffee plantation estates) for the shade coffee sampling points (Figure 1): Kamundu (1° 08′ 10″

S, 36° 47′ 23″ E), Ruiru (1° 06′ 28″ S, 36° 54′ 27″ E), Ting'ang'a (1° 07′ 35″ S, 36° 48′ 04″ E) and Gulmarg (1° 18′ 35″ S, 36° 44′ 35″ E). The shade coffee farms include rows of coffee shrubs with systematically distributed shade tree species of one to several native tree species, corresponding to a “shaded monoculture” cultivation strategy as described by *Moguel and Toledo (1999)*. Cordia (*Cordia africana*) was the most common shade tree in this study, with scattered *Prunus africanas, Vitex kinyensis* and *Ficus sthoningii*. Farms with the exotic grevillea shade tree (*Grevillea robusta*) were excluded from this study.

The dominant understory weed present during surveys was Blackjack, *Bidens pilosa*. Blackjack was spread throughout the farms, both between and within the coffee rows. It was controlled by physical methods with hand-held hoes or with chemicals (herbicide) where it was intense. Other weeds detected in the farm included *Oxalis latifolia*, *Sporobolas sp*, *Commelina bengalensis,* couch grass, *Klenia abyssinica*, and *Gloriosa superba* among others.

At the beginning of the survey, coffee shrubs were flowering with sweet aroma on several estates, and flowering transitioned to fruiting by the end of my surveys, though shrubs at Ruiru and Ting’ang’a were mostly fruiting during my first visit. Where they were flowering, the coffee shrubs were greener, thicker and moister than those which were either picked or having fruits.

In natural forest, two forests were chosen for this study for comparison to the shade coffee plantations (Figure 1). Karura Forest (1° 14′ 25″ S, 36° 49′ 25″ E) is located adjacent to the Kenya Forest Service headquarters facilities in Nairobi County. It was gazetted in the year 1932 with area cover of 1041.3 ha (Karura Management Plan 2010). It is a dry upland forest and a water catchment for Thigiri, Karura, Ruaka, Gitathura and Mathare river systems. The forest is situated in the northern part of Nairobi city. The forest supports plantation trees, indigenous trees, and grasslands. All bird surveys were conducted in areas of indigenous forest, which was generally between 50 and 100 years old. Typical trees in Karura Forest include *Olea europaea* subsp. *Cuspidate, Croton megalocarpus, Warburgia ugandensis* (Muthiga), *Brachyleana huillensis* (Muhugu), *Uvaridendron anisatum, Strychnos henningsii, Markhamia lutea, Newtonia buchananii, Salvadora persica, Ficus thonningii, Trichilia emetic, Calondendrum capense* and *Dombeya goetzenii*. This forest receives 928 mm of annual rainfall and lies 1500-1850 m asl.

Ngong Road Forest (1° 18′ 35″ S, 36° 44′ 35″ E) is a dry land forest located within the purview of western Nairobi city, between 1800-1820m. It experiences both dry and wet seasons like Karura Forest. The forest has an average temperature of 16.7 °C and the average rainfall is 865 mm annually. The forest was gazette in 1952. Due to increased development of Nairobi city and its environs, Ngong Road Forest has undergone severe reduction in size from its original size 2,927 ha to the current 1,224 ha mostly due to expansion of Karen and Ngong residential area as well as educational facilities such as Lenana School and Ngong Racecourse. Ngong Road forest have similar tree species as Karura Forest (see above), although with species associated with drier conditions such as *Drypetes gerrardii, Maytenus undata and Strychnos henningsii* among others. Ngong

Road Forest is managed by Kenya Forest Service (KFS) and the Ngong Road Forest Association, a Community Forest Association formed under the Forest Act of 2005.

Sampling procedure

This study was conducted between February and April 2020. Using a stratified sampling design, I selected eight replicate study sites on each of the two land cover types (shade coffee and natural forest). Each study site was separated from another by at least 400 m and was chosen to include habitat with relatively consistent structure and species composition (e.g., similar shade tree species and age, similar forest tree composition and age). Within each of these selected 16 study sites, I distributed ten sampling points (total 160) where both birds and vegetation data were recorded. Adjacent sampling points were 150 m apart. All the shade coffee study sampling points were placed at least 200 m from the forest edge and/or major road, while the natural forest study sampling point were at least 200 m away from the forest edge. Areas adjacent to roads, buildings and trails were avoided to reduce disturbance and increase natural observation of the birds. At each study site, point counts were conducted three times (February 2020 through April 2020) to increase and enable modeling of detectability. The sequence of sampling sites was initially random, then kept consistent so that there was a relatively consistent interval between each successive visit to a sample point (21 days). Vegetation data were only collected once during the first session of point counts.

I surveyed birds by a standardized point count protocol (Ralph et al. 1993). On arrival to the sampling point, birds were allowed to settle for 1 min and then all the birds seen or heard were recorded for a period of 9 min totaling to 10 min. Flyover birds were not counted because I assumed that they were not using the habitat. I only recorded birds seen or detected within a fixed radius of 50 m, using a rangefinder to aid in distance estimation. Birds were recorded in the order of detection with their respective time.

A total of eight (8) vegetation variables were recorded in all the 160 sampling points within a 50 m radius from the center of the plot. For the four canopy trees nearest to each sampling point, I measured tree height and canopy depth (via clinometer), the trunk's diameter at the breast height (1.3 m off the ground via DBH tape). I also measured the canopy (shade canopy) cover at each point using a hand-held densiometer recorder. Within each quadrant of a 10 x 10m plot, I recorded the estimate of the percentage of shrub cover (defined as vegetation <2.5 m), the number shrub stems present in each quadrat, the height of the herbaceous vegetation (with aid of tape measure) and the percentage of the understory herbaceous vegetation that was flowering (estimated visually). The vegetation variables recorded in these four quadrants in each plot were averaged for analyses. Several of these variables were correlated with each other, so to avoid multicollinearity and simplified statistical model, only 6 variables were used in analyses: canopy depth, canopy, herbaceous layer height, shrub cover, shrub stems, and shrub stems squared. These variables were selected because of their hypothesized roles in potentially influencing birds in coffee and forests (Smith et al. 2015, Kammerichs-Berke et al. in press). Shrubs stems squared was included for a potential quadratic (humped) relationship between birds and the number of shrub stems.

All the field protocols were approved following Humboldt State University Institutional Animal Care and Use Committee (IACUC) permission number 16/17. W306-A.

All birds recorded during the surveys were classified into one of six feeding guilds, (1) Carnivores (feeding on vertebrates), (2) Insectivores (feeding on invertebrates), (3) Omnivores (feeding on both plants and animal materials), (4) Granivores (feeding mainly on grains and seeds), (5) Frugivores (feeding mainly on fruits) and (6) Nectivores (feeding mainly on nectar and pollen grains) (Gray et al. 2007, Kissling et al. 2007) and one of four forest-association guilds, (1) Forest specialists, (2) Forest generalists, (3) Forest visitors, and (4) No forest association (Bennun et al. 1996).

All analyses were conducted within R version 4.0.2. I tested the association between species' feeding guilds and forest association status using chi-square test of independence for k groups (Preacher 2001). I used species accumulation curves to examine the adequacy of vegetation sampling effort in shade coffee and natural forest. Specifically, I calculated species accumulation curves for each land cover type as a function of the number of sample points, using the vegan package (Martensen et al. 2008), and the number of individual birds detected, using the iNEXT package which also included rarefaction and extrapolation of species diversity (Hsieh et al. 2016). The species accumulation curve approaching a plateau in estimating species richness showed that my sampling points were enough. I examined differences in vegetation variables between coffee and natural forest sites using two sample *t*-tests. All the vegetation variables conform to the two-sample *t*-tests assumptions and therefore were included in the analysis.

I used community N-mixture models to estimate bird abundance and species richness detected during the survey period (Bellier et al. 2016, Kéry and Royle 2016, Yamaura et al. 2016). The community N-mixture model describes the relationship between latent abundance N_{ik} of species k at site i and the observed response y_{ijk}, which is the *count* of species k at site i during visit j as follows:

$a_{ik} \sim \text{dbern}(\text{phi}_k)$

$N_{ik} \sim \text{dpois}(a_{ik} * \text{lambda}_{ik})$

$y_{ijk} | N_{ik} \sim Binomial\ (N_{ik}, p_{ijk})$

$\log(\lambda_{ik}) = beta0_k + theta_{ik} * \text{habitat}_i + betaX_k \times vegetation\ variables_i$

$\text{logit}(p_{ijk}) = \text{alpha0}_k$

$beta0_k \sim Normal\ (\mu_{beta0,}\ \sigma^2_{beta0})$

$betaX_k \sim Normal\ (\mu_{betaX,}\ \sigma^2_{betaX})$

$alpha0_k \sim Normal\ (\mu_{alpha0}\ \sigma^2)$

Where p = detection probability, N = abundance, alpha0 = is the random effect of (mean) detection probability for each species k on the logit scale, *beta0* = random effect for mean abundance of each species with a mean of μ_{beta0} and a precision of σ^2_{beta0}, $betaX_k$ = a matrix of random effects representing the effects of six vegetation covariates on each species k. Each random effect has a mean μ_{betaX} and precision σ^2_{betaX}, vegetation variables_i = a matrix of measured values of six vegetation variables at each site i, *theta* representing effect of habitat_i (land cover type; 1 = shade coffee, 2 = natural forest). As noted above, only six vegetation variables were included.

I conducted all the statistical modeling in JAGS (Ken Kellner 2021) using R version 4.0.2 (R Core Team 2020). I ran two chains of 70000 iterations, with a burn-in of 1200 iterations as suggested by Yamaura et al. (2016). I considered abundances or richness between the two land cover types to be significant if their modelled estimates had posterior distributions with $< 5\%$ overlap.

I calculated species similarity index between shade coffee and natural forest using Jaccard Index formula $Cj = j/(a+b+j)$, where j = species detected in both shade coffee and natural forest, a = species detected only in forest and b = species detected only in shade coffee.

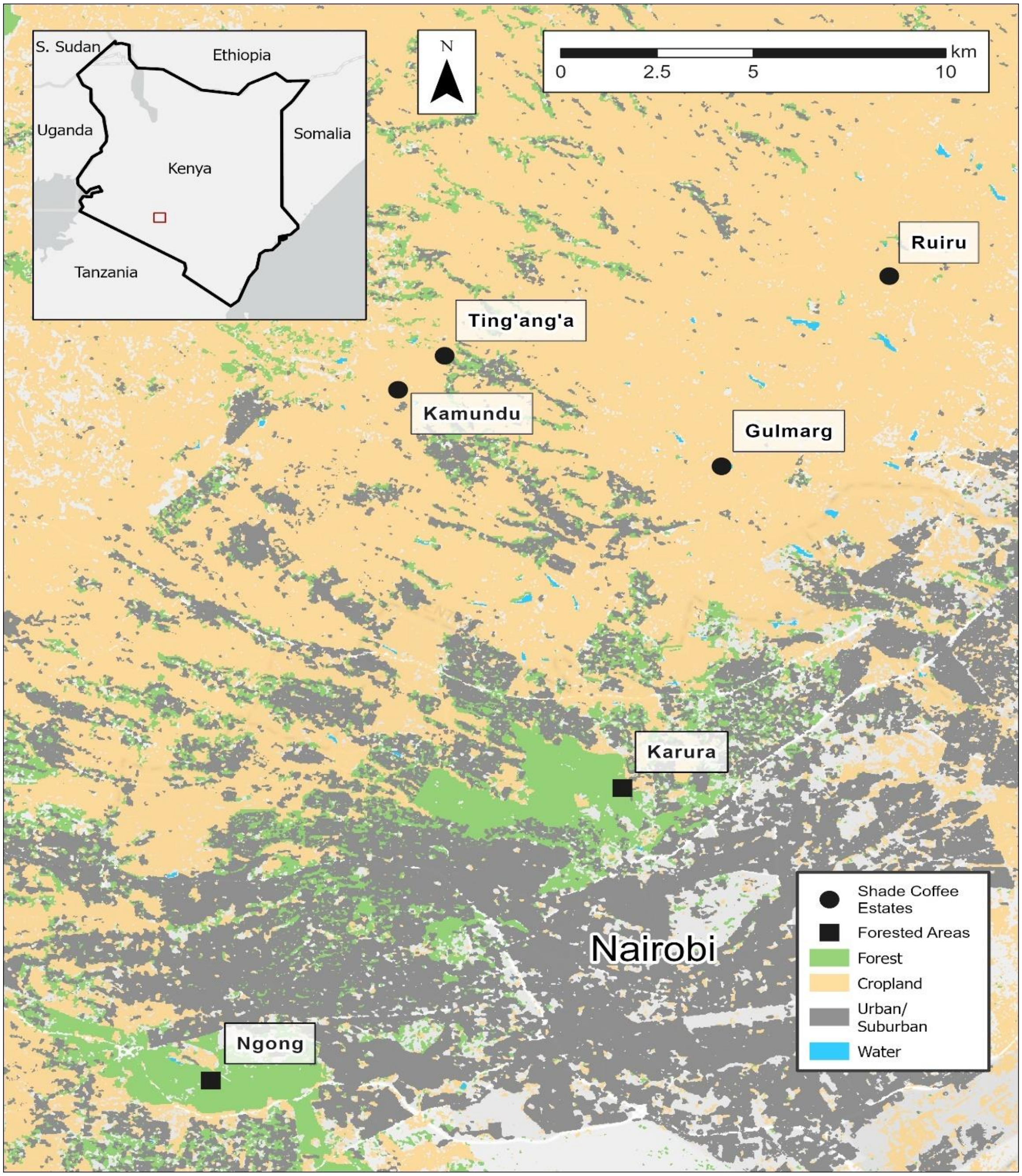

Figure 1. Study area and sampling sites for bird species detected in natural forest and shade coffee on 3 visits to each of 160-point count locations in natural forest (80) and shade coffee sites (80) in Central Kenya, February to April 2020. Map created by Samantha Chavez.

RESULTS

A total of 4318 individual birds belonging to 145 species were recorded across all 160 sampling points during the study period (Appendix A); 2781 individuals of 127 species were recorded in shade coffee and 1537 individuals of 79 species were recorded in natural forests (Table 1). Species accumulation curves suggested an adequate sampling effort, with the number of species detected approaching an asymptote in both coffee and natural forest beyond 70 sampling points (Figure 2). Rarefied species richness as a function of individuals sampled also suggested that sampling effort was similarly thorough in coffee and natural forest (Figure 3).

Among total raw detections, insectivores and omnivores were the most commonly detected feeding guilds, comprising 43% and 21% of all detections and 42% and 14% of all species, respectively (Table 1). Among forest-association guilds, forest generalists and species with no forest association were most commonly detected, comprising 51% and 20% of all detections and 26% and 51% of all species, respectively (Table 1). Feeding guilds and forest–association guilds were not independent (χ^2 = 1048.9, df = 15, $P < 0.05$), with omnivores somewhat more strongly forest-associated than the other guilds (44% of forest specialists vs. 14% of all species were omnivores), and granivores and carnivores were less strongly forest-associated (11% of forests specialists vs. 18% of all species were granivores or carnivores; Table 2).

Table 1. Total bird detections against percentages and total number of species detected against percentages among 6 feeding guilds and 4 forest association guilds on 3 visits to each of 160-point count locations in natural forest (80) and shade coffee sites (80) in Central Kenya, February to April 2020.

	Forest		Coffee		Total	
Guilds	# detections	# species	# detections	# species	# detections	# species
Feeding guilds						
Carnivore	84 (5%)	10 (13%)	132 (5%)	23 (18%)	216 (5%)	26 (18%)
Frugivore	108 (7%)	2 (3%)	84 (3%)	3 (2%)	192 (4%)	4 (3%)
Granivore	28 (2%)	10 (13%)	486 (17%)	26 (20%)	514 (12%)	26 (18%)
Insectivore	772 (50%)	39 (49%)	1068 (38%)	54 (43%)	1840 (43%)	61 (42%)
Nectivore	228 (15%)	5 (6%)	428 (15%)	7 (6%)	656 (15%)	7 (5%)
Omnivore	317 (21%)	13 (16%)	583 (21%)	14 (11%)	900 (21%)	21(14%)
Forest association guilds						
Forest specialist	134 (9%)	8 (10%)	1 (0%)	1 (1%)	135 (3%)	9 (6%)
Forest visitor	709 (46%)	21 (27%)	442 (16%)	20 (16%)	1151 (27%)	25 (17%)
Forest generalist	534 (35%)	28 (35%)	1653 (59%)	35 (28%)	2187 (51%)	37 (26%)
Non-forest-associated	160 (10%)	22 (28%)	685 (25%)	71 (56%)	845 (20%)	74 (51%)
Total	1537	79	2781	127	4318	145

Table 2. Distribution of 145 species detected against percentages on points counts by feeding guilds and forest association status on 3 visits to each of 160-point count locations in natural forest (80) and shade coffee sites (80) in Central Kenya, February to April 2020.

Feeding guild	Forest Specialist	Forest Generalist	Forest Visitor	Non-Forest Associated	Total	%
Carnivore	1 (11%)	4 (16%)	4 (11%)	17 (23%)	26	18
Insectivore	2 (22%)	12 (48%)	18 (49%)	29 (39%)	61	42
Omnivore	4 (44%)	5 (20%)	4 (11%)	8 (10%)	21	14
Granivore	1 (11%)	1 (4%)	7 (19%)	17 (23%)	26	18
Frugivore	1 (11%)	2 (8%)	0 (0%)	1 (1%)	4	3
Nectivore	0 (0%)	1 (4%)	4 (11%)	2 (3%)	7	5
Total	9	25	37	74	145	100
%	6	17	26	51	0	100

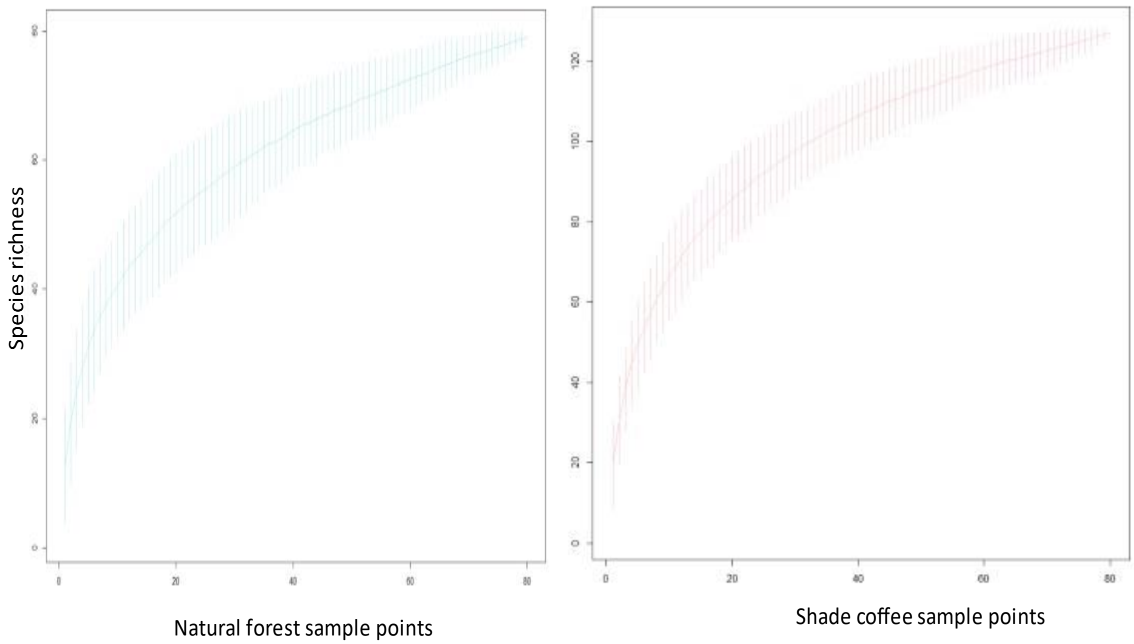

Figure 2. Species accumulation curve for bird species (145 in total) detected per sampling point on 3 visits to each of 160-point count locations in natural forest (80) and shade coffee sites (80) in Central Kenya, February to April 2020. The species accumulation curve is represented by a solid blue and pink line with its upper and lower bounds (estimate ± 1 standard deviation).

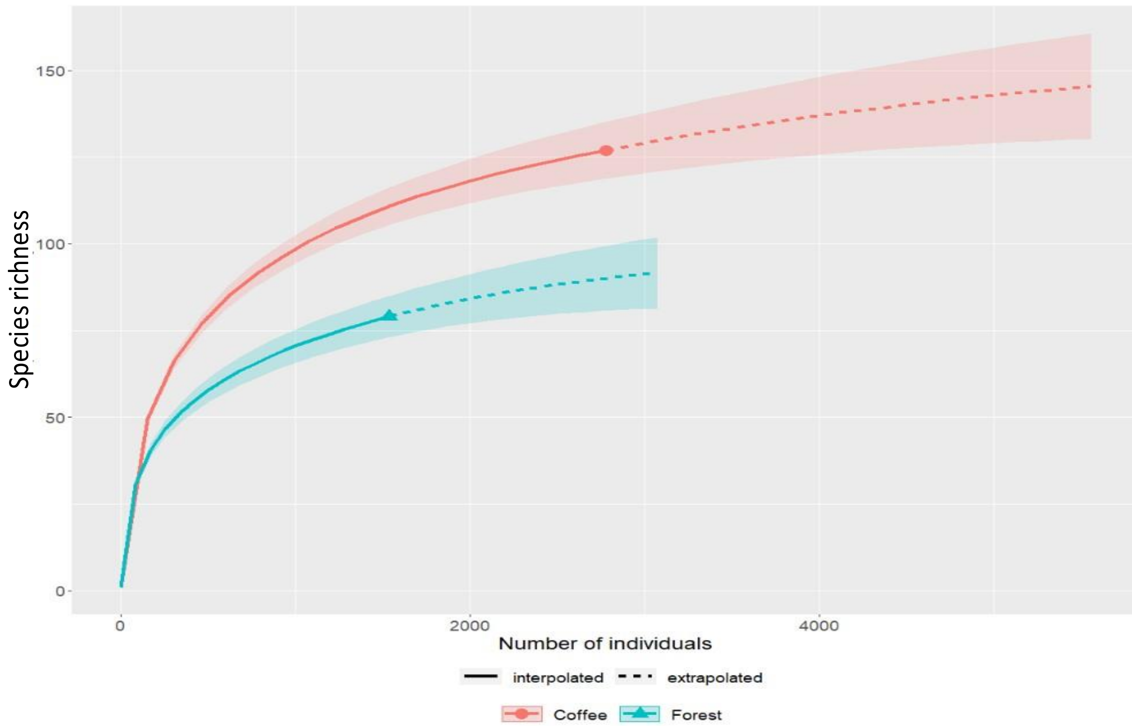

Figure 3. Species accumulation curve for bird species (145 species in total) detected on 3 visits to each of 160-point count locations in natural forest (80) and shade coffee sites (80) in Central Kenya, February to April 2020 predicting species richness, sampling effort required to detect 95% Credible Interval (shaded area) of the predicted number of species in shade coffee and natural forest. The interpolated (solid lines) show the maximum number of species detected against detected individuals (shade coffee = 127 species against 2900 individuals, natural forest = 79 species against 1800 individuals), and the extrapolated (dotted lines) shows the maximum number of the species would have been recorded had the survey continued (shade coffee = 150 species against 6000 individuals, natural forest =100 species against 3200 individuals).

Modeled estimates of species abundance suggested there were strong differences between natural forest and coffee. Of 145 total species analyzed, 57 had a modeled land cover type effect with a credible interval that did not overlap zero, with 18 showing higher modeled abundance in natural forest and 39 showing higher abundance in coffee (Appendix A). Likewise, there were strong differences in the modeled abundance of feeding and forest association guilds between natural forest and coffee. Among feeding guilds, carnivores, granivores, insectivores, and omnivores all had higher estimated abundance per point count in coffee than in forest (Figure 4). Among forest-association guilds, forest specialists and forest generalists had higher estimated abundance per point count in forest than in coffee, whereas forest visitors and non-forest associated species had higher estimated abundance in coffee than in forest (Figure 5). These results partly confirm my predictions that natural forest has higher abundance of forest specialists. However, contrary to my prediction, insectivorous species were more abundant in the shade coffee than in natural forest while there was no difference in the frugivorous abundance between shade coffee and natural forest (Figure 4). Forest visitors, non-forest associated species and granivores were all more abundant in the shade coffee than natural forest as per my prediction (Figure 4 & 5). However, the model estimated forest generalists to be more abundant in natural forest than in the shade coffee, contrary to my prediction (Figure 5).

The patterns observed in the differential abundance of guilds between land cover types arise from differences in individual species, some of which merit special mention. For example, the higher abundance of nectivores in shade coffee was driven largely by many more detections of Bronze and Scarlet-chested Sunbirds in coffee (168 and 72, respectively) than in forest (2 and 8, respectively, see Appendix A, where all common and scientific names are provided). In contrast, the similar total abundance of omnivores in shade coffee and natural forest came about because some omnivores were far more abundant in coffee whereas other omnivores were more abundant in forest, rather than most or all omnivore species being similarly abundant in both habitats. For instance, omnivorous Baglafecht Weavers were detected primarily in coffee (121 vs. 1 in forest), whereas omnivorous Yellow-whiskered Greenbuls were detected exclusively in forest (136 vs. 0 in coffee). Similarly, there were more detections of the omnivorous Kikuyu White-eye and Variable Sunbird in shade coffee than in natural forest, but more detections of the omnivorous Collared Sunbird and Yellow-rumped Tinkerbirds in forest than in coffee (Appendix A). There were only four species of true frugivores detected, and the most abundant of these showed opposite patterns: Hartlaub's Turacos were detected only in forest, whereas Violet-back Starlings were detected only in coffee.

Importantly, several species were not detected at all-in-one habitat or the other. For example, African Green Pigeon, Kenya Rufous Sparrow, Golden–breasted Bunting and Jackson's Francolin among others were detected in coffee but not forest, whereas Brown-chested Alethe, Crowned Eagle, Cabanis's Greenbul, Green-backed Twinspot, Lemon Dove, and Slender-billed Greenbul were detected in forest but not in coffee (Appendix A). Some species such as Little Swift, Northern Double-collared Sunbird, Tambourine Dove, Tropical Boubou, and Yellow-breasted Apalis among others showed similar detections in shade coffee and natural forest (Appendix A).

There were also strong differences in species richness between natural forest and shade coffee. Overall, the number of species detected was higher in coffee (127) than in the forest (79), with 66 (46%) species detected in coffee only, 18 (12%) in forest only, and 61 (42%) detected in both, yielding a community similarity index of 42% (Niwattanakul et al. 2013). The estimates of species richness of all feeding guilds except frugivores was modeled to be higher in shade coffee than in natural forest (Figure 6). Frugivores were more speciose in natural forest than shade coffee (Figure 6). Among forest association guilds, species richness of forest specialists and forest generalists were higher in natural forest than in shade coffee, whereas species richness was higher in coffee than in forest for forest visitors and non-forest associated species (Figure 7). The higher species richness of forest specialists and frugivores in natural forest than in shade coffee (Figure 6 & 7) is consistent with my predictions. However, the richness of insectivores was higher in shade coffee than in the natural forest, contrary to my predictions (Figure 6). The higher species richness of forest visitors, non-forest associated species, and granivores in shade coffee than natural forest concurs with my predictions (Figure 6 & 7). Contrary to my predictions, forest generalist's richness was higher in natural forest than in shade coffee (Figure 7).

As expected, there were very strong differences in the vegetation structure between land cover types (Table 3). Coffee sample points had, on average, greater canopy depth (+1.2 m), higher shrub cover (+22%), understory flowing (+1%), tree height (+3.4m), and tree diameter (+18.5 cm), but a lower number of shrub stems per plot (-4.5), lower canopy cover (-13 densiometer points) and shorter herbaceous layer (-2 cm).

The modeled vegetation variables showed relatively few significant relationships with bird abundance. Among estimated coefficients of 6 vegetation variables for 145 bird species, only 4 species showed a coefficient with a posterior distribution that did not overlap 0, all for shrub stem^2 (Appendix B). Nonetheless, inclusion of these vegetation variables improved model performance, with clearer effects of land cover once vegetation variables were also parameterized.

Table 3. Comparison of the mean ± SE of the vegetation variables recorded per point count between two land cover types at 160-point count locations in natural forest (80) and shade coffee sites (80) in Central Kenya, February to April 2020.

	Shade coffee		Natural forest				
Variables	Mean	SE	Mean	SE	t	df	*P*
Canopy depth (m)	5.3	0.2	4.1	0.2	4.3	158	< 0.01
Densiometer (0-96 “closed” points)	68.8	1.6	81.5	2.2	-4.7	158	< 0.01
Herbaceous layer height (cm)	21.7	1.3	24	1.2	-1.3	158	< 0.01
Shrub cover (%)	47.4	0.1	25.2	0.8	9.1	158	< 0.01
Shrub stems (#)	4.1	0.1	8.6	0.1	-5.4	158	< 0.01
Understory flowering (%)	1.4	1.4	0.4	2.0	9.0	158	< 0.01
Tree height (m)	11.9	0.4	8.5	0.3	6.8	158	< 0.01
Diameter at breast height (cm)	39.3	1.0	20.8	1.0	13.2	158	< 0.01

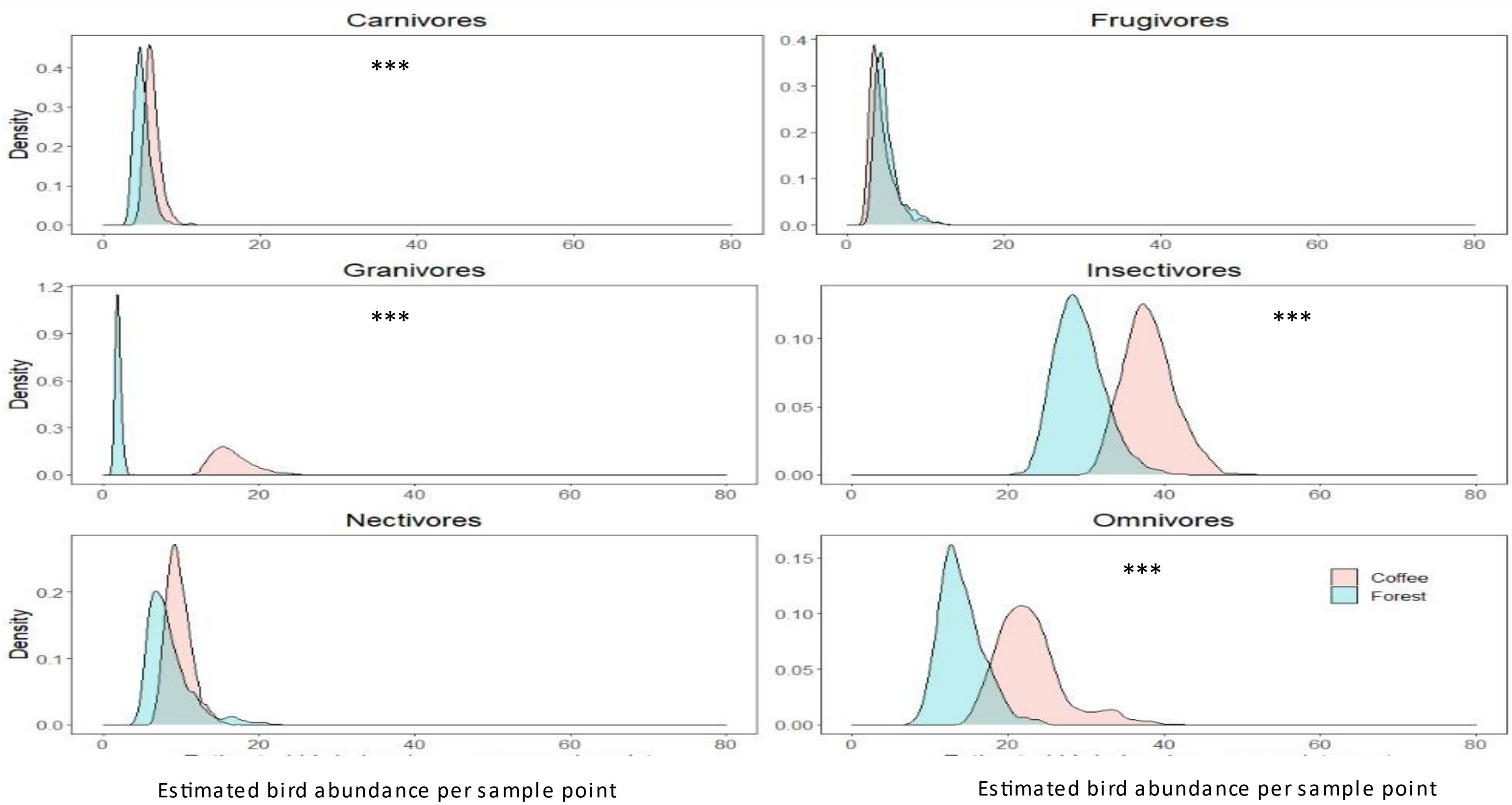

Figure 4. Posterior distributions of total bird abundance per sample point for six feeding guilds based on point count surveys in Central Kenya, February to April 2020. Distributions with < 5% overlap are indicated with asterisks. Carnivores graph--The forest slope is on the left; Frugivores graph--The coffee slope is on the left; Granivores graph--The forest slope is on the left; Insectivores graph-- The forest slope is on the left; Nectivore's graph--The forest slope is on the left; Omnivore's graph--The forest slope is on the left.

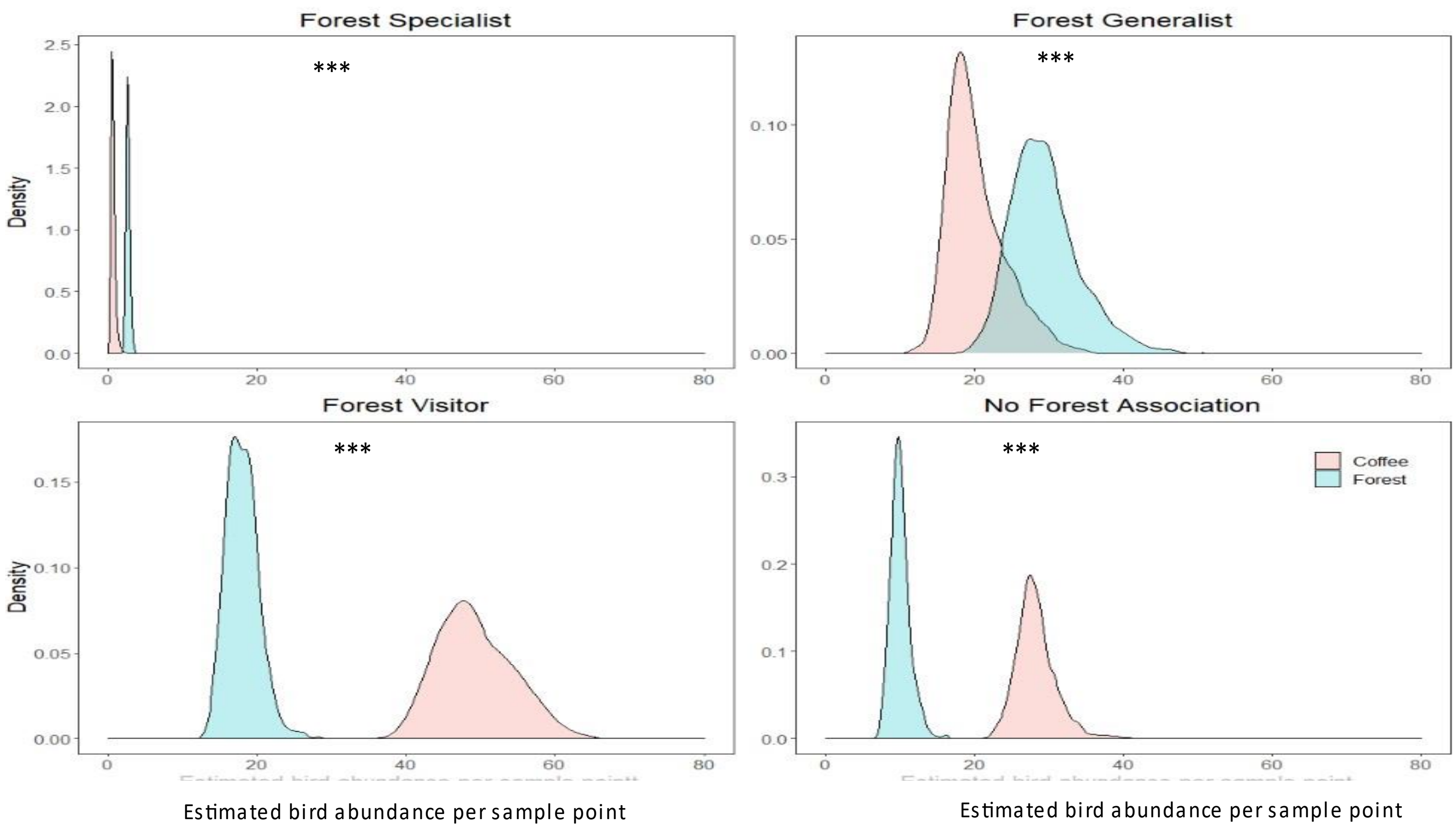

Figure 5. Posterior distributions of total bird abundance per sample point for four forest association guilds based on point count surveys in Central Kenya, February to April 2020. Distributions with <5% overlap are indicated with an asterisk. Forest Specialist graph--The coffee slope is on the left; Forest Generalist graph--The coffee slope is on the left; Forest Visitor graph--The forest slope is on the left; No Forest Association graph-- The forest slope is on the left.

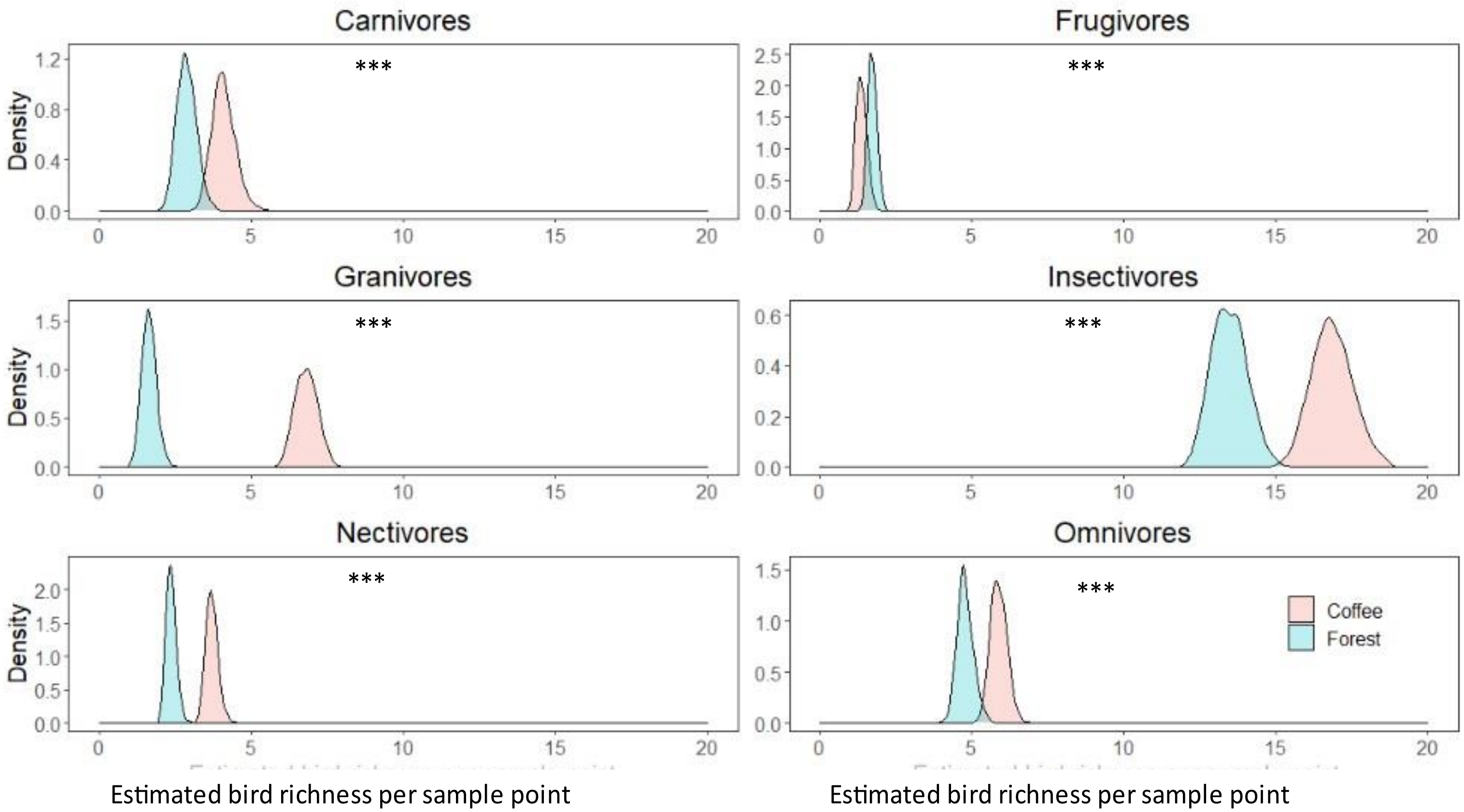

Figure 6. Posterior distributions of total species bird richness per sample point for six feeding guilds based on point count surveys in Central Kenya, February to April 2020. Distributions with <5% overlap are indicated with asterisks. Carnivores graph--The forest slope is on the left; Frugivores graph--The coffee slope is on the left; Granivores graph--The forest slope is on the left; Insectivores graph-- The forest slope is on the left; Nectivore's graph--The forest slope is on the left; Omnivore's graph--The forest slope is on the left.

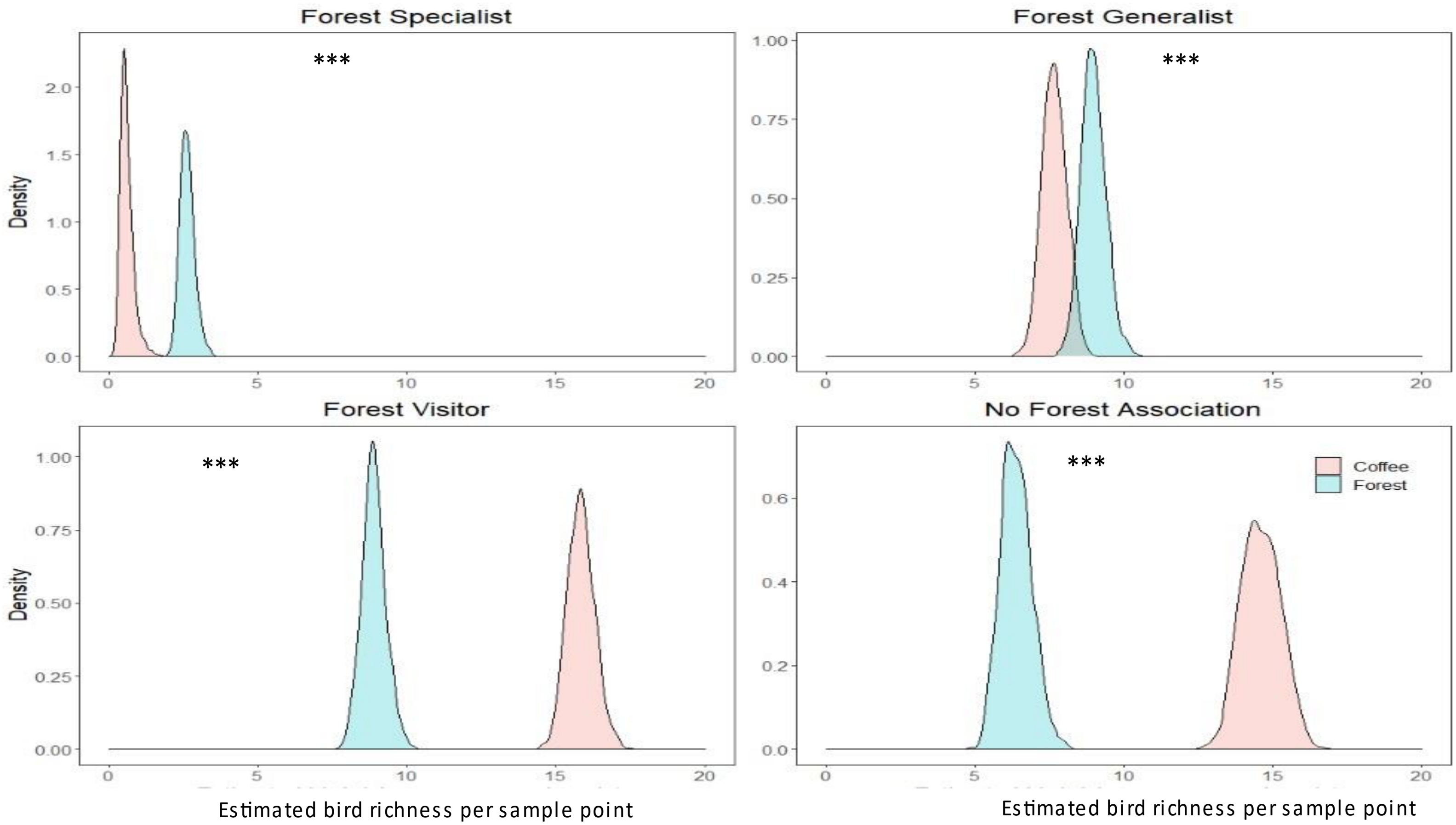

Figure 7. Posterior distributions of total species bird richness per sample point for four forest association guilds based on point count surveys in Central Kenya, February to April 2020. Distributions with <5% overlap are indicated with asterisks. Forest Specialist graph--The coffee slope is on the left; Forest Generalist graph--The coffee slope is on the left; Forest Visitor graph--The forest slope is on the left; No Forest Association graph-- The forest slope is on the left.

DISCUSSION

Shade coffee farms can provide excellent habitat for many tropical birds (Jha et al. 2014), but several authors have noted that shade coffee may not provide resources necessary for all types of birds (Tejeda-Cruz and Sutherland 2004, Komar 2006), and more comparisons of bird communities between coffee and intact forests are needed (Mendenhall et al. 2016), especially in Africa (Powell et al. 2015). My findings support the concept that shade coffee is valuable for birds in Kenya; indeed, I found higher overall bird abundance and species richness in shade coffee farms than in natural forest sites. However, my findings also provide some support for the *forest specialization and dietary guild hypotheses* which posit that the suitability of shade coffee farms for birds varies with their forest-association and feeding guilds. The Hierarchical Modelling analysis that I used allowed me interpret the responses of avian guilds to vegetation structure and land cover type (Yamaura et al. 2016). I found distinct patterns in the abundance and species richness based on birds' different feeding guilds and forest-association status. These differences are likely due to the fact that shade coffee and natural forest have different vegetation structure and composition (Norfolk et al. 2017, *Table 3*). Vegetation cover plays an integral role by influencing resource availability (Clough et al. 2009, Milligan et al. 2016), nesting habitat, and security, which in turn affects bird abundance and species richness (Patterson and Best 1996, Burke and Nol 1998, Grarock et al. 2013, Bergner et al. 2015).

While my results generally support the hypotheses that the value of shade coffee varies depending on birds' feeding guilds and forest association guilds, results were not entirely consistent with my predictions. For example, I predicted based on the literature that the abundance and species richness of insectivores and frugivores would be higher in natural forest, but my results showed more insectivores in shade coffee (Figures 4 & 6). This result could be due to resources provided by shade trees. For example, native flowering *Cordia* trees provide both insect and nectar resources for birds (Feinsinger 1976, Smith et al. 2015, Kammerichs-Berke et al. in press). Additionally, large and widely spaced shade trees can provide excellent feeding opportunities for insectivores and omnivores, especially if the trees are native species (Moguel and Toledo 1999, Johnson 2000, Reitsma et al. 2001, Komar 2006) which is consistent with my results. Vegetation surveys showed that trees were larger on the shade coffee farms than in natural forest in my study sites (Table 3) therefore providing resources for insectivores and omnivores.

Farm management activities could also enhance the availability of insects for birds. For example, I observed a general trend of more detections of insectivorous bird species in sampling sites where farm workers were actively weeding and/or picking, which could cause disturbance and the flushing of insects, thus aiding foraging. Although I did not quantify this possibility, it could merit further research. As predicted, the abundance and species richness of granivores was markedly higher in shade coffee than in natural forest (Figures 4 & 6). I argue that the presence of understory plants seeding and flowering at the time of surveys (pers. obs.) could have contributed to this higher detection of granivores in shade coffee than in the natural forest. In fact, previous work in Kenya has shown that granivores can respond to the temporarily abundant seed sources in shade coffee farms with abundant weeds (Smith et al. 2015).

I hypothesized that the abundance and richness of birds in shade coffee and natural forest would vary with forest association status and predicted that the most strongly forest-associated species (forest specialists) would be more common in natural forest, while the other three forest association categories would be more common on shade coffee farms. My findings show that the forest-association patterns were even stronger than predicted. Both forest specialists and forest generalists were more abundant and species-rich in natural forest than in shade coffee farms, while forest visitors and those species with no forest association were more abundant and richer on shade coffee farms (Figures 5 & 7). Of the 9 species of forest specialists detected in my study, 8 were detected exclusively in the forest (Appendix 1); the Thick-billed Seedeater was the only forest specialist species detected in coffee (a single detection). Interestingly, this species was not detected in the forest. I argued that the bill morphology of the Thick-billed Seedeater enables it to feed on a variety plant material hence presumably able to live in a wide array of land cover types (Forboseh et al. 2003). Among the 25 species of forest generalists, 9 had a significantly higher abundance in natural forest than in shade coffee farms, while 4 showed the reverse. Three forest generalist species were dramatically more common in forest, with >100 detections in forest and <20 in coffee (Black-backed Puffback, Collared Sunbird, and Yellow-whiskered Greenbul; Appendix A). These results suggest that there are some forest attributes favored by even generalist species that are insufficient or lacking in the shade coffee sites I studied.

It is unsurprising that forest specialist bird species prefer natural forests (Reitsma et al. 2001, Waltert et al. 2005, Clough et al. 2009, Gilroy et al. 2015) in correspondence to their comparatively narrow ecological needs found in natural habitats (Hinsley et al. 2009, Mulwa et al. 2012), and their susceptibility to habitat modification. Although shrub cover was higher in shade coffee than in the natural forest (Table 3), this shrub layer was composed nearly exclusively of a single species shrub (coffee) which is known to harbor relatively few insects (Johnson 2000). In contrast, the natural forest sample points had a higher diversity of shrubs species, nearly all of which were native, and could harbor more insects (Wenninger and Inouye 2008). My work did not quantity the relative abundance of insects in the understory of shade coffee and natural forest, but this topic is worth future research. The mid canopy of a forest is composed of orchids, mosses, and other epiphytes and lianas that can help support arboreal gleaner bird species (Waltert et al. 2005) while the top canopy is utilized by forest raptors (Waceke 2014). It can be said that forest specialists are secretive species that prefer habitats with minimal disturbance (Bennun et al. 1996). The strong association of the forest specialists in the natural forest suggests that tree density and tree species richness play a crucial role in the conservation of threatened forest associated species. My findings concur with other studies done elsewhere (Naidoo 2004, Mulwa et al. 2012, Helbig-Bonitz et al. 2015, Smith et al. 2015) and emphasize the crucial role natural forests play in providing habitat for species less likely to use human-disturbed habitats such as coffee farms.

The abundance and species richness of forest generalists was higher in natural forest than in the shade coffee contrary to my prediction. I argue that this could be due to the fact that many species of the forest generalist would prefer diverse habitat with various food resources that may be present in shade coffee farms but are common in natural forests (Waltert et al. 2005, Table 2) as suggested by other work (Naidoo 2004). Also, because of the dry season during the survey period, most of the shade coffee sites surveyed during this time either had bare ground or a relatively dry understory (own observation), with a demonstrably lower herbaceous habitat later (Table 3). Forest generalists have the ability to utilize both natural forest and shade coffee (Norfolk et al. 2017), and therefore these adaptation mechanisms enable them to shift from shade coffee to natural forest to track resources, which may have been limited in the dry season in coffee. My study did not quantify the variation of forest generalists throughout the year to understand their abundance and richness, therefore calling for future work.

Consistent with my prediction, the abundance and species richness of both forest visitors and those birds with no forest association status were higher in shade coffee than in natural forest. This was expected, as there is a large pool of open-country and farmland associated species in East Africa (Luck and Daily 2003, Mulwa et al. 2012, Smith et al. 2015, Mahiga et al. 2019) that can make use of the relatively open canopy and widely spaced trees in coffee farms (Johnson 2000). This finding shows that shade coffee habitats provide suitable conditions for forest visitors and those birds with no forest association status. For instance, during the survey, most of the weeds and plant material finished seeding and had a lot of grains and seeds sources of food for species such as

Dusky Turtle Dove, Holub's Golden Weaver, African Citril, Kenya Rufous Sparrow and Purple Grenadier among others.

It is important to note that bird abundance and species richness are incomplete measures of the quality of habitats for birds (Horne 1983, Johnson 2007). A full understanding of the value of shade coffee farms in Kenya and elsewhere will require examination of their capacity to also support reproduction and survival (Gleffe et al. 2006, Komar 2006). Nonetheless, this study has for the first time documented which bird species in Kenya can be abundant in shade coffee farms in comparison to reference natural forest sites.

I hope that the findings of this project will contribute to the global conservation and will help land managers with their management plans, as well as enhance conservation efforts. Further investigation on seasonal changes, food supply, and the response of other specific guilds of birds, such as understory insectivores (Powell et al. 2015) could be useful for understanding the capacity for shade coffee to advance conservation of East African birds.

REFERENCES

Bawa, K. S., W. J. Kress, N. M. Nadkarni, and S. Lele. 2004. Beyond paradise-meeting the challenges in tropical biology in the 21st century. Biotropica 36:437–446.

Bellier, E., M. Kéry, and M. Schaub. 2016. Simulation-based assessment of dynamic *N* -mixture models in the presence of density dependence and environmental stochasticity. D. Hodgson, editor. Methods in Ecology and Evolution 7:1029–1040.

Bennun, L., C. Dranzoa, and D. Pomeroy. 1996. The forest birds of Kenya and Uganda. Journal of East African Natural History 85:23–48.

Bergner, A., M. Avcı, H. Eryiğit, N. Jansson, M. Niklasson, L. Westerberg, and P. Milberg. 2015. Influences of forest type and habitat structure on bird assemblages of oak (*Quercus spp*.) and pine (*Pinus spp*.) stands in southwestern Turkey. Forest Ecology and Management 336:137–147.

Bregman, T. P., C. H. Sekercioglu, and J. A. Tobias. 2014. Global patterns and predictors of bird species responses to forest fragmentation: Implications for ecosystem function and conservation. Biological Conservation 169:372–383.

Buechley, E. R., Ç. H. Şekercioğlu, A. Atickem, G. Gebremichael, J. K. Ndungu, B. A. Mahamued, T. Beyene, T. Mekonnen, and L. Lens. 2015. Importance of Ethiopian shade coffee farms for forest bird conservation. Biological Conservation 188:50–60.

Burke, D. M., and E. Nol. 1998. Influence of food abundance, nest-site habitat, and forest fragmentation on breeding ovenbirds. The Auk 115:96–104.

Bütler, R., T. Lachat, L. Larrieu, and Y. Paillet. 2013. Key elements for forest biodiversity. European Forest Institute. 284 pp.

Carlo, T. A., and J. M. Morales. 2016. Generalist birds promote tropical forest regeneration and increase plant diversity via rare-biased seed dispersal. Ecology 97:1819–1831.

Carrara, E., V. Arroyo-Rodríguez, J. H. Vega-Rivera, J. E. Schondube, S. M. de Freitas, and L. Fahrig. 2015. Impact of landscape composition and configuration on forest specialist and generalist bird species in the fragmented Lacandona rainforest, Mexico. Biological Conservation 184:117–126.

Clough, Y., D. Dwi Putra, R. Pitopang, and T. Tscharntke. 2009. Local and landscape factors determine functional bird diversity in Indonesian cacao agroforestry. Biological Conservation 142:1032–1041.

Cuni-Sanchez, A., P. Omeny, M. Pfeifer, L. Olaka, M. B. Mamo, R. Marchant, and N. D. Burgess. 2019. Climate change and pastoralists: perceptions and adaptation in montane Kenya. Climate and Development 11:513–524.

Donald, P. F. 2004. Biodiversity impacts of some agricultural commodity production systems. Conservation Biology 18:17–38.

Estrada-Carmona, N., A. Martínez-Salinas, F. A. J. DeClerck, S. Vílchez-Mendoza, and K. Garbach. 2019. Managing the farmscape for connectivity increases conservation value for tropical bird species with different forest-dependencies. Journal of Environmental Management 250:109504.

Feinsinger, P. 1976. Organization of a tropical guild of nectarivorous birds. Ecological Monographs 46:257–291.

Forboseh, P. F., E. C. Keming, C. L. Toh, and I. N. B. Wultof. 2003. Monitoring of Kilum-Ijim forest bird communities: Initial findings. Bird Conservation International 13:255–271.

Gakinya, S. K. 2014. Strategic responses by Sasini coffee company limited to environmental changes in Kenya. University of Nairobi.

Geist, H. J., and E. F. Lambin. 2002. Proximate causes and underlying driving forces of tropical deforestation. BioScience 52:143.

Giam, X. 2017. Global biodiversity loss from tropical deforestation. Proceedings of the National Academy of Sciences 114:5775–5777.

Gilroy, J. J., C. A. Medina Uribe, T. Haugaasen, and D. P. Edwards. 2015. Effect of scale on trait predictors of species responses to agriculture: Species' responses to agriculture. Conservation Biology 29:463–472.

Gleffe, J. D., J. A. Collazo, M. J. Groom, and L. Miranda-Castro. 2006. Avian reproduction and the conservation value of shaded coffee plantations. Ornitologia Neotropical 17: 271–282.

Grarock, K., D. B. Lindenmayer, J. T. Wood, and C. R. Tidemann. 2013. Does human-induced habitat modification influence the impact of introduced species? A case study on cavity-nesting by the introduced common myna (*Acridotheres tristis*) and Two Australian Native Parrots. Environmental Management 52:958–970.

Gray, M. A., S. L. Baldauf, P. J. Mayhew, and J. K. Hill. 2007. The response of avian feeding guilds to tropical forest disturbance. Conservation Biology 21:133–141.

Helbig-Bonitz, M., S. W. Ferger, K. Böhning-Gaese, M. Tschapka, K. Howell, and E. K. V. Kalko. 2015. Bats are not birds - different responses to human land-use on a tropical mountain. Biotropica 47:497–508.

Hinsley, S., R. Hill, R. Fuller, P. Bellamy, and P. Rothery. 2009. Bird species distributions across woodland canopy structure gradients. Community Ecology 10:99–110.

Horne, V. B. 1983. Density as a misleading indicator of habitat quality. The Journal of Wildlife Management 47:893.

Hsieh, T. C., K. H. Ma, and A. Chao. 2016. inext: An R package for rarefaction and extrapolation of species diversity (Hill numbers). Methods in Ecology and Evolution 7:1451–1456.

Jha, S., C. M. Bacon, S. M. Philpott, V. Ernesto Méndez, P. Läderach, and R. A. Rice. 2014. Shade coffee: Update on a disappearing refuge for biodiversity. BioScience 64:416–428.

Johnson, M. D. 2000. Effects of shade-tree species and crop structure on the winter arthropod and bird communities in a Jamaican shade coffee plantation1. Biotropica 32:133–145.

Johnson, M. D. 2007. Measuring habitat quality: A review. The Condor 109:489–504 16.

Karura management plan, B. L. P. T. 2010. Karura forest Strategic Management Plan. <https://docplayer.net/31641878-Karura-forest-strategic-management-plan.html>.

Ken Kellner. 2021. A wrapper around "rjags" to streamline "JAGS" analyses. <https://github.com/kenkellner/jagsUI>.

Kéry, M., and J. A. Royle. 2016. Applied hierarchical modeling in ecology. Academic Press. <http://www.mbr-pwrc.usgs.gov/pubanalysis/keryroyllebook/>.

Kissling, W. D., C. Rahbek, and K. Böhning-Gaese. 2007. Food plant diversity as broad-scale determinant of avian frugivore richness. Proceedings of the Royal Society B: Biological Sciences 274:799–808.

Komar, O. 2006. Priority contribution. Ecology and conservation of birds in coffee plantations: A critical review. Bird Conservation International 16:1.

Kremen, C., and A. M. Merenlender. 2018. Landscapes that work for biodiversity and people. Science 362:eaau6020.

Lambin, E. F., and P. Meyfroidt. 2011. Global land use change, economic globalization, and the looming land scarcity. Proceedings of the National Academy of Sciences 108:3465–3472.

Langat, D. K., E. K. Maranga, A. A. Aboud, and J. K. Cheboiwo. 2016. Role of forest resources to local livelihoods: The case of east Mau forest ecosystem, Kenya. International Journal of Forestry Research 2016:1–10.

Luck, G. W., and G. C. Daily. 2003. Tropical countryside bird assemblages: Richness, composition, and foraging differ by landscape context. Ecological Applications 13:235–247.

Mahiga, S. N., P. Webala, M. J. Mware, and P. K. Ndang'ang'a. 2019. Influence of land-use type on forest bird community composition in Mount Kenya forest. International Journal of Ecology 2019:1–8.

Martensen, A. C., R. G. Pimentel, and J. P. Metzger. 2008. Relative effects of fragment size and connectivity on bird community in the Atlantic Rain Forest: Implications for conservation. Biological Conservation 141:2184–2192.

Mendenhall, C. D., A. Shields-Estrada, A. J. Krishnaswami, and G. C. Daily. 2016. Quantifying and sustaining biodiversity in tropical agricultural landscapes. Proceedings of the National Academy of Sciences 113:14544–14551.

Milligan, M. C., M. D. Johnson, M. Garfinkel, C. J. Smith, and P. Njoroge. 2016. Quantifying pest control services by birds and ants in Kenyan coffee farms. Biological Conservation 194:58–65.

Moguel, P., and V. M. Toledo. 1999. Biodiversity conservation in traditional coffee systems of Mexico. Conservation Biology 13:11–21.

Mongabay. 2019. Tropical rainforest: Deforestation rates tables and chats. mongabay.com. <https://rainforests.mongabay.com/deforestation/2000/Kenya.htm>.

Morante-Filho, J. C., D. Faria, E. Mariano-Neto, and J. Rhodes. 2015. Birds in anthropogenic landscapes: The responses of ecological groups to forest loss in the Brazilian Atlantic forest. Plos One 10: e0128923.

Mulwa, R. K., K. Böhning-Gaese, and M. Schleuning. 2012. High bird species diversity in structurally heterogeneous farmland in western Kenya. Biotropica 44:801–809.

Naidoo, R. 2004. Species richness and community composition of songbirds in a tropical forest-agricultural landscape. Animal Conservation 7:93–105.

Narango, D. L., D. W. Tallamy, and P. P. Marra. 2018. Nonnative plants reduce population growth of an insectivorous bird. Proceedings of the National Academy of Sciences 115:11549–11554.

Ndang'ang'a, P. K., J. B. Njoroge, and M. Githiru. 2013. Vegetation composition and structure influences bird species community assemblages in the highland agricultural landscape of Nyandarua, Kenya. Ostrich 84:171–179.

Niwattanakul, S., J. Singthongchai, E. Naenudorn, and S. Wanapu. 2013. Using of Jaccard coefficient for keywords similarity. Proceedings of the International Multiconference of Engineers and Computer Scientists IMECS 2013:380–384.

Norfolk, O., M. Jung, P. J. Platts, P. Malaki, D. Odeny, and R. Marchant. 2017. Birds in the matrix: The role of agriculture in avian conservation in the Taita Hills, Kenya. African Journal of Ecology 55:530–540.

Otieno, N. E., N. Gichuki, N. Farwig, and S. Kiboi. 2011. The role of farm structure on bird assemblages around a Kenyan tropical rainforest: Habitat structure and farm bird assemblage. African Journal of Ecology 49:410–417.

Patterson, M. P., and L. B. Best. 1996. Bird abundance and nesting success in Iowa CRP fields: The importance of vegetation structure and composition. American Midland Naturalist 135:153.

Perfecto, I., R. A. Rice, R. Greenberg, and M. E. van der Voort. 1996. Shade coffee: A disappearing refuge for biodiversity. BioScience 46:598–608.

Philpott, S. M., W. J. Arendt, I. Armbrecht, P. Bichier, T. V. Diestch, C. Gordon, R. Greenberg, I. Perfecto, R. Reynoso-Santos, L. Soto-Pinto, C. Tejeda-Cruz, G. Williams-Linera, J. Valenzuela, and J. M. Zolotoff. 2008. Biodiversity loss in Latin American coffee landscapes: Review of the evidence on ants, birds, and trees. Conservation Biology 22:1093–1105.

Pouliot, M., T. Treue, B. D. Obiri, and B. Ouedraogo. 2012. Deforestation and the limited contribution of forests to rural livelihoods in west Africa: Evidence from Burkina Faso and Ghana. AMBIO 41:738–750.

Powell, L. L., N. J. Cordeiro, and J. A. Stratford. 2015. Ecology and conservation of avian insectivores of the rainforest understory: A pantropical perspective. Biological Conservation 188:1–10.

Preacher, K. J. 2001. Calculation for the chi-square test: An interactive calculation tool for chi-square tests of goodness of fit and independence [Computer software]. <http://quantpsy.org.>.

R Core Team. 2020. R: A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. <http://www.r-project.org/index.html>.

Ralph, C. J., G. R. Geupel, P. Pyle, T. E. Martin, and D. F. DeSante. 1993. Handbook of field methods for monitoring landbirds. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA. <https://www.fs.usda.gov/treesearch/pubs/3639>. Accessed 7 Oct 2021.

Reidy, J. L., F. R. Thompson, and S. W. Kendrick. 2014. Breeding bird response to habitat and landscape factors across a gradient of savanna, woodland, and forest in the Missouri Ozarks. Forest Ecology and Management 313:34–46.

Reitsma, R., J. D. Parrish, and W. McLarney. 2001. The role of cacao plantations in maintaining forest avian diversity in southeastern Costa Rica. Agroforestry Systems 53:185–193.

Rodrigues, P., G. Shumi, I. Dorresteijn, J. Schultner, J. Hanspach, K. Hylander, F. Senbeta, and J. Fischer. 2018. Coffee management and the conservation of forest bird diversity in southwestern Ethiopia. Biological Conservation 217:131–139.

Sekercioglu, C. H. 2002. Effects of forestry practices on vegetation structure and bird community of Kibale National Park, Uganda. Biological Conservation 107: 229–240.

Sekercioglu, C. H. 2012. Bird functional diversity and ecosystem services in tropical forests, agroforests and agricultural areas. Journal of Ornithology 153:153–161.

Sekercioglu, C. H., G. C. Daily, and P. R. Ehrlich. 2004. Ecosystem consequences of bird declines. Proceedings of the National Academy of Sciences 101:18042–18047.

Smith, C., D. Barton, M. D. Johnson, C. Wendt, M. C. Milligan, P. Njoroge, and P. Gichuki. 2015. Bird communities in sun and shade coffee farms in Kenya. Global Ecology and Conservation 4:479–490.

Tejeda-Cruz, C., and W. J. Sutherland. 2004. Bird responses to shade coffee production. Animal Conservation 7:169–179.

Turner, I. M. 1996. Species loss in fragments of tropical rain forest: A review of the evidence. The Journal of Applied Ecology 33:200.

Villard, M.-A., and R. Foppen. 2018. Ecological adaptations of birds to forest environments. Ecology and Conservation of Forest Birds pp. 9 - 134.

Waceke, L. 2014. Impacts of the southern bypass road construction through ngong forest on the african crowned eagle, nairobi county. Kenyatta University.

Waltert, M., K. S. Bobo, N. M. Sainge, H. Fermon, and M. Mühlenberg. 2005. From forest to farmland: Habitat effects on afro tropical forest bird diversity. Ecological Applications 15:1351–1366.

Wenninger, E. J., and R. S. Inouye. 2008. Insect community response to plant diversity and productivity in a sagebrush–steppe ecosystem. Journal of Arid Environments 72:24–33.

Wenny, D. G., T. L. DeVault, M. D. Johnson, D. Kelly, C. H. Sekercioglu, D. F. Tomback, and C. J. Whelan. 2011. The need to quantify ecosystem services provided by birds. The Auk 128:1–14.

Yamaura, Y., M. Kéry, and J. Andrew Royle. 2016. Study of biological communities subject to imperfect detection: Bias and precision of community N-mixture abundance models in small-sample situations. Ecological Research 31:289–305.

Zulu, L. C., and R. B. Richardson. 2013. Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa. Energy for Sustainable Development 17:127–137.

Zurita, G. A., N. Rey, D. M. Varela, M. Villagra, and M. I. Bellocq. 2006. Conversion of the Atlantic Forest into native and exotic tree plantations: Effects on bird communities from the local and regional perspectives. Forest Ecology and Management 235:164–173.

APPENDICES

Appendix A. Raw detection data, modeled habitat effect, and modeled abundance per point count between feeding guild and forest – associated guild for bird species (n=145) detected during point counts on 3 visits to each of 160-point count locations in natural forest (80) and shade coffee sites (80) in Central Kenya, February to April 2020. The highlighted values indicate habitat effects with credible intervals that did not overlap zero. O = omnivore, G = granivore, C = carnivore, I =insectivore, N= nectivore, F = frugivore, FF = forest specialist, FG = forest generalist, f = forest visitor, Non = No forest association

					Raw #	Detecti ons	Modeled Habitat Effect	Modele d Abund ance	per point
Species Code	Common Name	Scientific Name	Feeding guild	Forest-association guild	Forest	Coffee		Forest	Coffee
ABTH	Abyssinian Thrush	*Turdus abyssinicus*	O	FG	11	62	**-1.3469**	0.6248	2.3876
AFBD	African Black Duck	*Anas sparsa*	O	Non	1	0	0.1350	0.1788	0.1613
AFCI	African Citril	*Crithagra citrinelloides*	G	f	0	129	**-3.3338**	0.1290	3.6509
AFDF	African Dusky Flycatcher	*Indicator minor*	I	FG	22	2	**1.8098**	1.7603	0.2882
AFEC	African Emerald Cuckoo	*Passer gongonensis*	G	Non	33	1	**2.3034**	2.4847	0.2413
AFFE	African Fish Eagle	*Prinia subflava*	C	Non	2	0	0.4157	0.2580	0.1735
AFGO	African Goshawk	*Cypsiurus parvus*	C	FG	7	3	0.5896	0.6252	0.3464
AFGP	African Green Pigeon	*Treron calvus*	F	FG	0	60	**-2.9272**	0.2194	4.0807
AFHH	African Harrier Hawk	*Crithagra burtoni*	C	f	0	8	**-1.4569**	0.1270	0.5594
AFHO	African Hobby	*Falco cuvieri*	C	Non	0	4	-1.0574	0.1167	0.3169
AFPF	African Paradise Flycatcher	*Balearica regulorum*	I	f	34	92	**-0.8606**	1.1867	2.8111
AFPS	African Palm Swift	*Motacilla flava*	I	Non	3	13	-0.9487	0.3487	0.8974
AMSU	Amethyst Sunbird	*Chalcomitra amethystina*	N	f	33	20	0.4613	1.2169	0.7597
APWA	African Pied Wagtail	*Lagonosticta senegala*	I	Non	0	3	-0.9192	0.1160	0.2894

Species Code	Common Name	Scientific Name	Feeding guild	Forest-association guild	Raw # Forest	Detections Coffee	Modeled Habitat Effect	Modeled Abundance Forest	per point Coffee
AUBU	Augur Buzzard	*Euplectes albonotatus*	C	Non	0	3	-0.9092	0.1049	0.2589
AYHA	Ayres's Hawk	*Pogoniulus bilineatus*	C	FG	0	4	-1.0688	0.1143	0.3511
BASW	Barn Swallow	*Accipiter tachiro*	I	Non	0	2	-0.7603	0.1008	0.2138
BAWE	Baglafecht Weaver	*Ploceus baglafecht*	O	f	1	121	**-3.0800**	0.1907	4.1025
BAWM	Black-and-white Mannikin	*Caprimulgus poliocephalus*	G	f	5	1	0.6866	0.4524	0.2285
BBPU	Black-backed Puffback	*Dryoscopus cubla*	I	FG	121	7	**2.4961**	5.5951	0.4856
BBWP	Brown-backed Woodpecker	*Picoides obsoletus*	I	Non	0	3	-0.9226	0.0958	0.2475
BCAL	Brown-chested Alethe	*Alethe poliocephala*	I	FF	16	0	**1.9987**	1.4035	0.1888
BCAP	Black-collared Apalis	*Oreolais pulcher*	I	FG	16	0	**1.8815**	1.1844	0.1829
BHHE	Black-headed Heron	*Ardea melanocephala*	C	Non	0	3	-0.8811	0.1160	0.2884
BLCA	Blackcap	*Sylvia atricapilla*	I	FG	2	8	-0.7784	0.3304	0.7019
BLCU	Black Cuckooshrike	*Campephaga flava*	F	f	1	1	-0.1354	0.1845	0.2081
BLKI	Black Kite	*Milvus migrans*	C	Non	17	7	**0.8613**	1.3613	0.5754
BLMO	Blue-naped Mousebird	*Urocolius macrourus*	F	Non	0	3	-0.7396	0.1077	0.2232
BLSA	Black Saw-wing	*Psalidoprocne holomelas*	I	f	6	20	-0.8238	0.5275	1.2011
BLTC	Black-crowned Tchagra	*Tchagra senegalus*	I	Non	0	1	-0.5376	0.0981	0.1719
BOEA	Booted Eagle	*Aquila pennata*	C	Non	0	2	-0.7536	0.1097	0.2287
BRCA	Brimstone Canary	*Crithagra sulphurata*	G	Non	0	4	-1.0597	0.1196	0.3582
BRMA	Bronze Mannikin	*Spermestes cucullatus*	G	Non	1	15	**-1.5243**	0.1903	0.8736
BRPA	Brown Parisoma	*Parisoma lugens*	I	Non	0	2	-0.7889	0.1024	0.2216
BRSU	Bronze Sunbird	*Nectarinia kilimensis*	N	f	2	168	**-2.9601**	0.1329	2.5750
BTWE	Black-throated Wattle-eye	*Platysteira peltata*	I	FG	11	0	**1.7013**	1.1676	0.2021

Species Code	Common Name	Scientific Name	Feeding guild	Forest-association guild	Raw #	Detecti ons	Modeled Habitat Effect	Modele d Abund ance	per point
					Forest	Coffee		Forest	Coffee
CAGR	Cabanis's Greenbul	*Phyllastrephus cabanisi*	O	FF	59	0	**2.8111**	2.6574	0.1546
CARC	Cape Robin Chat	*Cossypha caffra*	C	f	2	183	**-3.1188**	0.1395	3.1489
CAWO	Cardinal Woodpecker	*Dendropicos fuscescens*	I	f	0	1	-0.5438	0.0945	0.1650
CCBE	Cinnamon-chested Bee-eater	*Merops oreobates*	I	FG	4	18	-0.8531	0.3660	0.8542
CHBA	Chin-spot Batis	*Batis molitor*	I	Non	28	80	**-1.0271**	0.7237	2.0094
COBU	Common Bulbul	*Pycnonotus barbatus*	O	f	67	192	**-0.7971**	3.5329	7.8331
COGR	Common Greenshank	*Tringa nebularia*	C	Non	0	1	-0.5762	0.1020	0.1858
COHM	Common House Martin	*Delichon urbicum*	I	Non	0	1	-0.5613	0.1024	0.1799
COMB	Common Buzzard	*Buteo buteo*	C	Non	0	4	-1.0472	0.1204	0.3412
COSU	Collared Sunbird	*Hedydipna collaris*	O	FG	162	17	**2.1199**	5.6412	0.6788
COSW	Common Swift	*Apus apus*	I	Non	0	3	-0.4903	1.2939	2.0890
CREA	Crowned Eagle	*Stephanoaetus coronatus*	C	FF	10	0	**1.4672**	0.7269	0.1749
DUTD	Dusky Turtle Dove	*Streptopelia lugens*	G	f	1	29	**-2.0903**	0.2059	1.6339
EAOW	Eastern Olivaceous Warbler	*Hippolais pallida*	I	Non	0	4	-1.0731	0.1055	0.3029
EGGO	Egyptian Goose	*Alopochen aegyptiaca*	O	Non	1	2	-0.3491	0.1804	0.2506
ESWD	Emerald-spotted Wood Dove	*Turtur chalcospilos*	G	f	7	4	0.2681	0.7761	0.5848
EUBE	Eurasian Bee-eater	*Merops apiaster*	I	Non	14	42	**-1.0094**	0.9686	2.6442
EUHO	Eurasian Hobby	*Falco subbuteo*	C	Non	0	1	-0.5578	0.0987	0.1729
GAWA	Garden Warbler	*Sylvia borin*	I	f	1	11	**-1.3255**	0.2052	0.7694
GBBU	Golden-breasted Bunting	*Emberiza flaviventris*	O	Non	0	16	**-1.8509**	0.1331	0.8496
GBCA	Grey-backed Camaroptera	*Camaroptera brachyura*	I	f	160	1	**3.0126**	1.9436	0.0956

Species Code	Common Name	Scientific Name	Feeding guild	Forest-association guild	Raw #	Detections	Modeled Habitat Effect	Modeled Abundance	per point
					Forest	Coffee		Forest	Coffee
GBHO	Green-backed Honeybird	*Prodotiscus zambesiae*	I	f	3	6	-0.3500	0.2916	0.4149
GBTW	Green-backed Twinspot	*Mandingoa nitidula*	O	FF	3	0	0.6990	0.3782	0.1878
GCCR	Grey Crowned Crane	*Balearica regulorum*	O	Non	0	6	-1.2153	0.1762	0.5787
GCWA	Grey-capped Warbler	*Eminia lepida*	I	f	1	3	-0.4516	0.2046	0.3319
GOGR	Grey-olive Greenbul	*Phyllastrephus cerviniventris*	O	FF	1	0	0.1314	0.1859	0.1602
GRCE	Green-capped Eremomela	*Eremomela scotops*	I	FG	0	3	-0.8993	0.1153	0.2834
GRCO	Great Cormorant	*Phalacrocorax carbo*	C	Non	0	2	-0.7534	0.0801	0.1719
GRHO	Greater Honeyguide	*Indicator indicator*	I	f	2	3	-0.1812	0.2350	0.2858
GRSP	Great Sparrowhawk	*Accipiter melanoleucus*	C	FG	2	7	-0.7269	0.2546	0.5315
GWSU	Golden-winged Sunbird	*Drepanorhynchus reichenowi*	N	f	0	1	-0.5913	0.1019	0.1903
HAIB	Hadada Ibis	*Bostrychia hagedash*	I	Non	10	49	**-1.3069**	0.5973	2.2126
HATU	Hartlaub's Turaco	*Tauraco hartlaubi*	F	FF	41	0	**2.6021**	2.7998	0.2152
HOGW	Holub's Golden Weaver	*Ploceus xanthops*	O	Non	0	16	**-1.9029**	0.1471	0.9667
HOOP	Hoopoe	*Upupa epops*	I	Non	0	4	-1.0342	0.1119	0.3032
JAFR	Jackson's Francolin	*Francolinus jacksoni*	O	FG	0	1	-0.5477	0.1199	0.2018
KIWE	Kikuyu White-eye	*Zosterops kikiyuensis*	O	FG	43	132	**-0.9264**	2.4080	6.1169
KLCU	Klaas's Cuckoo	*Chrysococcyx klaas*	I	f	4	0	0.8576	0.4214	0.1682
KRSP	Kenya Rufous Sparrow	*Passer rufocinctus*	G	Non	0	55	**-2.6518**	0.1661	2.3185
LEDO	Lemon Dove	*Aplopelia larvata*	O	FF	1	0	0.1197	0.1974	0.1673
LEHO	Lesser Honeyguide	*Indicator minor*	O	f	2	1	0.2173	0.2306	0.1871
LESS	Lesser Striped Swallow	*Cecropis abyssinica*	I	Non	1	14	**-1.4856**	0.1833	0.7989
LIGR	Little Grebe	*Tachybaptus ruficollis*	C	Non	0	3	-0.4713	1.3387	2.0092

					Raw #	Detections		Modeled Abundance	per point
Species Code	Common Name	Scientific Name	Feeding guild	Forest-association guild	Forest	Coffee	Modeled Habitat Effect	Forest	Coffee
LISP	Little Sparrowhawk	*Accipiter minullus*	C	f	1	2	-0.3464	0.1691	0.2399
LISW	Little Swift	*Apus affinis*	I	Non	6	5	0.1673	0.5023	0.4220
LTCO	Long-crested Eagle	*Lophaetus occipitalis*	C	f	0	1	-0.5783	0.1019	0.1816
MASU	Marico Sunbird	*Cinnyris mariquensis*	N	Non	0	1	-0.5498	0.0958	0.1661
MONG	Montane Nightjar	*Caprimulgus poliocephalus*	I	FG	1	5	-0.9074	0.1510	0.3634
MOWA	Mountain Wagtail	*Motacilla clara*	I	FG	2	0	0.4415	0.2601	0.1699
NATR	Narina Trogon	*Apaloderma narina*	I	f	29	0	**2.3383**	1.9789	0.1836
NDCS	Northern Double-collared Sunbird	*Cinnyris reichenowi*	I	FG	3	3	-0.0918	0.5183	0.5676
NOFI	Northern Fiscal	*Lanius humeralis*	I	Non	0	18	**-1.9198**	0.1133	0.7799
NUWO	Nubian Woodpecker	*Campethera nubica*	I	Non	0	2	-0.7352	0.0897	0.1913
PAFL	Pale Flycatcher	*Bradornis pallidus*	I	Non	0	22	**-2.0930**	0.1193	0.9730
PBSP	Parrot-billed Sparrow	*Passer gongonensis*	G	Non	0	3	-0.4537	1.1910	1.8325
PICR	Pied Crow	*Corvus albus*	O	Non	12	25	-0.5269	1.0366	1.7215
PIKI	Pied Kingfisher	*Ceryle rudis*	C	Non	0	1	-0.5714	0.0962	0.1736
PLMA	Plain Martin	*Riparia paludicola*	I	Non	0	2	-0.7488	0.1071	0.2296
PTWH	Pin-tailed Whydah	*Vidua macroura*	G	Non	0	2	-0.7421	0.1030	0.2132
PUGR	Purple Grenadier	*Granatina ianthinogaster*	G	Non	1	10	-1.1851	0.3078	1.0134
RBFI	Red-billed Firefinch	*Lagonosticta senegala*	G	Non	1	4	-0.6335	0.1836	0.3316
RCCB	Red-cheeked Cordon-bleu	*Uraeginthus bengalus*	G	Non	0	8	-1.2894	0.1047	0.3785
RCCU	Red-chested Cuckoo	*Cuculus solitarius*	I	FG	5	12	-0.6747	0.4219	0.8373

Species Code	Common Name	Scientific Name	Feeding guild	Forest-association guild	Raw # Detections Forest	Raw # Detections Coffee	Modeled Habitat Effect	Modeled Abundance per point Forest	Modeled Abundance per point Coffee
RECO	Reed Cormorant	*Phalacrocorax africanus*	C	Non	0	8	**-1.3723**	0.1230	0.4833
REDO	Red-eyed Dove	*Streptopelia semitorquata*	G	f	5	113	**-2.4888**	0.3722	4.4685
RESE	Reichenow's Seedeater	*Crithagra reichenowi*	G	Non	0	17	**-1.8869**	0.1457	0.9637
RFCR	Red-faced Crombec	*Sylvietta whytii*	I	Non	1	10	**-1.2251**	0.2232	0.7666
RNDO	Ring-necked Dove	*Streptopelia capicola*	O	Non	0	6	-1.2836	0.1186	0.4326
ROMA	Rock Martin	*Ptyonoprogne fuligula*	I	Non	0	8	**-1.4055**	0.1344	0.5556
RRSW	Red-rumped Swallow	*Cecropis daurica*	I	Non	0	24	**-2.1488**	0.1275	1.0767
RTWR	Red-throated Wryneck	*Jynx ruficollis*	I	f	1	16	**-1.5472**	0.2555	1.2220
RURC	Rüppell's Robin Chat	*Cossypha semirufa*	I	FG	62	27	**0.8017**	2.1482	0.9574
SAIB	Sacred Ibis	*Threskiornis aethiopicus*	O	Non	2	0	0.4301	0.2769	0.1762
SBFL	Southern Black Flycatcher	*Melaenornis pammelaina*	I	Non	0	9	**-1.5251**	0.1227	0.5631
SBGR	Slender-billed Greenbul	*Andropadus gracilirostris*	O	FF	3	0	0.6559	0.3639	0.1939
SCSU	Scarlet-chested Sunbird	*Chalcomitra senegalensis*	N	Non	8	72	-1.6698	0.6439	3.4309
SCWE	Spectacled Weaver	*Ploceus ocularis*	I	f	0	1	-0.5537	0.1035	0.1750
SFBA	Spot-flanked Barbet	*Tricholaema lacrymosa*	O	Non	14	1	**1.4782**	1.2837	0.3070
SICI	Singing Cisticola	*Cisticola cantans*	I	Non	0	12	**-1.6732**	0.1147	0.6013
SKWE	Speke's Weaver	*Ploceus spekei*	O	Non	1	10	**-1.2637**	0.1566	0.5439
SPFL	Spotted Flycatcher	*Muscicapa striata*	I	Non	1	3	-0.5406	0.1672	0.2986
SPWG	Spur-winged Goose	*Plectopterus gambensis*	O	Non	0	1	-0.5182	0.1171	0.1864
STSE	Streaky Seedeater	*Crithagra striolata*	G	f	0	31	**-2.2342**	0.1027	0.9463

Species Code	Common Name	Scientific Name	Feeding guild	Forest-association guild	Raw # Forest	Detections Coffee	Modeled Habitat Effect	Modeled Abundance Forest	per point Coffee
TADO	Tambourine Dove	*Turtur tympanistria*	G	FG	5	3	0.3867	0.6935	0.4658
TAEA	Tawny Eagle	*Aquila rapax*	C	Non	2	1	0.3617	0.8227	0.5806
TFPR	Tawny-flanked Prinia	*Prinia subflava*	I	f	1	2	-0.3411	0.1809	0.2623
THSE	Thick-billed Seedeater	*Crithagra burtoni*	G	FF	0	1	-0.5532	0.1183	0.1991
TRBO	Tropical Boubou	*Laniarius aethiopicus*	O	f	36	34	0.1849	2.3279	1.9234
TRPI	Tree Pipit	*Anthus trivialis*	I	f	0	6	-1.2712	0.1169	0.4226
VASU	Variable Sunbird	*Cinnyris venustus*	O	f	23	149	**-1.7646**	0.4744	2.7687
VBST	Violet-backed Starling	*Cinnyricinclus leucogaster*	F	f	0	27	**-2.2508**	0.1541	1.4890
VIIN	Village Indigobird	*Vidua chalybeata*	G	Non	0	1	-0.5583	0.0999	0.1720
VIWE	Village Weaver	*Ploceus cucullatus*	G	Non	0	1	-0.5394	0.1013	0.1626
WAEA	Wahlberg's Eagle	*Aquila wahlbergi*	C	Non	0	3	-0.9097	0.1123	0.2801
WBCO	White-browed Coucal	*Centropus superciliosus*	I	Non	0	1	-0.5695	0.1007	0.1940
WBSW	White-browed Sparrow Weaver	*Plocepasser mahali*	O	Non	0	3	-0.7785	0.1001	0.2188
WBTI	White-bellied Tit	*Parus albiventris*	I	f	23	54	**-0.7622**	1.3936	2.9620
WESF	White-eyed Slaty Flycatcher	*Melaenornis fischeri*	I	FG	3	47	**-2.0873**	0.2529	2.0267
WHRS	White-rumped Swift	*Apus caffer*	I	Non	0	1	-0.5610	0.1111	0.1901
WIWA	Willow Warbler	*Phylloscopus trochilus*	I	f	9	125	**-2.1829**	0.4097	3.6482
WSRO	White-starred Robin	*Pogonocichla stellata*	O	FG	24	0	**1.7262**	0.7973	0.1431
WTSA	Wire-tailed Swallow	*Hirundo smithii*	I	Non	0	1	-0.5476	0.0935	0.1620
WWWI	White-winged Widowbird	*Euplectes albonotatus*	G	Non	0	8	-0.4781	4.3306	7.6987
YBAP	Yellow-breasted Apalis	*Apalis flavida*	I	f	74	97	-0.3024	2.3653	3.2005
YBDU	Yellow-billed Duck	*Anas undulata*	G	Non	0	1	-0.5753	0.0845	0.1561

					Raw #	Detections	Modeled Habitat Effect	Modeled Abundance	per point
Species Code	Common Name	Scientific Name	Feeding guild	Forest-association guild	Forest	Coffee		Forest	Coffee
YEWA	Yellow Wagtail	*Motacilla flava*	I	Non	0	10	**-1.5356**	0.2039	0.9777
YNSP	Yellow-necked Spurfowl	*Francolinus leucoscepus*	O	Non	0	1	-0.5448	0.1060	0.1757
YRTI	Yellow-rumped Tinkerbird	*Pogoniulus bilineatus*	O	FG	67	21	**1.1538**	2.6959	0.8577
YWGR	Yellow-whiskered Greenbul	*Andropadus latirostris*	O	FG	136	0	**3.4647**	5.7621	0.1713

Appendix B. Modeled effects of vegetation variables on bird abundance bird species detected in natural forest and shade coffee on 3 visits to each of 160-point count locations in natural forest (80) and shade coffee sites (80) in Central Kenya, February to April 2020. The bold numbers indicate which vegetation covariates with credible intervals that did not overlap zero.

Common Name	**Shrub Stem**	**Shrub Stem Square**	**Canopy Depth**	**Shrub Cover**	**Habitat Layer Height**	**Densiometer**
Abyssinian Thrush	-0.0006	**-0.0651**	0.0070	0.0009	0.0000	0.0230
African Black Duck	-0.0004	-0.0460	-0.0011	0.0003	0.0002	0.0343
African Citril	-0.0006	-0.0521	0.0278	0.0017	-0.0002	0.0235
African Dusky Flycatcher	-0.0006	-0.0638	0.0097	0.0017	0.0008	0.0377
African Emerald Cuckoo	-0.0007	**-0.0754**	-0.0199	0.0012	0.0009	0.0374
African Fish Eagle	-0.0004	-0.0478	-0.0089	0.0004	0.0004	0.0330
African Goshawk	0.0000	-0.0216	-0.0189	-0.0001	0.0008	0.0331
African Green Pigeon	-0.0004	-0.0076	-0.0893	0.0012	0.0009	0.0247
African Harrier Hawk	-0.0004	-0.0475	0.0048	0.0001	0.0002	0.0398
African Hobby	-0.0004	-0.0419	0.0060	0.0011	0.0000	0.0336
African Paradise Flycatcher	-0.0003	-0.0149	0.0200	0.0013	0.0006	0.0409
African Palm Swift	-0.0005	-0.0472	0.0011	0.0009	0.0006	0.0333
Amethyst Sunbird	-0.0002	0.0040	-0.0145	-0.0003	0.0008	0.0533
African Pied Wagtail	-0.0004	-0.0444	0.0100	0.0006	0.0005	0.0309
Augur Buzzard	-0.0004	-0.0413	0.0015	0.0008	0.0006	0.0347
Ayres's Hawk	-0.0004	-0.0491	-0.0023	0.0003	0.0006	0.0357
Barn Swallow	-0.0004	-0.0438	-0.0058	0.0000	0.0006	0.0375
Baglafecht Weaver	-0.0005	-0.0469	-0.0139	0.0007	0.0008	0.0203
Black-and-white Mannikin	-0.0005	-0.0510	-0.0250	0.0006	0.0006	0.0358
Black-backed Puffback	0.0002	-0.0182	-0.0122	0.0000	0.0012	0.0445
Brown-backed Woodpecker	-0.0004	-0.0410	-0.0093	0.0007	0.0002	0.0355

Common Name	Shrub Stem	Shrub Stem Square	Canopy Depth	Shrub Cover	Habitat Layer Height	Densiometer
Brown-chested Alethe	-0.0007	**-0.0752**	0.0139	0.0010	0.0008	0.0220
Black-collared Apalis	-0.0003	-0.0135	-0.0409	0.0005	0.0007	0.0385
Black-headed Heron	-0.0004	-0.0450	0.0071	0.0003	0.0003	0.0338
Blackcap	-0.0005	-0.0510	-0.0028	0.0005	0.0006	0.0377
Black Cuckooshrike	-0.0004	-0.0452	-0.0085	0.0004	0.0007	0.0352
Black Kite	-0.0004	-0.0410	-0.0061	0.0005	0.0007	0.0364
Blue-naped Mousebird	-0.0004	-0.0466	-0.0098	0.0004	0.0006	0.0362
Black Saw-wing	-0.0005	-0.0370	-0.0563	-0.0006	0.0021	0.0457
Black-crowned Tchagra	-0.0004	-0.0424	-0.0060	0.0003	0.0006	0.0362
Booted Eagle	-0.0004	-0.0416	-0.0026	0.0005	0.0005	0.0365
Brimstone Canary	-0.0004	-0.0440	0.0083	0.0008	0.0002	0.0346
Bronze Mannikin	-0.0004	-0.0442	-0.0159	0.0000	0.0016	0.0400
Brown Parisoma	-0.0004	-0.0447	-0.0088	0.0001	0.0004	0.0363
Bronze Sunbird	-0.0005	-0.0556	-0.0358	0.0000	0.0024	0.0244
Black-throated Wattle-eye	-0.0005	-0.0574	0.0039	0.0002	0.0011	0.0373
Cabanis's Greenbul	0.0001	-0.0102	0.0226	-0.0001	-0.0002	0.0327
Cape Robin Chat	-0.0006	-0.0498	0.0164	0.0019	0.0008	0.0281
Cardinal Woodpecker	-0.0004	-0.0410	-0.0079	0.0005	0.0003	0.0367
Cinnamon-chested Bee-eater	-0.0004	-0.0451	-0.0461	-0.0004	0.0016	0.0481
Chin-spot Batis	-0.0001	0.0174	-0.0005	0.0020	0.0006	0.0340
Common Bulbul	-0.0004	-0.0468	-0.0301	-0.0002	0.0002	0.0243
Common Greenshank	-0.0004	-0.0436	-0.0039	0.0003	0.0003	0.0365
Common House Martin	-0.0004	-0.0442	-0.0058	0.0002	0.0005	0.0373
Common Buzzard	-0.0004	-0.0437	0.0231	0.0007	0.0003	0.0274

Common Name	Shrub Stem	Shrub Stem Square	Canopy Depth	Shrub Cover	Habitat Layer Height	Densiometer
Collared Sunbird	0.0000	0.0004	-0.0268	0.0005	0.0005	0.0420
Common Swift	-0.0004	-0.0342	-0.0028	0.0006	0.0009	0.0358
Crowned Eagle	0.0000	-0.0132	0.0179	0.0007	0.0007	0.0339
Dusky Turtle Dove	-0.0004	-0.0193	0.0150	0.0016	0.0001	0.0239
Eastern Olivaceous Warbler	-0.0004	-0.0422	-0.0164	0.0003	0.0010	0.0384
Egyptian Goose	-0.0003	-0.0313	-0.0167	0.0007	0.0004	0.0377
Emerald-spotted Wood Dove	-0.0002	-0.0157	-0.0028	0.0003	0.0008	0.0392
Eurasian Bee-eater	-0.0003	-0.0010	0.0106	0.0006	0.0012	0.0435
Eurasian Hobby	-0.0004	-0.0418	0.0120	0.0006	0.0002	0.0321
Garden Warbler	-0.0004	-0.0460	0.0119	0.0006	0.0009	0.0356
Golden-breasted Bunting	-0.0004	-0.0431	-0.0201	0.0001	0.0002	0.0305
Grey-backed Camaroptera	0.0001	0.0037	0.0111	-0.0007	-0.0014	0.0575
Green-backed Honeybird	-0.0002	-0.0253	-0.0100	0.0004	0.0002	0.0402
Green-backed Twinspot	-0.0004	-0.0511	-0.0139	0.0005	0.0004	0.0367
Grey Crowned Crane	-0.0004	-0.0529	-0.0127	0.0003	0.0012	0.0330
Grey-capped Warbler	-0.0003	-0.0410	-0.0254	-0.0002	0.0003	0.0339
Grey-olive Greenbul	-0.0003	-0.0362	0.0010	0.0002	0.0004	0.0373
Green-capped Eremomela	-0.0004	-0.0485	-0.0174	0.0000	0.0010	0.0355
Great Cormorant	-0.0004	-0.0440	-0.0093	0.0004	0.0005	0.0359
Greater Honeyguide	-0.0004	-0.0502	-0.0090	0.0007	0.0002	0.0314
Great Sparrowhawk	-0.0004	-0.0447	-0.0011	0.0008	0.0011	0.0245
Golden-winged Sunbird	-0.0004	-0.0436	-0.0037	0.0004	0.0002	0.0349
Hadada Ibis	-0.0001	-0.0235	-0.0188	0.0000	0.0012	0.0387
Hartlaub’s Turaco	0.0000	-0.0195	0.0427	0.0010	-0.0006	0.0357

Common Name	Shrub Stem	Shrub Stem Square	Canopy Depth	Shrub Cover	Habitat Layer Height	Densiometer
Holub's Golden Weaver	-0.0004	-0.0410	-0.0131	0.0009	-0.0001	0.0224
Hoopoe	-0.0004	-0.0450	-0.0078	0.0001	0.0011	0.0331
Jackson's Francolin	-0.0004	-0.0412	-0.0035	0.0004	0.0006	0.0370
Kikuyu White-eye	-0.0003	-0.0290	0.0435	0.0025	-0.0001	0.0261
Klaas's Cuckoo	-0.0003	-0.0196	0.0233	0.0002	0.0003	0.0403
Kenya Rufous Sparrow	-0.0006	**-0.0740**	-0.0236	-0.0006	0.0012	0.0420
Lemon Dove	-0.0004	-0.0443	-0.0065	0.0003	0.0006	0.0344
Lesser Honeyguide	-0.0004	-0.0517	-0.0046	0.0003	0.0008	0.0384
Lesser Striped Swallow	-0.0004	-0.0425	-0.0285	0.0004	0.0010	0.0395
Little Grebe	-0.0004	-0.0327	-0.0055	0.0006	0.0010	0.0372
Little Sparrowhawk	-0.0004	-0.0436	-0.0091	0.0004	0.0002	0.0358
Little Swift	0.0000	-0.0212	-0.0151	0.0008	0.0007	0.0380
Long-crested Eagle	-0.0004	-0.0424	-0.0058	0.0004	0.0005	0.0345
Marico Sunbird	-0.0004	-0.0462	-0.0093	0.0002	0.0006	0.0363
Montane Nightjar	0.0001	-0.0102	0.0167	0.0009	0.0004	0.0331
Mountain Wagtail	-0.0004	-0.0476	0.0012	0.0004	0.0004	0.0340
Narina Trogon	-0.0002	-0.0135	-0.0105	0.0008	0.0002	0.0389
Northern Double-collared Sunbird	-0.0004	-0.0484	-0.0150	0.0004	0.0009	0.0427
Northern Fiscal	-0.0005	-0.0413	-0.0108	0.0006	0.0009	0.0288
Nubian Woodpecker	-0.0004	-0.0430	-0.0012	0.0002	0.0009	0.0366
Pale Flycatcher	-0.0003	-0.0239	0.0056	0.0008	0.0005	0.0304
Parrot-billed Sparrow	-0.0003	-0.0245	-0.0181	0.0010	0.0007	0.0338
Pied Crow	-0.0001	-0.0185	0.0138	0.0008	0.0017	0.0360
Pied Kingfisher	-0.0004	-0.0448	0.0042	0.0005	0.0003	0.0345

Common Name	Shrub Stem	Shrub Stem Square	Canopy Depth	Shrub Cover	Habitat Layer Height	Densiometer
Plain Martin	-0.0004	-0.0433	-0.0036	0.0005	0.0005	0.0383
Pin-tailed Whydah	-0.0004	-0.0457	-0.0129	0.0001	0.0009	0.0349
Purple Grenadier	-0.0005	-0.0542	-0.0127	0.0001	0.0010	0.0345
Red-billed Firefinch	-0.0004	-0.0485	0.0020	0.0008	0.0007	0.0350
Red-cheeked Cordon-bleu	-0.0004	-0.0524	-0.0035	0.0001	0.0007	0.0347
Red-chested Cuckoo	0.0000	-0.0089	-0.0301	0.0002	0.0005	0.0383
Reed Cormorant	-0.0004	-0.0494	-0.0028	0.0005	0.0003	0.0289
Red-eyed Dove	-0.0003	-0.0259	-0.0250	-0.0011	0.0011	0.0247
Reichenow’s Seedeater	-0.0004	-0.0435	0.0168	0.0010	0.0002	0.0343
Red-faced Crombec	-0.0004	-0.0466	0.0097	0.0003	0.0011	0.0301
Ring-necked Dove	-0.0004	-0.0492	-0.0248	-0.0001	0.0015	0.0362
Rock Martin	-0.0004	-0.0606	-0.0236	-0.0002	0.0008	0.0330
Red-rumped Swallow	-0.0004	-0.0414	0.0132	0.0006	0.0004	0.0218
Red-throated Wryneck	-0.0005	-0.0490	0.0159	0.0010	0.0008	0.0282
Rüppell’s Robin Chat	0.0003	-0.0269	-0.0032	0.0005	0.0001	0.0377
Sacred Ibis	-0.0003	-0.0329	-0.0098	0.0004	0.0005	0.0375
Southern Black Flycatcher	-0.0004	-0.0395	-0.0174	-0.0001	0.0011	0.0409
Slender-billed Greenbul	-0.0004	-0.0502	-0.0056	0.0004	0.0004	0.0349
Scarlet-chested Sunbird	-0.0005	-0.0511	-0.0225	-0.0002	0.0022	0.0499
Spectacled Weaver	-0.0004	-0.0454	-0.0010	0.0002	0.0007	0.0343
Spot-flanked Barbet	-0.0001	0.0061	-0.0138	-0.0002	-0.0001	0.0389
Singing Cisticola	-0.0004	-0.0455	-0.0152	0.0004	0.0006	0.0324
Speke’s Weaver	-0.0003	-0.0205	-0.0264	0.0007	0.0007	0.0336
Spotted Flycatcher	-0.0004	-0.0362	-0.0009	0.0000	0.0009	0.0355

Common Name	Shrub Stem	Shrub Stem Square	Canopy Depth	Shrub Cover	Habitat Layer Height	Densiometer
Spur-winged Goose	-0.0004	-0.0449	0.0068	0.0005	0.0003	0.0365
Streaky Seedeater	-0.0005	-0.0396	0.0093	0.0011	0.0000	0.0378
Tambourine Dove	-0.0004	-0.0404	0.0167	0.0010	0.0007	0.0381
Tawny Eagle	-0.0004	-0.0455	-0.0095	0.0000	0.0010	0.0401
Tawny-flanked Prinia	-0.0004	-0.0452	-0.0062	0.0008	0.0006	0.0308
Thick-billed Seedeater	-0.0004	-0.0463	-0.0059	0.0001	0.0003	0.0361
Tropical Boubou	-0.0002	-0.0290	0.0258	0.0001	0.0019	0.0487
Tree Pipit	-0.0004	-0.0396	-0.0056	0.0009	0.0004	0.0342
Variable Sunbird	-0.0001	-0.0050	0.0190	0.0010	0.0004	0.0400
Violet-backed Starling	-0.0004	-0.0393	-0.0516	0.0006	0.0006	0.0267
Village Indigobird	-0.0004	-0.0392	-0.0103	0.0005	0.0005	0.0349
Village Weaver	-0.0004	-0.0419	-0.0024	0.0006	0.0003	0.0335
Wahlberg's Eagle	-0.0004	-0.0424	0.0036	0.0005	0.0007	0.0357
White-browed Coucal	-0.0004	-0.0463	-0.0061	0.0004	0.0005	0.0343
White-browed Sparrow Weaver	-0.0004	-0.0447	-0.0127	0.0002	0.0008	0.0375
White-bellied Tit	-0.0002	-0.0116	-0.0409	0.0018	0.0008	0.0413
White-eyed Slaty Flycatcher	-0.0004	-0.0147	0.0159	0.0008	0.0009	0.0321
White-rumped Swift	-0.0004	-0.0406	-0.0100	0.0005	0.0004	0.0333
Willow Warbler	-0.0005	-0.0156	0.0712	0.0021	0.0000	0.0266
White-starred Robin	0.0002	0.0376	-0.0026	0.0001	0.0000	0.0470
Wire-tailed Swallow	-0.0004	-0.0441	-0.0074	0.0002	0.0008	0.0363
White-winged Widowbird	-0.0004	-0.0341	-0.0072	0.0007	0.0012	0.0394
Yellow-breasted Apalis	-0.0002	0.0103	0.0553	0.0001	0.0002	0.0487
Yellow-billed Duck	-0.0004	-0.0408	-0.0110	0.0004	0.0003	0.0338

Common Name	Shrub Stem	Shrub Stem Square	Canopy Depth	Shrub Cover	Habitat Layer Height	Densiometer
Yellow Wagtail	-0.0004	-0.0442	0.0369	0.0009	0.0003	0.0301
Yellow-necked Spurfowl	-0.0004	-0.0457	-0.0046	0.0003	0.0003	0.0353
Yellow-rumped Tinkerbird	-0.0001	-0.0131	-0.0280	0.0005	-0.0010	0.0522
Yellow-whiskered Greenbul	0.0000	-0.0060	-0.0104	0.0004	-0.0002	0.0350

Appendix C. Vegetation variables recorded at each of 160-point count locations in natural forest (80) and shade coffee sites (80) in Central Kenya, February to April 2020. AVCD = average canopy depth (m), AVDEN = average densiometer (0-96 “closed” points), AVHH = average herbaceous layer height (cm), AVSC =average shrub cover (%), AVST= average shrub stem (#).

	AVCD		AVDEN		AVHH		AVSC		AVST	
Sampling point	coffee	forest	coffee	forest	coffee	forest	coffee	forest	coffee	forest
1	3.8	2.2	70.3	93.8	35.5	27.5	35.8	47.5	3.8	19.3
2	4.7	3.2	78.0	92.3	31.0	13.5	29.5	18.8	4.0	6.5
3	9.4	4.3	48.0	89.3	11.0	36.0	36.8	8.8	4.0	4.0
4	6.9	3.8	73.0	93.3	25.8	14.3	31.3	15.0	4.0	8.8
5	5.9	4.9	75.8	92.8	20.0	23.0	29.5	16.3	3.8	12.5
6	4.6	3.7	77.5	93.0	16.8	20.0	31.3	37.5	4.0	21.0
7	7.9	5.0	66.8	92.5	11.3	20.8	57.5	21.3	3.3	7.5
8	6.5	2.8	66.0	71.5	13.0	17.3	35.0	37.5	4.0	16.5
9	7.7	3.3	68.0	92.8	13.0	18.3	25.0	31.3	3.3	16.3
10	5.7	3.6	63.3	90.5	49.0	8.0	23.8	20.0	3.3	9.5
11	5.2	5.5	78.8	74.5	17.8	15.0	47.5	67.0	4.5	31.5
12	4.4	2.9	60.0	88.8	21.0	38.8	48.8	28.0	4.0	16.0
13	5.2	5.8	76.0	91.8	18.3	21.5	31.3	27.5	3.3	9.3
14	4.6	5.4	64.5	92.0	25.0	19.0	38.8	26.8	5.0	12.5
15	2.1	6.5	47.8	90.8	21.3	25.3	58.8	10.5	6.0	9.5
16	4.2	6.8	74.3	88.3	19.8	0.0	50.0	4.0	6.0	2.3
17	4.5	5.6	93.0	90.5	17.5	16.5	51.3	13.8	4.0	9.0
18	4.8	9.0	83.5	90.3	32.0	18.3	42.5	24.5	3.5	13.5
19	4.2	7.6	55.5	90.3	22.5	30.8	50.0	22.5	4.0	13.0
20	3.1	4.2	66.5	74.0	21.0	35.3	35.0	5.5	3.5	3.3
21	5.2	4.2	78.5	92.8	6.0	33.5	47.5	32.5	3.8	10.5
22	7.1	5.0	69.3	93.0	21.3	16.8	55.0	31.5	3.5	15.3
23	6.2	3.3	54.3	93.3	9.8	17.5	70.0	26.3	4.0	14.0
24	6.5	2.8	75.8	91.3	10.0	6.8	72.5	59.0	4.0	30.5
25	5.2	6.1	36.8	89.5	16.3	22.8	70.0	8.0	4.0	9.3
26	5.5	4.6	50.0	79.3	16.5	17.3	45.0	20.0	4.0	10.8
27	4.0	4.2	66.3	83.0	24.5	13.5	45.0	46.8	4.0	29.5
28	4.8	3.7	64.8	90.5	12.3	13.8	47.5	31.3	4.0	17.3
29	8.2	5.1	69.0	89.3	23.3	10.5	52.5	33.8	4.0	21.5
30	7.1	6.4	60.8	89.0	20.0	12.0	45.0	22.5	4.3	11.8
31	11.0	3.4	39.0	93.5	7.5	15.5	73.8	78.8	4.8	14.8
32	9.2	4.0	78.5	92.0	13.8	24.3	58.8	58.8	3.3	19.8
33	4.9	3.6	66.3	92.8	18.8	23.8	53.8	21.3	3.3	18.3
34	4.0	4.0	68.0	92.5	18.5	20.3	46.3	18.8	4.0	10.3

Sampling point	AVCD coffee	AVCD forest	AVDEN coffee	AVDEN forest	AVHH coffee	AVHH forest	AVSC coffee	AVSC forest	AVST coffee	AVST forest
35	2.8	4.4	73.8	92.0	35.8	17.8	56.3	17.5	3.5	8.8
36	3.0	2.9	22.8	93.5	36.5	19.3	60.0	40.0	3.8	22.3
37	3.0	3.1	86.5	94.3	12.5	19.0	61.3	23.3	5.0	9.0
38	5.4	3.3	73.0	85.7	12.8	23.0	52.5	0.0	4.5	0.0
39	3.9	6.5	78.7	72.0	15.5	13.8	72.5	7.5	4.0	3.5
40	6.8	6.0	37.0	89.8	14.3	14.8	52.5	22.5	4.0	11.0
41	3.6	2.4	66.0	90.3	19.0	42.5	55.0	13.8	3.8	1.8
42	2.5	2.7	66.0	91.0	15.3	23.8	77.5	17.5	4.0	2.8
43	3.0	0.0	86.0	0.0	17.0	0.0	57.5	0.0	3.3	0.0
44	1.8	2.9	76.5	79.0	23.0	47.8	45.0	6.8	3.3	1.8
45	5.4	3.5	82.5	40.5	23.5	29.8	75.0	27.5	6.0	4.3
46	6.3	4.1	69.8	71.5	57.5	31.8	32.5	18.8	3.8	2.8
47	6.9	2.3	73.8	80.8	60.8	27.5	32.5	1.5	3.3	0.8
48	5.1	5.9	79.3	89.5	43.3	39.0	32.5	5.0	3.8	1.8
49	4.6	4.9	54.3	89.5	30.8	42.0	27.5	3.8	3.3	1.0
50	3.5	3.5	83.8	49.8	36.0	40.0	40.0	20.0	3.8	4.0
51	3.4	5.2	76.0	0.0	18.3	19.8	55.3	13.8	4.0	3.5
52	5.3	4.2	76.8	74.0	13.3	14.8	42.5	10.0	3.8	1.8
53	5.1	3.6	90.3	87.0	16.5	53.5	37.5	20.0	4.0	3.3
54	1.0	2.2	91.0	88.8	24.0	23.0	43.8	22.5	3.8	2.8
55	2.8	2.6	57.5	68.0	18.3	22.5	54.0	53.8	6.0	6.8
56	2.9	3.8	50.3	91.8	28.5	31.0	65.0	28.8	6.3	3.0
57	4.7	2.6	81.5	82.0	39.3	28.8	41.3	21.3	4.0	2.0
58	7.2	4.0	82.3	57.5	33.3	29.8	41.3	40.5	4.0	2.3
59	7.9	4.2	69.0	80.5	38.5	41.3	65.0	50.0	7.3	6.0
60	6.2	3.6	28.8	92.5	42.5	38.5	47.5	17.5	4.5	2.0
61	8.9	1.3	87.8	44.0	8.3	13.0	45.0	5.0	4.0	0.8
62	8.0	4.4	91.0	80.8	19.0	40.8	68.8	16.3	8.0	3.0
63	7.3	5.3	69.5	84.3	17.8	35.8	40.0	6.5	4.5	1.5
64	9.5	4.4	82.8	89.0	6.5	30.8	57.5	13.8	4.0	2.3
65	5.4	3.7	66.3	76.5	15.8	28.8	35.0	5.0	2.3	0.8
66	5.1	3.2	71.3	82.8	10.0	33.0	70.0	0.3	3.5	0.3
67	6.7	2.7	72.5	75.5	19.5	23.5	37.5	35.0	4.0	5.0
68	7.0	3.7	71.5	81.8	22.5	21.3	36.3	27.5	3.8	4.5
69	4.7	2.5	56.8	67.8	44.5	38.3	37.5	25.0	4.0	3.0
70	3.2	3.5	45.5	88.5	26.3	38.3	40.0	22.5	4.0	3.5
71	6.2	5.2	81.8	80.8	30.5	34.8	35.3	42.5	3.8	5.5
72	4.8	5.1	58.3	90.5	8.5	26.0	46.3	4.5	4.0	2.3
73	4.2	4.5	66.0	84.5	22.0	13.0	33.8	12.5	3.3	4.3

Sampling point	AVCD		AVDEN		AVHH		AVSC		AVST	
	coffee	forest	coffee	forest	coffee	forest	coffee	forest	coffee	forest
74	4.5	6.0	64.8	88.0	9.3	16.3	53.8	43.8	5.0	8.8
75	5.4	2.7	75.0	91.3	14.0	17.3	40.0	26.3	3.8	5.5
76	5.7	4.5	90.0	85.5	17.8	14.8	41.3	58.8	3.3	16.3
77	6.1	4.6	60.3	92.8	5.5	25.5	41.3	43.8	3.8	5.5
78	3.3	3.6	66.8	80.0	33.5	16.5	46.3	37.5	4.0	9.0
79	3.0	6.4	85.0	87.8	13.3	17.5	47.5	76.3	4.8	5.5
80	5.5	0.0	64.5	0.0	8.0	31.5	42.5	36.3	4.0	14.3