THE EFFECT OF SHADE TREE SPECIES ON BIRD COMMUNITIES IN CENTRAL KENYAN COFFEE FARMS

By

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ABSTRACT

THE EFFECT OF SHADE TREE SPECIES ON BIRD COMMUNITIES IN CENTRAL KENYAN COFFEE FARMS

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Shade coffee has been recognized as a well-studied example of a land-sharing management strategy that both creates habitat for tropical birds while also maintaining agricultural yield. Despite the general consensus that shade coffee is more "bird-friendly" than a sun coffee monoculture, little work has been done to investigate the effects of specific shade tree species on bird diversity and their capacity to help deliver ecosystem services. Previous studies in temperate regions have demonstrated that due to shared evolutionary histories, native plant species are better at promoting native arthropod numbers, which in turn support a greater number of birds. This study investigated bottom-up effects of two shade tree taxa - native *Cordia* sp. and introduced *Grevillea robusta* - on insectivorous bird communities in central Kenya. Results indicate that foliage-dwelling arthropod abundance and the richness, and overall abundance of foraging birds were all higher on *Cordia* than on *Grevillea*. Furthermore, multivariate analyses of bird community data indicate a significant difference in community composition between the canopies of the two tree species, though the communities of birds using the coffee understory under these shade trees were similar. In addition, both shade trees buffered temperatures in coffee, which could help slow the growth of insect pests, and this was more pronounced under *Cordia*. These results suggest that native *Cordia* trees may be better at mitigating habitat loss and promoting ecosystem services in

Kenyan coffee systems. Identifying differences in prey abundance and preferences in bird foraging behavior aids in developing region-specific information to optimize functional diversity, ecosystem services, and the conservation of birds in agricultural landscapes.

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This manuscript is dedicated in loving memory to Marc David Berke (1941-2008).

There are three kinds of lies: lies, damned lies, and statistics.

– Mark Twain, *Chapters from My Autobiography* (1907)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

Agricultural intensification is one of the greatest threats to biodiversity (Foley et al. 2005), particularly because of its association with deforestation, which has a disproportionately negative effect on biological communities (Donald 2004, Betts et al. 2017). In the tropics, where most of the world's biodiversity is concentrated (Brown 2014), the agricultural landscape is commonly a matrix of intact forest fragments surrounded by agriculture. Traditional conservation has focused on minimizing the amount of area used by agriculture in order to preserve areas of natural vegetation, generally ignoring agricultural areas within the matrix (Perfecto et al. 2009). However, evidence shows that an emphasis on agricultural habitats is vital for successful conservation for a variety of ecological and socioeconomic reasons (Perfecto et al. 2009, Perfecto and Vandermeer 2010, Mehrabi et al. 2018).

In addition to holding the majority of the world's biodiversity, tropical regions are also home to the majority of the world's economically impoverished people (Bonds et al. 2012), many of whom live in rural areas and are economically dependent on agriculture (World Bank 2018). A conservation strategy that sets aside large areas of habitat, thereby foreclosing future land use (the so-called "land-sparing" model), can have a negative impact on the economic potential of rural communities (Norton-Griffiths and Southey 1995, Mehrabi et al. 2018). Currently, agricultural landscapes cover approximately 37% of the earth's land surface, and agricultural production is projected to increase 100-110% by 2050 to meet a growing global crop demand (Tilman et al. 2011). Meeting this rising agricultural demand will require identifying strategies to minimize the loss of biodiversity while also maximizing agricultural yield (Vandermeer and Perfecto 1997, Fischer et al. 2014, Mehrabi et al. 2018). A popular concept is that of a "land-sharing" strategy, in which biodiversity is encouraged within farms either by incorporating areas that are structurally similar to native vegetation or by maintaining heterogeneity within farmed areas or along edges (Fischer et al. 2008).

Shade coffee (*Coffea* sp.) has been recognized as a well-studied example of the land sharing strategy (Perfecto et al. 2009, Jha et al. 2014, Perfecto and Vandermeer 2015). Coffee is an understory shrub originating in forests of southwestern Ethiopia and southeast Sudan (Pendergast 2010, Teketay 1999), and thus generally grows better in the shade of trees (Soto-Pinto et al. 2000). Traditionally cultivated coffee is grown under a canopy of shade trees with few to no agrochemicals, creating a heterogeneous forest-like environment (Moguel and Toledo 1999, Perfecto et al. 2014). This contrasts with a more industrial strategy, generally referred to as "sun coffee," which involves few to no shade trees to maximize short-term production (Jha et al. 2014). In the Neotropics (Armbrecht and Perfecto 2003, Philpott et al. 2008, Philpott and Bichier 2012) and India (Raman 2006), research suggests that the shade strategy supports a higher diversity of economically important taxa such as birds. In turn, bird populations can play a key role in the provisioning of natural pest control services in coffee through top-down effects in which birds prey on pest arthropods (Perfecto et al. 2004, Kellermann et al. 2008, Philpott et al. 2009, Karp et al. 2014). Bird species richness (Perfecto et al. 2004, Van Bael et al. 2008), density (Perfecto et al. 2004), abundance (Jedlicka et al. 2011), and functional richness (Philpott et al. 2009) are all positively correlated with the top-down control of pests, especially the coffee berry borer (*Hypothenemus hampei*), in coffee.

In all regions, the term "shade coffee" belies tremendous variation among and within farms that contain shade trees (Moguel and Toledo 1999). The most diverse form of shade farms are "rustic farms," in which the understory vegetation is replaced with coffee plants, thereby maintaining natural tree diversity and forest structure. In contrast, a shade plantation strategy that utilizes one or only a few species of tree, called a shaded monoculture (Moguel and Toledo 1999), is common in many regions, including among large plantations established during the colonial era in Kenya and now run usually by African or international enterprises (Tignor 2015). Often, a few key tree species dominate shaded monocultures within a region, such as several species of *Inga* in Mexico (Romero-Alvarado et al. 2000) and Jamaica (Johnson 2000a), *Erythrina poeppigeana* in Costa Rica (Perfecto and Vandermeer 2015), and *Grevillea robusta* in Kenya, Guatemala, Brazil, and India (Baggio et al. 1997, Muchiri 2004, Ambinakudige and Sathish 2009, Jha et al. 2011).

The selection of shade tree species has important implications for both the farmer and the wildlife that may use coffee farms. Farmers' criteria for selecting shade tree species tend to revolve around ecological or economic benefits provided by the trees, as well as aspects of tree phenology indirectly related to microclimates, which can promote increased crop yield (Soto- Pinto et al. 2007, Pinard et al. 2014b). Surveying coffee farmers in Chiapas, Mexico, Soto-Pinto et al. (2007) found that farmers preferred perennial trees that grew quickly, had greater branch hardness and root strength, aided in soil fertilization through fast litter decomposition rates, and/or had moderate foliage density. Shade tree products such as fruit and timber can also buffer the impact of coffee income volatility, particularly for coffee farmers with small land holdings (Jassogne et al. 2012, Davis et al. 2017).

Understanding the ecology of specific shade tree species is also important because they affect coffee understory pest species in at least two ways - by influencing the abundance and richness of natural bird predators that can act as a top-down control on pest populations (Kellerman et al. 2008, Railsback and Johnson 2014), and by affecting temperature, which can impact pest populations (Teodoro et al. 2008).

Previous studies of Neotropical shade farms have suggested that differences in shade tree species can have significant effects on avian communities, potentially affecting top-down impacts of predatory birds on insect pests in the coffee understory. Johnson (2000a) found that Jamaican coffee plantations in which the native genus *Inga* was dominant supported the highest abundances of both birds and non-pest arthropods, an observation also noted by Greenberg et al. (1997*a*) and Greenberg et al. (1997*b*) in Guatemala and Mexico, respectively. This follows ecological theory regarding insect coevolution with plants (Tallamy 2004). Insects adapt to evolutionarily novel plants slowly (Southwood et al. 1982), and coevolution with particular host plants is a strong driving force of species diversification and radiation for many insect taxa (Farrell and Mitter 1997, Becerra and Venable 1999). Most herbivorous insects specialize on one or a few native plant groups with which they have shared an evolutionary history (Erhlich and Raven 1964, Bernays and Graham 1988, Forister et al. 2015), with specialization being more pronounced at lower latitudes (Schemske et al. 2009). Thus, ecosystems dominated by non-native plants tend to exhibit lower insect diversity, abundance, and biomass than systems dominated by native host plants (Burghardt et al. 2010, Litt et al. 2014). This has implications for the selection of shade tree species and their effects on top-down impacts of insectivorous pest-eating birds in shade coffee farms (Narango et al. 2018).

Shade trees may also affect insects and birds in coffee through bottom-up impacts on temperature (Schooler et al. in press). Jaramillo et al. (2009), reporting on the thermal tolerance of coffee berry borer, forecasted that a 1-2º Celsius increase could lead to an increase in the number of generations per year, dispersion, and damage by coffee berry borer. Trees that provide higher amounts of shade may lower ambient temperatures in the coffee understory, reducing potential for pest proliferation. With rising temperatures expected in much of the world's coffee growing regions (Bunn et al. 2015), and possible increases in the prevalence of pests (Jaramillo et al. 2009, Jaramillo et al. 2011), the use of shade trees could be a useful climate adaptation strategy for coffee farmers (Kagezi et al. 2018, Rahn et al. 2018).

In central Kenya, two of the most common trees on shaded coffee monocultures are *Grevillea robusta* (hereafter *Grevillea*) and several species of *Cordia*, especially *Cordia africana* (collectively hereafter *Cordia*). Vegetation surveys among 41 coffee sites in central Kenya showed that *Grevillea* and *Cordia* comprised 36% and 27% all shade trees sampled, respectively (n = 850, Johnson et al. unpubl. data). *Grevillea* is a deciduous tree introduced to Kenya from eastern Australia in the 19th century, and is well-regarded amongst farmers because of its moderate to fast growth (as much as 3 meters a year in some sites) and a tall branch system that provides a strong windbreak

(Negash 1995). *Cordia*, on the other hand, is an evergreen native to east Africa that generally has a shorter and wider branching canopy than Grevillea, as well as broader leaves (D. Kammerichs-Berke, pers. obs.) that provides high amounts of shade on farms where planted, which could help buffer temperature and lower pest productivity. Both tree species are also appealing as shade trees due to their nitrogen-fixing abilities (Negash 1995, Lott et al. 2000). Despite the prominence of these two shade tree species, ecological aspects of shade tree selection on East African coffee farms remains understudied (Pinard et al. 2014a, 2014b).

This study sought to investigate the influence of these two tree species on the avian community, with a special emphasis on insectivorous birds that may provide pest control services in Kenyan coffee. Native *Cordia* trees were hypothesized to offer more potential for pest control services in Kenyan coffee farms than non-native *Grevillea* because they attract more insectivorous birds and because they can lower understory coffee temperatures that could slow pest growth. Specifically, the following predictions were tested: (1) Non-pest foliage arthropods are more abundant on *Cordia* than *Grevillea*, (2) insectivorous birds forage more in *Cordia* than in *Grevillea*, (3) insectivorous birds foraging in the shade layer also use the coffee understory (at the species level), and this pattern differs between *Cordia* and *Grevillea*, (4) insectivorous birds are more common in the coffee layer under or near *Cordia* than *Grevillea*, and (5) understory temperatures are lower under *Cordia* than under *Grevillea.*

METHODS

Study Area

This study was conducted on coffee farms along an elevational gradient (1,567 - 1,874 m) in Kiambu County, Kenya from 16 December 2018 through 19 January 2019. Both sun and shade coffee farms occur along this elevational gradient (Jaramillo et al. 2013), with variation in farming intensity, acreage, and habitat components. A variety of tree species are utilized within the shade farms, including acacias (*Acacia* sp.), broad-leaved croton (*Croton macrostaphylus*), Meru oak (*Vitex keniensis*), and Nandi flame (*Spathodea campanulate*), though the two most commonly used species are *Grevillea* and *Cordia*. Because of the focus on tree species selection, only sites with some amount of shade were surveyed; full sun farms were excluded from this study. In order to investigate insectivorous bird use of *Cordia* and *Grevillea*, farms that had low total tree species diversity and a relatively even distribution of both *Grevillea* and *Cordia* were selected. Surveys were conducted on 6 sites (Fig. 1a); each site was a different coffee farm, except in one case a single farm was divided into two sites because it was large (approximately 91 ha) and contained multiple fields (separated by dirt roads or paths) with different characteristics (size and density of shade trees, density of coffee trees).

Field Methods

Spatial Design of Study Site

Arthropod, bird, vegetation, and temperature sampling was organized around individual shade trees at each study site. To select trees, a four-quadrant grid was overlaid on an aerial image of the site, recording the UTM coordinates for the center of each quadrant (Fig. 1b). Then, in the field from the centroid of each quadrant, 3-4 avian observation points were selected, defined as a point with 3-4 *Cordia* or *Grevillea* trees that could be visually monitored simultaneously for avian foraging observations and also met the survey criteria: 23-40 cm diameter at breast height (dbh), at least 50 m from the site edge, and within 20 m of each other. This dbh range was selected to minimize the confounding effects of tree size and corresponds to the 25th and 75th percentiles of trees measured in a companion study of these farms in 2017-2018 (Schooler 2019; Kammerichs-Berke unpubl. data). An effort was made to survey an equal number of *Cordia* and *Grevillea* trees at each site, though this was not always possible due to their arrangement and availability. In total, there were 333 trees (184 *Cordia* and 149 *Grevillea*) spread among the 6 farms for avian surveys, of which 146 (75 *Cordia* and 71 *Grevillea*) were also sampled for arthropods, and 72 (36 *Cordia* and 36 *Grevillea*) sampled with mist-nets. Basic vegetation data were recorded for all 333 trees, with more detailed data measured on the 146 trees also sampled for arthropods. Lastly, temperature loggers were deployed under 12 of the trees (6 *Cordia* and 6 *Grevillea*, 1 per species per site) and at 6 locations nearby under no shade trees (1 sun location per site).

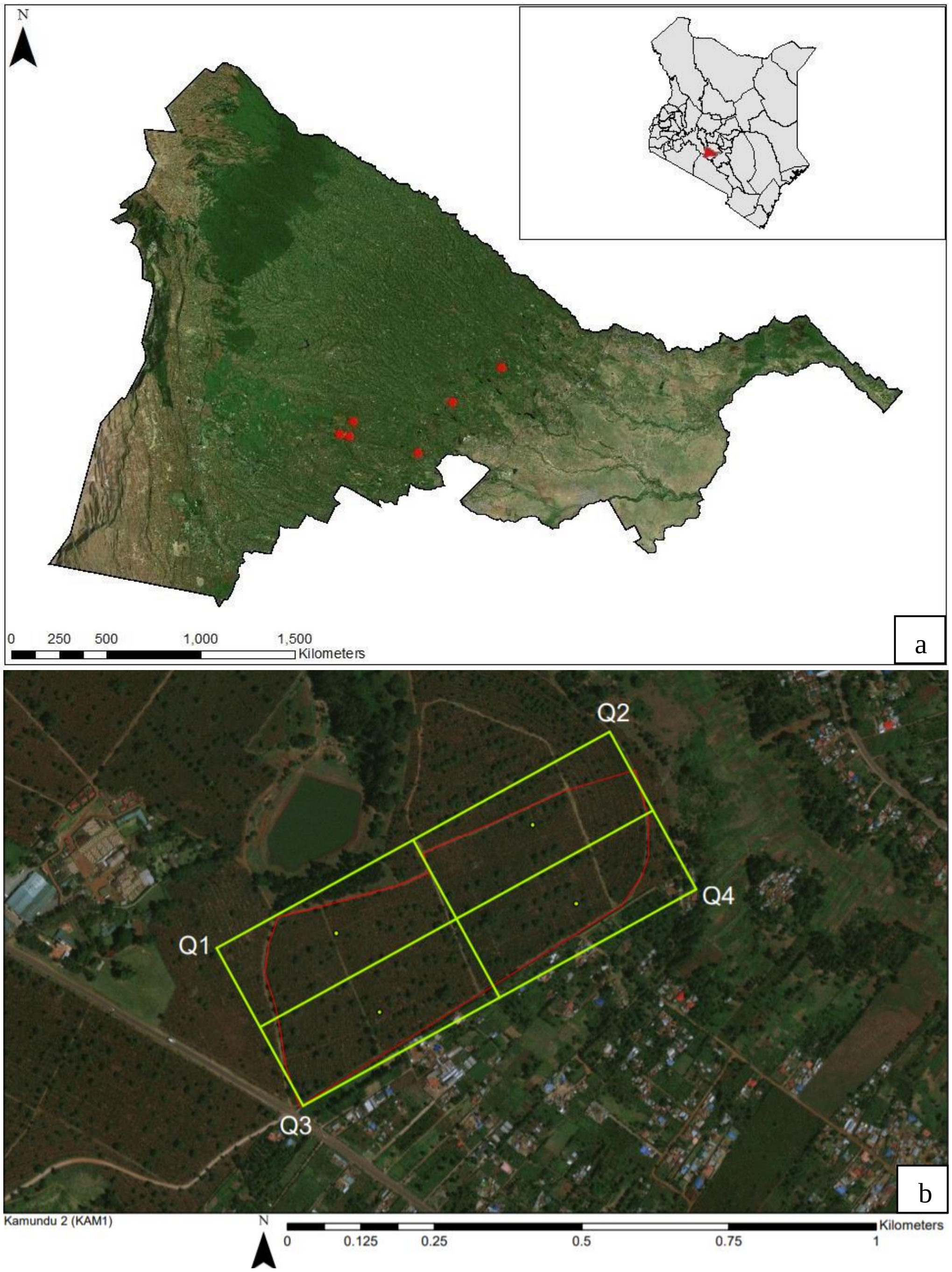


Figure 1. (a) Map depicting the spatial arrangement of the six farms surveyed in Kiambu County, Kenya from 16 December 2018 – 19 January 2019. (b) Site map depicting 4 quandrants overlaid on one of the coffee farms. Avian observation points were selected by going to the center of each quadrant (green dots) and from there selecting 3-4 points each with 3-4 trees between 23-40 cm diameter at breast height (dbh). All points were at least 50 m from the site edge (shown here in red) and within 20 m of each other.

Arthropod Sampling

The branch clipping method described in Johnson (2000b) was used to sample arthropod communities at each site. At each sampled tree, 2 branches were sampled, selected from areas of the foliage profile most similar to those generally used by foliage-gleaning birds (Johnson 2000a) during focal tree observations and within reach of extendable poles (i.e., outer branches, <5 m high). Although an effort was made to sample 2 branches per tree, some trees only had one sample-able branch, leading to an odd number of branches surveyed in total (147 *Cordia* branches and 136 *Grevillea* branches, for a total of 283 branches across all farms). After a branch was selected, the pole was extended to the height of the branch, enclosed the branch within the bag, and pulled the drawstring to cinch the bag over the branch as quickly as possible. A pruning pole was used to clip the branch free. Once the branch was free, the bagged branch was shaken to dislodge any arthropods. The clipped branches were checked for arthropods afterwards to ensure that all insects were captured in the sample. Arthropods were identified to order or class in the field and recorded the number of individuals of each order and the length (mm) of each arthropod.

Determining Avian Community Composition

Avian surveys were conducted at the avian observation points from 0600-1000 h EAT, a time of day when birds are most active (D. Kammerichs-Berke, pers. obs.). Two well-trained and experienced field technicians conducted all surveys, and they generally alternated between sampling *Cordia* and *Grevillea* trees throughout the morning. Due to the spatial design one observer surveyed 71 more trees in total than the other, but the difference in proportions of *Cordia* and *Grevillea* was not significant (χ^2 = 1.605, df =1, P = 0.205). Once at an observation point, each observer simultaneously monitored the 3-4 focal survey trees that were near the point, for a total of 10 minutes. While this simultaneous design is unusual, we found that the number of birds present in or coming to/from a given tree in a 10-minute period was low (see Results), and the habitat was open and individual trees easily monitored, so this design optimized replication while maintaining precision. For each observation, observers recorded species abundances, and the number of individuals actively foraging in the trees. Foraging was defined as any of the stereotyped behaviors described in Remsen and Robinson (1981). If there were greater than 10 individuals of a species within a tree, observers estimated flock size to the nearest 5; for groups of a species fewer than 10, observers were able to accurately count individuals. Observers counted all birds seen in the trees within the 10-minute observation period, including arriving birds.

Mist nets were used to quantify presence/absence and relative abundances of insectivorous birds in the coffee layer. A team of field technicians set up 12 2.5 x 9 m, 30-mm mesh nets in the coffee layer under 12 of the survey trees at each site, with nets deployed so that half of the nets were near *Grevillea* and half near *Cordia*. Nets were placed no more than 5 m from the base of a tree, parallel to the coffee crop row. Nets were opened 10 min before sunrise and were run for 5 hrs for 3 mornings per site. Birds were banded using bands supplied by the National Museums of Kenya. Recaptures from the same day as initial banding were released directly at the net without re-processing, while recaptures from a previous day were processed and recorded.

Shade Tree Microclimate

Maxim iButton temperature loggers were deployed to measure temperatures under each tree species. 3 temperature loggers were deployed on each site, one under each shade tree species of similar dbh and canopy cover, and one in an unshaded control area (18 in total). Temperature loggers were tied to the base of coffee shrubs within 3 m of a shade tree, 2 m above ground and not in direct sunlight (Garedew et al. 2017). The loggers collected data once every half hour to capture the warmest and coolest parts of the day, until the batteries died (approximately 43 days). Temperature loggers were retrieved in April 2019, with 11 successfully located and retrieved (4 *Cordia*, 4 *Grevillea*, 3 unshaded).

Vegetation Composition

Tree species, height, and diameter at breast height (dbh) were measured at each surveyed shade tree (n = 333). Canopy coverage (via densiometer), crown length, width, and depth, and flowering score were also measured for a third of shade trees (n = 146). Tree height and crown depth were calculated from angles to top and bottom of tree and the bottom of crown (excluding small branches at the bottoms, where the bulk of the trees leaves end; measured with a clinometer) and distance to the tree (measured with a rangefinder in m). Crown width was estimated as the average of the crown diameter measured on 2 axes with a 50m tape below the tree. Flowering was recorded on a scale of 0-4, representing none, up to 25% of branches with flowers, up to 50%, 75%, and 100%, respectively.

Coffee understory data were measured in a square 10x10 m plot directly adjacent to each surveyed tree (n = 146). The number of coffee shrubs (stems) in each quadrant of the 10x10m plot was recorded, the percent coffee cover in each quadrant was visually estimated (to nearest 10%), and the coffee flowering (if any) was recorded using the same scale as the shade tree measurements. Additionally, whether there was prominent flowering (>10 stems) and/or seed prevalence in the understory was recorded.

Analysis

Univariate Analyses of Arthropods and Birds

Multiple linear mixed-effects models were used to examine the effects of tree vegetation covariates on arthropod abundance. A two-sample t-test showed mean branch weights of *Cordia* and *Grevillea* to be unequal ($df = 234.37$, $t = -5.5236$, $p < 0.001$). As such, arthropod density was used as the response variable, calculated as the number of individual arthropods per g of clipped and inspected branch biomass × 100. A Shapiro-Wilks normality test of the assumption of normality was used for the response variable, and arthropod density was log-transformed to improve normality ($W = 0.9888$, $p = 0.03613$). Since arthropods were sampled from the same trees for which full vegetation variables were measured, model selection for predicting arthropod biomass included all vegetation variables. Because multiple branches were sampled from the same trees, tree was treated as a random effect in the model.

Generalized linear mixed-effects models (GLMM) with a Poisson distribution were used to examine the effects of vegetation variables on bird communities in the canopy of shade trees on farms. Although data was collected for all bird species detected on the farms regardless of foraging guild (Appendix 1), analysis of bird communities was limited to insectivores, since that is the guild most relevant to farmers in terms of potential pest control services. Species were classified as insectivorous based on major dietary preferences (HBWA 2018). Three separate stepwise model selection analyses were conducted for the bird community data, using species richness, total abundance of individuals, and abundance of foraging individuals specifically as response variables, respectively. Rarefaction revealed that the bird community was sampled adequately with the full sample size (n = 333 trees, Appendix 2), but not the subset of trees that also included arthropod and detailed vegetation sampling (n = 146 trees), so predictive models for the bird community included only the vegetation data collected at all trees (tree species, dbh, height). None of the final vegetation variables had a strong correlation with each other (all $r < 0.75$, VIF < 5), so collinearity was not an issue. A Poisson distribution was used to account for the zero-inflated nature of the detection data, and helped meet the model assumptions necessary for GLMMs. For each analysis, site was treated as a random effect to account for any measured landscape-level variable that may influence species richness or abundance (e.g., elevation).

GLMM with a Poisson distribution was used to examine the effects of vegetation variables on bird communities sampled by mist-nets in the crop layer. Smith et al. (2015) used Bayesian modeling to assess bird density in Kenyan coffee farms using very similar field procedures as in this study, and they found that a simple measure of number of captures was adequate as a relative measure of bird abundance. Therefore, the number of captures per net and number of species per net were used as indices of abundance and species richness of birds as the response variables, with tree species, height, canopy cover, dbh, coffee flowering score, and average percent understory cover as predictor variables; site was again used as a random effect. For both canopy and crop layer GLMM analyses, Akaike Information Criterion corrected for small sample size (AICc) was used to select top models and establish model weights (Burnham and Anderson 2002).

Multivariate Community Analysis

Non-metric multidimensional scaling (NMDS) was used to ordinate Bray-Curtis dissimilarity indices and to identify patterns in the bird community composition data. Because ordinations cannot be constructed using zero values, the survey data was subsampled to only include trees that had at least one detection of any species (n = 139 trees). Bird community matrices were then constructed for the canopy and understory of each tree species from the foraging and banding data, respectively. Bray-Curtis dissimilarity distances were calculated between each tree community, which were ordinated using a NMDS with no more than 1,000 random starts and 4 dimensions (k = 4). Four dimensions were used because any scaling done with fewer dimensions failed to converge after 1,000 starts. A pairwise Permutational Multivariate Analysis of Variance (PERMANOVA) with a Bonferroni p-value correction was conducted to compare the community composition of each analysis of canopy and understory, under the null hypothesis that there is no difference in community composition between four vegetation levels (canopy and understory each of *Cordia* and *Grevillea*). 999 permutations were used for the PERMANOVA. A multivariate analogue of Levene's test was used to test for homogeneity of group variances (Anderson 2006).

Temperature Data Analysis

Daily maximum, minimum, and mean daily temperatures were calculated for *Cordia* (n = 4), *Grevillea* (n = 4) and control (n = 3). Analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) test were used to compare differences in daily maximum, minimum, and mean daily temperatures between each tree species and the control.

RESULTS

In total, 184 *Cordia* and 149 *Grevillea* trees were surveyed. *Cordia* was typically taller and thicker than *Grevillea*, with a wider and denser canopy. *Grevillea*, however, had a greater crown depth than *Cordia* (Table 1). Shade trees buffered temperatures in coffee, and this was more pronounced under *Cordia* than under *Grevillea* Appendix 3, Appendix 4). The maximum daily temperature was significantly lower under shade trees than in the unshaded control (*Cordia*-Control: -3.191^{o} C difference, 95% CI = -4.299, -2.084; *Grevillea*-Control: -3.526^{o} C difference, 95% CI = -4.721, -2.331), and this effect was similar between *Cordia* and *Grevillea* (-0.33^{o} C difference, 95% CI = -1.530, 0.861). The minimum daily temperature was significantly warmer under *Cordia* than in the unshaded control (+1.2^{o} C difference, 95% CI = 0.310, 2.218), and this buffering effect was stronger than under *Grevillea* (+0.8^{o} C difference, 95% CI = -0.217, 1.840). Mean daily temperatures were similar among both shade tree species and in the unshaded control sites (*Cordia*-Control: -0.283^{o} C difference, 95% CI = -0.810, 0.244; *Grevillea*-Control: 0.243^{o} C difference, 95% CI = -0.326, 0.812), though mean temperatures were marginally cooler under *Cordia* than *Grevillea* (-0.5^{o} C difference, 95% CI = -0.043, 1.096).

Overall, 2,386 individuals across 23 arthropod taxa groups were detected on *Cordia*, while 682 individuals across 18 arthropod groups were detected on *Grevillea*. The top performing model predicting arthropod density included tree species and height (Table 2), with *Grevillea* and tree height both negatively associated with arthropod density (Fig. 2). The mean density of arthropods per 100 g of clipped and inspected branch vegetation was over four times higher on *Cordia* branches (17.07 ± 2.10) than on *Grevillea* (3.39 ± 0.39).

841 individuals of 19 insectivorous bird species were detected in the avian surveys: *Batis molitor, Terpisphone viridis, Melaniparus albiventris, Sylvietta whytii, Apalis flavida*, *Phylloscopus trochilus, Ploceus baglafecht*, two species of Sylviid warblers (Family Sylviidae), two white-eyes (Family Zosteropidae), two Old World Flycatchers (Family Muscicapidae), and six species of sunbirds (Family Nectariniidae). Tree species and height were the top predictors for avian species richness, total abundance, and abundance of foraging individuals (Table 3). *Grevillea* was negatively associated with richness (β = -0.743 ± 0.097, 95% CI = -0.935, -0.554), total abundance (β = -1.019 ± 0.092, 95% CI = -1.203, -0.835), and foraging abundance (β = -1.327 ± 0.133, 95% CI = -1.595, -1.069). Tree height was positively associated with richness (β = 0.038 ± 0.009, 95% CI = 0.019, 0.057), total abundance (β = 0.035 ± 0.008, 95% CI = 0.018, 0.053), and foraging abundance (β = 0.039 ± 0.012, 95% CI = 0.015, 0.063; Table 4). Relative to *Grevillea*, surveys of *Cordia* trees on average contained 0.98 more species, 1.61 more total birds, and 1.1 more foraging birds per 10-minute survey (Fig. 3).

In total, 278 individuals of the same 19 insectivorous bird species were detected by mist-nets in the understory of shade farms. Average coffee flowering score, canopy cover, and understory cover were the top predictors for total relative abundance in the crop layer, whereas average coffee flowering score and canopy cover were top predictors of species richness (Appendix 5). Average coffee flowering score was negatively associated with total abundance (β = -0.688 ± 0.184, 95% CI = -1.061, -0.333), whereas canopy cover was positively associated with abundance (β = 0.013 ± 0.003,95% CI = 0.006, 0.019), as was understory cover (β = 0.006 ± 0.003, 95% CI = 0.0008, 0.013). Average coffee flowering score was negatively associated with species richness (β = -0.899 ± 0.241, 95% CI = -1.393, -0.440), while canopy cover was positively associated with richness (β = 0.007 ± 0.003, 95% CI = -0.0001, 0.0147; Appendix 6). Shade tree species was not strongly associated with bird abundance or richness sampled by mist-nets in the understory.

Table 1. Descriptive statistics (mean ± 1 SE, or mode) of sampled *Cordia* and *Grevillea* trees on shade coffee farms in Kiambu County, Kenya, winter 2018-2019. Full vegetation measurements were collected for a subset (n = 146) of all trees (N = 333).

Measurement	**Tree Species**	
	Cordia	**Grevillea**
Tree Height (m)[A]	31.31 ± 3.72	17.57 ± 4.82
Diameter at Breast Height (dbh, cm)[A]	37.55 ± 9.43	33.47 ± 9.72
Canopy Depth (m)[B]	8.26 ± 2.59	11.14 ± 3.63
Average Crown Spread (m)[B]	11.34 ± 1.87	9.70 ± 1.82
Canopy Cover (%)[B]	68.56 ± 18.63	50.21 ± 18.26
Flowering Score (mode)[B]	0-25%	0-25%
Fruiting Score (mode)[B]	0-25%	0-25%

[A]n = 333

[B]n = 146

Table 2. AICc results of the competing linear regression model set which included tree species, tree height, and diameter at breast height (dbh) as predictors to arthropod biomass on coffee farms in Kiambu County, Kenya, winter 2018-2019.

Response Variable	**Model**	**K[a]**	**$Log_e(L)$[b]**	**AIC_c[c]**	**ΔAIC_c[d]**	**Wi[e]**
Arthropod Biomass	Tree Species + Height	5	-392.29	794.81	0.00	**0.65**
	Tree Species	4	-393.90	795.96	1.15	0.35
	Tree Species + Height + Av. Crown Spread.	6	-394.46	801.23	6.42	0.03
	Tree Species + Height + Av. Crown Spread + Canopy Cover	7	-398.79	812.00	17.19	0.00
	All Vegetation	8	-401.63	819.81	25.00	0.00
	Height	4	-406.21	820.58	25.76	0.00
	Null	3	-420.67	847.43	52.61	0.00
	Av. Crown Spread	4	-421.29	850.72	55.91	0.00
	Canopy Cover	4	-422.17	852.50	57.69	0.00
	Dbh	4	-423.71	855.58	60.77	0.00

[a]Number of parameters
[b]Log_e(likelihood)
[c]Akaike's Information Criterion corrected for small sample size
[d]Difference between AIC_c and top model AIC_c
[e]AIC_c weight

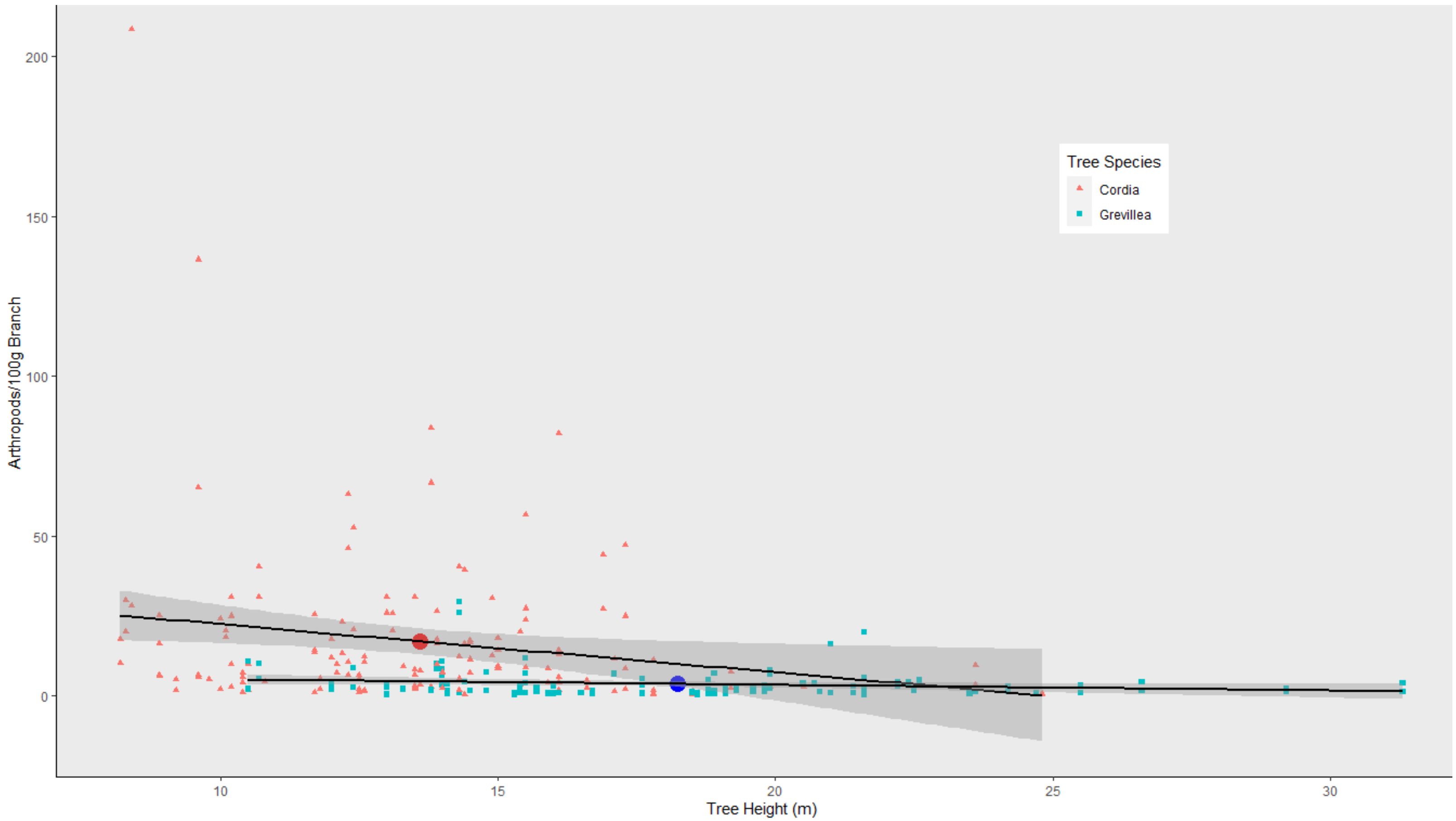


Figure 2. Arthropod density (arthropods per 100 g clipped and inspected vegetation) on *Cordia* and *Grevillea* trees on coffee farms in Kiambu County, Kenya, winter 2018-2019. *Cordia* had significantly higher arthropod density than *Grevillea* ($p = 0.0002$), and shorter trees had higher biomass regardless of tree species ($p = 0.0167$). Enlarged dots represent the mean arthropod density for each tree species and mean height.

All 19 focal species were detected in the canopy of *Cordia*, 18 in the understory of *Cordia*, 11 in the canopy of *Grevillea*, and 17 in the understory of *Grevillea*, with 10 species detected in all 4 vegetation levels (Table 5). In the ordination, a stress level of 0.141was obtained at convergence, indicating good ordination goodness-of-fit. Pairwise PERMANOVA indicated that the bird community composition in the *Grevillea* canopy was significantly different from the *Cordia* canopy ($r^2 = 0.086$, $F = 6.437$, $p_{adj} = 0.006$, $df = 1$), the *Cordia* understory ($r^2 = 0.103$, $F = 7.857$, $p_{adj} = 0.006$, $df = 1$), and the *Grevillea* understory ($r^2 = 0.100$, $F = 7.185$, $p_{adj} = 0.006$, $df = 1$). The community composition did not differ significantly between any other pair of vegetation layers (Table 6, Fig. 4). Variance was also shown to be inequal between most groups ($F = 21.596$, $p < 0.001$, $df = 3$), with only *Cordia* understory and *Grevillea* understory communities having equal variance. However, pairwise PERMANOVAs are resilient to heterogeneity of variance in balanced designs such as this one (Anderson and Walsh 2013), so the results of the pairwise PERMANOVA should not be a result of inequal variances.

Table 3. AICc results of the competing general linear model set which included tree species, tree height, and diameter at breast height (dbh) as predictors to insectivorous bird species richness, abundance, and foraging on coffee farms in Kiambu County, Kenya, winter 2018-2019.

Response Variable	Model	K[a]	$Log_e(L)$[b]	AIC_c[c]	Delta AIC_c[d]	Wi[e]
Richness	**Species + Height + (1|Site)**	**4**	**-620.70**	**1249.51**	**0.00**	**0.69**
	Species + Height + dbh + (1|Site)	5	-620.48	1251.15	1.64	0.30
	Species + dbh + (1|Site)	4	-624.85	1257.82	8.31	0.01
	Species + (1|Site)	3	-628.83	1263.73	14.22	0.00
	dbh + (1|Site)	3	-643.92	1293.91	44.40	0.00
	Height + dbh + (1|Site)	4	-643.03	1294.17	44.66	0.00
	1 + (1|Site)	2	-651.96	1307.95	58.44	0.00
	Height + (1|Site)	3	-651.85	1309.77	60.26	0.00
Abundance	**Species + Height + (1|Site)**	**4**	**-825.37**	**1658.86**	**0.00**	**0.68**
	Species + Height + dbh + (1|Site)	5	-825.15	1660.48	1.62	0.30
	Species + dbh + (1|Site)	4	-829.42	1666.96	8.10	0.01
	Species + (1|Site)	3	-833.29	1672.64	13.78	0.00
	Height + dbh + (1|Site)	4	-875.74	1759.60	100.74	0.00
	dbh + (1|Site)	3	-875.74	1772.28	113.42	0.00
	Height + (1|Site)	3	-892.08	1790.23	131.37	0.00
	1 + (1|Site)	2	-893.32	1790.67	131.80	0.00
Foraging	**Species + Height + (1|Site)**	**4**	**-614.42**	**1236.95**	**0.00**	**0.69**
	Species + Height + dbh + (1|Site)	5	-614.36	1238.89	1.94	0.26
	Species + dbh + (1|Site)	4	-617.27	1242.65	5.70	0.04
	Species + (1|Site)	3	-619.43	1244.92	7.97	0.01
	Height + dbh + (1|Site)	4	-658.99	1326.10	89.15	0.00
	dbh + (1|Site)	3	-666.94	1339.96	103.00	0.00
	Height + (1|Site)	3	-671.36	1348.79	111.84	0.00
	1 + (1|Site)	2	-673.43	1350.90	113.95	0.00

[a]Number of parameters
[b]Log_e(likelihood)
[c]Akaike's Information Criterion corrected for small sample size
[d]Difference between AIC_c and top model AIC_c
[e]AIC_c weight

Table 4. Results from top models for insectivorous bird species richness, abundance, and foraging on coffee farms in Kiambu County, Kenya, winter 2018-2019.

Response	**Covariate**	**β**	**SE**	**CI (95%)**
Richness	Intercept	0.327	0.147	0.036, 0.616
	Species (Grevillea)	-0.743	0.097	-0.935, -0.554
	Height	0.038	0.009	0.019, 0.057
Abundance	Intercept	0.700	0.183	0.316, 1.084
	Species (Grevillea)	-1.019	0.092	-1.203, -0.835
	Height	0.035	0.008	0.018, 0.053
Foraging	Intercept	0.096	0.232	-0.381, 0.572
	Species (Grevillea)	-1.327	0.133	-1.595, -1.069
	Height	0.039	0.012	0.015, 0.063

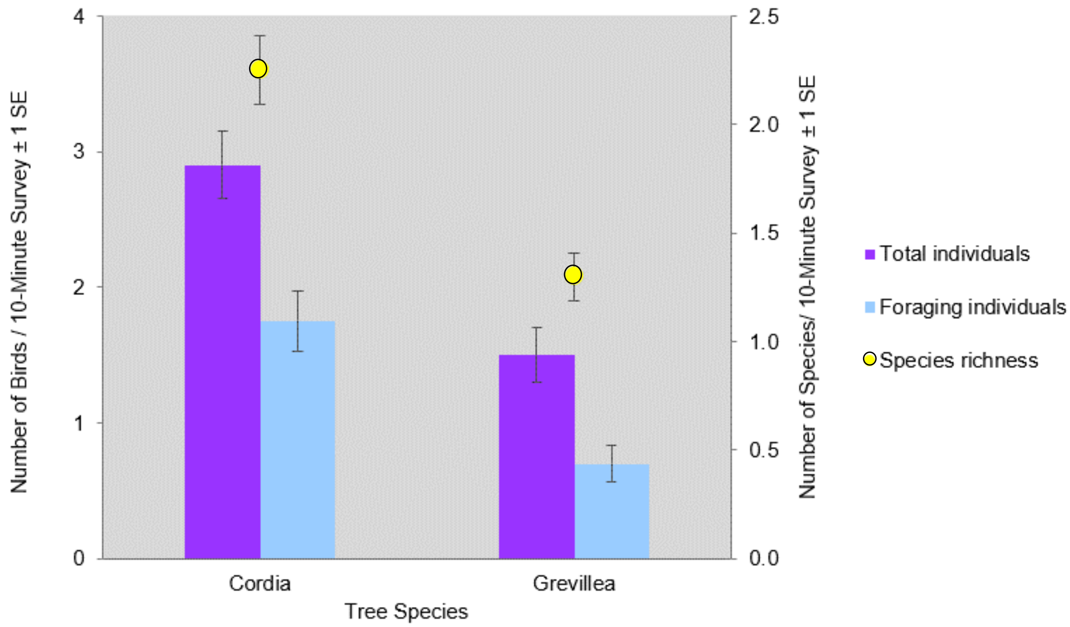


Figure 3. Mean number (X̄ / 10-minute survey ±1 SE) of total individuals, foraging individuals, and bird species richness per 10-minute survey of *Cordia* and *Grevillea* shade trees on coffee farms in Kiambu County, Kenya, winter 2018-2019.

Table 5. Detected abundances of each focal insectivorous bird species for each vegetation level on coffee farms in Kiambu County, Kenya, winter 2018-2019. Birds were detected at the canopy level using 10-minute focal tree observations and at the understory level using mist nets.

Common Name	**Latin Name**	**Vegetation Level**			
		Canopy-Cordia	Understory-Cordia	Canopy-Grevillea	Understory-Grevillea
Chinspot Batis	*Batis molitor*	2	4	0	2
African Paradise-Flycatcher	*Terpsiphone viridis*	3	7	2	11
White-bellied Tit	*Melaniparus albiventris*	1	9	0	3
Red-faced Crombec	*Sylvietta whytii*	1	7	1	9
Yellow-breasted Apalis	*Apalis flavida*	1	8	5	5
Willow Warbler	*Phylloscopus trochilus*	17	7	1	7
Eurasian Blackcap	*Sylvia atricapilla*	4	6	0	7
Garden Warbler	*Sylvia borin*	1	1	0	1
Pale White-Eye	*Zosterops flavilateralis*	7	3	7	2
Kikuyu White-Eye	*Zosterops kikuyuensis*	9	47	13	19
Pale Flycatcher	*Agricola pallidus*	7	4	0	2
White-eyed Slaty-Flycatcher	*Melaenornis fischeri*	4	2	0	5
Collared Sunbird	*Hedydipna collaris*	1	4	0	0
Green-headed Sunbird	*Cyanomitra verticalis*	1	1	1	0
Amethyst Sunbird	*Chalcomitra amethystina*	1	0	1	1
Scarlet-chested Sunbird	*Chalcomitra senegalensis*	4	1	1	9
Bronze Sunbird	*Nectarinia kilimensis*	12	20	2	15
Variable Sunbird	*Cinnyris venustus*	16	12	3	13
Baglafecht Weaver	*Ploceus baglafecht*	2	12	1	12

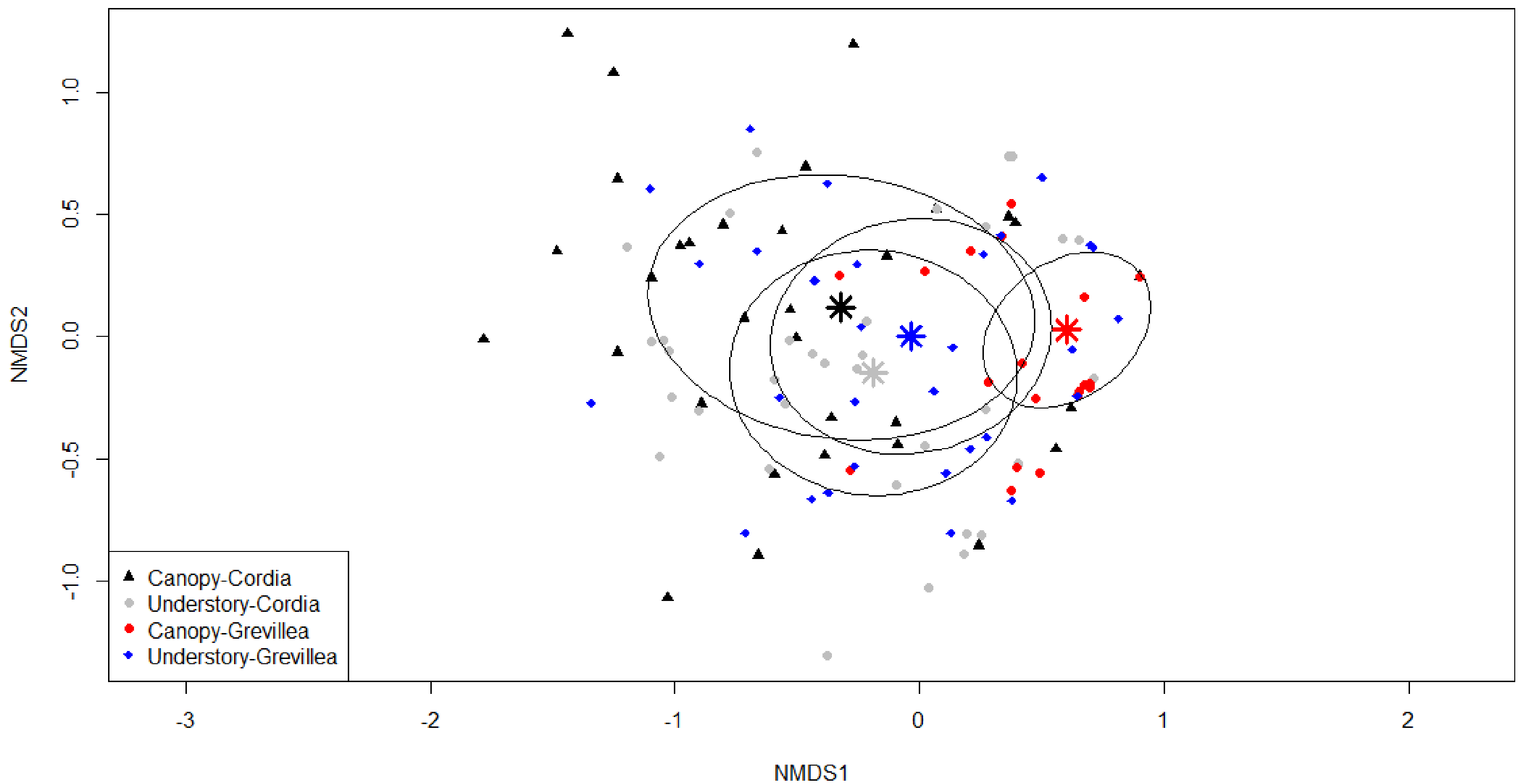


Figure 4. Non-metric multi-dimensional scaling (NMDS) plot of insectivorous bird community similarities between each vegetation level on coffee farms in Kiambu County, Kenya, winter 2018-2019. Canopy-*Grevillea* differs significantly from Canopy-*Cordia* (adj-p = 0.006), Understory-*Cordia* (adj-p = 0.006), and Understory-*Grevillea* (adj-p = 0.006). Ellipses represent 95% CI around the centroids of each community.

Table 6. Pairwise PERMANOVA results for insectivore community similarities between each pair of vegetation levels on coffee farms in Kiambu County, Kenya, winter 2018-2019.

Pairs	**Df**	**Sum of Squares**	**F**	$\mathbf{R^2}$	$\mathbf{P_{adj}}$
Canopy-Cordia / Understory-Cordia	1	0.530	3.269	0.043	0.054
Canopy-Cordia / Canopy-Grevillea	1	0.795	6.437	0.086	0.006**
Canopy-Cordia / Understory-Grevillea	1	0.366	2.233	0.031	0.300
Understory-Cordia / Canopy-Grevillea	1	1.046	7.857	0.103	0.006**
Understory-Cordia / Understory-Grevillea	1	0.170	0.981	0.014	1.000
Canopy-Grevillea / Understory-Grevillea	1	0.957	7.185	0.100	0.006**

**Statistically significant ($p_{adj} < 0.05$)

DISCUSSION

Shade coffee is important for the conservation of birds globally, but there is a need to better understand the effects of particular shade tree species on bird communities (Narango et al. 2019), and the implications for shade tree use for conservation and ecosystem services (Narango et al. 2018, Narango et al. 2019). As predicted by ecological theory (Tallamy 2004), native *Cordia* trees in Kenyan shade coffee farms hosted not only a higher density of arthropods than non-native *Grevillea* (Fig. 4), but also higher abundance of insectivorous birds and specifically more foraging individuals than *Grevillea* (Fig. 5). *Cordia* also had greater bird species richness than did *Grevillea*. All 19 focal species were detected in *Cordia*, and the most abundant species (*Phylloscopus trochilus,* Willow Warbler) accounted for 18% of all individual detections. In contrast, 12 of the focal insectivorous bird species were detected in *Grevillea*, and one species (*Zosterops kikuyuensis*, Kikuyu White-eye) accounted for 34% of all detections.

Optimal foraging theory predicts that animals distributed in patchy environments should select the most profitable patches to forage in and decide when to leave the patch they are using, given that the intake rates will vary among patches (Pyke 1984). Based on the functional response of animals to prey density (Holling 1965), feeding insectivorous birds should distribute among feeding patches according to their supply of insects, the so-called "habitat matching" rule (Fretwell 1972, Fagen 1987, Johnson and Sherry 2001). Because most insect taxa specialize on one or few native host plants, it is expected that herbivorous insects should be more common on native than exotic plants (Burghardt et al. 2010, Litt et al. 2014), and correspondingly insect-eating birds should forage more on natives than exotics (Narango et al. 2018). Although this study involved only a single pair of native and non-native tree species, the results are consistent with ecological theory of higher abundances of non-pest arthropods on native plants, which in turn would support more insectivorous birds that can forage on pest arthropods in the crop layer (Narango et al. 2018). This is relevant to farm managers because many of the ecosystem services that birds provide in agricultural landscapes result from their dietary preferences and foraging behavior (Wenny et al. 2011). Insectivorous birds are more likely than other foraging guilds to provide beneficial top-down control of pest species (Kellermann et al. 2008, Philpott et al. 2008, Johnson et al. 2010), and are generally also at higher conservation risk due to their stronger associations with forest habitats (Bennun et al. 1996, Sekercioglu et al. 2002, HBWA 2014).

The notion that shade trees could attract insectivorous birds helpful for pest control rests on the assumption that birds using the shade trees also forage in the associated understory, but this has rarely been examined explicitly (Smith et al. 2012). Because the preferred vegetation profiles for foraging vary among bird species, some natural variation between canopy and crop level bird communities is expected. Nonetheless, bird communities were nearly identical between *Cordia* canopy and understory (94.7% species overlap), whereas they were much less so between *Grevillea* canopy and understory (64.7% species overlap), with several species detected in the *Grevillea* understory but not in its canopy. The crop layer under both *Cordia* and *Grevillea* trees more closely resembled the canopy-level communities in *Cordia* trees, suggesting that *Grevillea* had comparatively less influence on the crop-level bird communities. The resemblance between the crop layer, regardless of shade tree species, and the *Cordia* canopy suggests that *Cordia* has a greater influence on crop-level communities by attracting birds to the canopy, which then move down and spread out to forage throughout the crop layer. By attracting greater numbers of non-pest arthropods, these results suggest *Cordia* attracts greater numbers of insect-eating birds to both the canopy and crop layer, increasing the potential for birds to predate on pest species such as coffee berry borer, white coffee stem-borer (*Xylotrechus quadripes*), and scale insects (Superfamily Coccoidea). In the Neotropics, avian predators of coffee berry borer and other coffee insects are mainly small-billed, small bodied, foliage gleaning insectivores, such as Parulid warblers (Karp et al. 2014, Sherry et al. 2016). Diet data are not yet available for the birds inhabiting East African coffee, but based on morphology, white-eyes (*Zosterops* sp.) may be a likely candidate for pest control. Notably, there were considerably more *Z. kikuyuensis* in the crop layer below *Cordia* than *Grevillea*, even though *Z. kikuyuensis* comprised most individuals detected in the canopy of Grevillea. While more *Z. kikuyuensis* were detected in the canopy of *Grevillea* than *Cordia*, most of the individuals were observed collecting nesting material such as spiderweb and tree fiber, and were rarely seen actively foraging.

Shade trees buffered temperatures in the coffee crop, and this effect was overall more pronounced under *Cordia* than under *Grevillea*. The range of temperatures was more constricted under *Cordia* than *Grevillea*, having similar mean daily temperatures but lower maximum mean and higher minimum mean daily temperatures. This analysis suggests that *Cordia* is likely a better choice as a shade tree for farmers because it better supports insect-eating birds that could help control pests, and because it buffers temperatures that could affect the productivity of pests that would proliferate under warmer temperatures (Jaramillo et al. 2009) and help adapt to expected climate warming (Schooler et al. in press). *Cordia* may thus promote both bottom-up and top-down controls on insect pest species.

Cordia may be preferred by farmers for other reasons besides pest control and climate adaptation. *Grevillea robusta* proliferated as a shade tree in central Kenya in the latter half of the 20th century largely due to the growth of the Greenbelt Movement. With the mission of community empowerment and conservation, the Green Belt Movement planted millions of trees throughout Kenya, particularly in agricultural areas such as the Kiambu region (Chikwendu 2008). *Grevillea* was chosen largely because it grows quickly (36+ inches per year; SelecTree 2020) and yields high, immediate material benefits such as firewood. However, in recent decades the Greenbelt Movement has shifted its stance to encouraging the use of native species, including *Cordia*, in environmentally sensitive areas (Murithi et al. 2009). *Cordia*, while slower growing, may yield greater environmental conservation benefits as well as similar material benefits in the long term (Alemayehu et al. 2016). *Cordia* has various uses as medicine, food, firewood, fodder, and mulch (Alemayehu et al. 2016), and is considered an attractive species for beekeeping and honey production (Fichtl and Adi 1994). *Cordia* are a generally wider canopied tree, which, while sometimes taking up more space on the farm, provide the coffee crop with greater amounts of shade. *Cordia* also provide a greater windbreak than *Grevillea*, offering greater crop protection during rainy season storm events (J. Murithi, pers. comm.).

The clear next step is to confirm that species detected in the crop understory are in fact removing insects from the coffee plants. Insectivorous birds have been confirmed to help control coffee pests in the Neotropics (Kellermann et al. 2008, Johnson et al. 2010, Karp et al. 2013, Sherry et al. 2016), but this phenomenon has been much less studied in East Africa. Exclosure experiments in Tanzanian coffee farms confirmed a significant increase in herbivory rates on bushes from which birds and bats were excluded (Classen et al. 2014), and a sentinel pest removal experiment in Nyeri County, Kenya, documented greater insect removal rates in shade versus sun farms (Milligan et al. 2016). However, confirmation of Kenyan birds as pest predators awaits examination of their diets and additional experimental exclosure studies. In this study area, fecal samples were collected from birds captured in mist nets, and on-going molecular analysis will reveal diet compositions of insectivorous birds (Jedlicka et al., unpubl. data).

With a combined worth of US$ 70 billion, the coffee industry plays a significant role in the global economy (Osorio 2002). Coffee is a major export of several tropical and sub-tropical countries in Central and South America, Asia, and Africa, and the industry supports roughly 125 million people worldwide (Osario 2002, FAO 2016). With roughly 20% of the world's 10 million hectares of harvested area, Africa is one of the world's leading producers of coffee. Coffee is a major cash crop in Kenya, third only to tea and horticulture produce in export earnings. Approximately 110,000 hectares of land are harvested for coffee, and the industry supports about 5 million people within these areas (KALRO 2015). Despite the economic, cultural, and ecological significance of coffee in

Africa, its role in conservation on the continent is poorly understood, especially compared to the abundance of coffee-related ecological research done in the western hemisphere. Few studies have been conducted on coffee in East Africa, but among them they show conflicting results (Pinard et al. 2014a, Buechley et al. 2015, Smith et al. 2015, Milligan et al. 2016). These various results arise from the first few studies of birds in East African coffee farms, and they have followed basic survey designs completed much earlier and replicated many times in the Neotropics, from which broad observable patterns have now emerged (Philpott et al. 2008). It is therefore vital to continue examining birds and other wildlife in coffee systems in East Africa to gain a more complete understanding of the agroecosystems in this region.

LITERATURE CITED

Alemayehu, G., Z. Asfaw, and E. Kelbessa. 2016. Cordia Africana (Boraginaceae) in Ethiopia: A review on its taxonomy, distribution, ethnobotany and conservation status. International Journal of Botany Studies 1:38-46.

Ambinakudige, S. and B. N. Sathish. 2009. Comparing tree diversity and composition in coffee farms and sacred forests in the Western Ghats of India. Biodiversity Conservation 18:987-1000.

Anderson, M. J. 2006. Distance-based tests for homogeneity of multivariate dispersions. Biometrics 62:245-253.

Anderson, M. J. and D. C. I. Walsh. 2013. PERMANOVA, ANOSIM, and the Mantel test in the face of heterogeneous dispersions: What null hypothesis are you testing? Ecological Monographs 83(4):557-574.

Armbrecht, I., and I. Perfecto. 2003. Litter-twig dwelling ant species richness and predation potential within a forest fragment and neighboring coffee plantations of contrasting habitat quality in Mexico. Agriculture, Ecosystems & Environment 97:107–115.

Ash, A., M. Coughenour, J. Fryxell, W. Getz, J. Hearne, N. Owen-Smith, D. Ward, and E. A. Laca. 1996. Second international foraging behavior workshop. Bulletin of the Ecological Society of America 77:36-38.

Baggio, A. J., P. H. Caramori, A. Androcioli Filho, and L. Montoya. 1997. Productivity of Southern Brazilian coffee plantations shaded by different stockings of Grevillea robusta. Agroforestry Systems 37:111-120.

Becerra, J. X., and D. L. Venable. 1999. Macroevolution of insect-plant associations: The relevance of host biogeography to host affiliation. Proceeding of the National Academy of Sciences 96:12626-12631.

Bernays, E. M. and M. Graham. 1988. On the evolution of host specificity in phytophagous arthropods. Ecology 69:886-892.

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

Betts, M. G., C. Wolf, W. J. Ripple, B. Phalan, K. A. Millers, A. Duarte, S. H. M. Butchart, and T. Levi. 2017. Global forest loss disproportionately erodes biodiversity in intact landscapes. Nature 547:441–444.

Bonds, M. H., A. P. Dobson, and D. C. Keenan. 2012. Disease ecology, biodiversity, and the latitudinal gradient in income. PLOS Biol 10:e1001456.

Brown, J. H. 2014. Why are there so many species in the tropics? Journal of Biogeography 41:8–22.

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.

Bunn, C., Läderach, P., Rivera, O. O., and Kirschke, D. 2015. A bitter cup: climate change profile of global production of Arabica and Robusta coffee. Climate Change 129:89-101.

Burghardt, K. T., D. W. Tallamy, C. Philips, and K. J. Shropshire. 2010. Non-native plants reduce abundance, richness, and host specialization in epidopteran communities. Ecosphere 1:art11.

Burnham, K. P. and D. R. Anderson. 2002. Model selection and multimodel inference: A practical information-theoretic approach. Springer-Verlag New York, New York, New York.

Cottam, G., and J. T. Curtis. 1956. The use of distance Measures in phytosociological sampling. Ecology 37:451–460.

Classen, A., M. K. Peters, S. W. Ferger, M. Helbig-Bonitz, J. M. Schmack, G. Maassen, M. Schleuning, E. K. V. Kalko, K. Böhnig-Gaese, and I. Steffan-Dewenter. 2014. Complementary ecosystem, services provided by pest predators and pollinators increase quantity and quality of coffee yields. Proceedings of the Royal Society 281: 20133148.

Chikwendu, E. 2008. Wangari Maathai: Nobel laureate, environmentalist, and engagement with the Kenya state. Pages 29-44 *in* C. J. Korieh and P. E. Okeke-Ihejirika (*eds.*). Gendering Global Transformations: Gender, Culture, Race, and Identity. Routelage, Abingdon-on-Thames, England.

Davis, H., R. Rice, L. Rockwood, T. Wood, and P. Marra. 2017. The economic potential of fruit trees as shade in blue mountain coffee agroecosystems of the Yallahs River watershed, Jamaica W.I. Agroforestry Systems 93:581-589.

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

Eagen, R. 1987. A generalized habitat matching rule. Evolutionary Ecology 1:5-10.

Ehrlich, P. L, and P. H. Raven. 1964. Butterflies and plants: A study in coevolution. Evolution 18:586-608.

Farrell, B. D., and C. Mitter. 2008. The timing of insect/plant diversification: might *Tetraopes* (Coleoptera: Cerambycidae) and *Asclepias* (Asclepiadaceae) have co-evolved? Biological Journal of the Linnean Society 63:553-577.

Fichtl, R. and A. Adi. 1994. Honeybee flora of Ethiopia. Margaf Verlag, Weikersheim, Germany.

Fischer, J., D. J. Abson, V. Butsic, M. J. Chappell, J. Ekroos, J. Hanspach, T. Kuemmerle, H. G. Smith, and H. von Wehrden. 2014. Land sparing versus land sharing: Moving forward. Conservation Letters 7:149–157.

Fischer, J., B. Brosi, G. C. Daily, P. R. Ehrlich, R. Goldman, J. Goldstein, D. B. Lindenmayer,

A. D. Manning, H. A. Mooney, L. Pejchar, J. Ranganathan, and H. Tallis. 2008. Should agricultural policies encourage land sparing or wildlife-friendly arming? Frontiers in Ecology and the Environment 6:380–385.

Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Prentice, N. Ramankutty, and P. K. Snyder. 2005. Global consequences of land use. Science 309:570–574.

Food and Agriculture Organization of the United Nations [FAO]. FAOSTAT. <http://www.fao.org/faostat/en/#home>. Accessed 6 Sep 2018.

Forister, M. L., V. Novotny, A. K. Panorska, L. Baje, Y. Basset, P. T. Butterill, L. Cizek, P. D. Coley, F. Dem, I. R. Diniz, D. Pavel, M. Fox, A. E. Glassmire, R. Hazen, J. Hrcek, J. P. Jahner, O. Kaman, T. J. Kozubowski, T. A. Kursar, O. T. Lewis, J. Lill, R. J. Marquis, S. E. Miller, H. C. Morais, M. Murakami, H. Nickel, N. A. Pardikes, R. E. Ricklefs, M. S. Singer, A. M. Smilanich, J. O. Stireman, S. Villamarin-Cortez, S. Vodka, M. Volf, D. L. Wagner, T. Walla, G. D. Weiblen, and L. A. Dyer. 2015. The global distribution of diet breadth in insect herbivores. Proceedings of the National Academy of Sciences 112:442– 447.

Fretwell, S. D. 1972. Populations in a seasonal environment. Princeton University Press, Princeton, United States.

Garedew, W., B. T. Hailu, F. Lemessa, P. Pellikka, and F. Pinard. 2017. Coffee shade tree management: An adaptation option for climate change impact for small scale coffee growers in south-west Ethiopia. Pages 647-659 *in* W. Leal Filho, S. Belay, J. Kalangu, W. Menas, P. Munishi, and K. Musiyima (*eds*.). Climate Change Management. Springer, Cham, Switzerland.

Greenberg, R., P. Bichier, and A. C. Angón. 2000. The conservation value for birds of cacao plantations with diverse planted shade in Tabasco, Mexico. Animal Conservation 3:105- 112.

Greenberg, R., P. Bichier, A. Cruz Angon, and R. Reitsma. 1997*a*. Bird populations in shade and sun coffee plantations in Central Guatemala. Conservation Biology 11:448–459.

Greenberg, R., P. Bichier, and J. Sterling. 1997*b*. Bird populations in rustic and planted shade coffee plantations of eastern Chiapas, Mexico. Biotropica 29:501–514.

Handbook of Birds of the World Alive [HBWA]. 2018. Species home page. <https://www.hbw.com/species>. Accessed 6 Sep 2018.

Holmes, R. T., and S. K. Robinson. 1981. Tree species preferences of foraging insectivorous birds in a northern hardwoods forest. Oecologia 48:31–35.

Hutto, R. L. 1990. Measuring the availability of food resources. Pages 20-28 *in*: Morrison, M. L., C. J. Ralph, J. Verner, and J. R. Jehl, Jr. Avian foraging: Theory, methodology, and applications. Volume 13. Studies in Avian Biology, Cooper Ornithological Society, Los Angeles, California.

Jaramillo, J., A. Chabi-Olaye, C. Kamonjo, A. Jaramillo, F. E. Vega, H. M. Poehling, and C. Borgemeister. 2009. Thermal tolerance of the coffee berry borer Hypothenemus hampei: predictions of climate change impact on a tropical insect pest. PloS one 4:e6487.

Jaramillo, J., E. Muchugu, F. E. Vega, A. Davis, C. Borgemeister, and A. Chabi-Olaye. 2011. Some like it hot: the influence and implications of climate change on coffee berry borer (Hypothenemus hampei) and coffee production in East Africa. PLoS One 6:e24528.

Jaramillo, J., M. Setamou, E. Muchugu, A. Chabi-Olaye, A. Jaramillo, J. Mukabana, J. Maina, S. Gathara, and C. Borgemeister. 2013. Climate change or urbanization? Impacts on a traditional coffee production system in East Africa over the last 80 years. J. P. Hart, editor. PLoS ONE 8:e51815.

Jassogne, L., P. J. A. van Astern, I. Wanyama, and P. Baret. 2012. Perceptions and outlook on intercropping coffee with banana as an opportunity for smallholder coffee farmers in Uganda. International Journal of Agricultural Sustainability 11:144-158.

Jedlicka, J. A., R. Greenberg, and D. K. Letourneau. 2011. Avian conservation practices strengthen ecosystem services in California vineyards. A. M. Merenlender, editor. PLoS ONE 6:e27347.

Jha, S. C. M. Bacon, S. M. Philpott, R. A. Rice, V. E. Méndez, and P. Läderach. 2011. A review of ecosystem services, farmer livelihoods, and value chains in shade coffee agroecosystems. Pages 141-208 *in*: Campbell, W., S. Lopez Ortiz (eds). Integrating agriculture, conservation and ecotourism: Examples from the field. Issues in Agroecology - Present Status and Future Prospects, vol 1. Springer, Dordrecht.

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

Johnson, M. D. 2000b. Evaluation of an arthropod sampling technique for measuring food availability for forest insectivorous birds. Journal of Field Ornithology 71:88-109.

Johnson, M. D. and T. W. Sherry. 2001. Effects of food availability on the distribution of migratory warblers among habitats in Jamaica. Journal of Animal Ecology 70:546-560.

Johnson, M. D., J. L. Kellermann, and A. M. Stercho. 2010. Pest reduction services by birds in shade and sun coffee in Jamaica. Animal Conservation 13:140–147.

Kagezi, H., K. Patrick, K. Judith, O. D. Nicholas, N. Lilian, and W. Wagoire. 2018. Predicting the response of insect pests and diseases of Arabica coffee to climate change along an altitudinal gradient in Mt. Elgon region, Uganda. Journal of

Agriculture and Environmental Sciences 7:134-140.

Karp, D. S., C. D. Mendenhall, R. F. Sandi, N. Chaumont, P. R. Ehrlich, E. A. Hadly, and G. C. Daily. 2013. Forest bolsters bird abundance, pest control and coffee yield. Ecology Letters 16(11):1339-1347.

Karp, D. S. and G. C. Daily. 2014. Cascading effects of insectivorous birds and bats in tropical coffee plantations. Ecology 95:1065-1074.

Karp, D.S., Judson, S., Daily, G.C. and Hadly, E.A., 2014. Molecular diagnosis of bird-mediated pest consumption in tropical farmland. *SpringerPlus*, *3*(1), p.630.

Kellermann, J. L., M. D. Johnson, A. M. Stercho, and S. C. Hackett. 2008. Ecological and economic services provided by birds on Jamaican Blue Mountain coffee farms. Conservation Biology 22:1177–1185.

Kenya Agricultural and Livestock Research Organization [KALRO]. 2015. Annual report 2014- 2015. Nairobi, Kenya.

Lack, D. 1954. The natural regulation of animal numbers. Oxford University Press, London, UK. Legendre, P. and L. Legendre. 2012. Numerical ecology. 3rd edition. Elsevier Science BV, Amsterdam, Netherlands.

Litt, A. R., E. E. Cord, T. E. Fulbright, and G. L. Schuster. 2014. Effects of invasive plants on arthropods. Conservation Biology 28:1532-1549.

Lott, J. E., S. B. Howard, C. Ong, and C. R. Black. 2000. Long-term productivity of a Grevillea robusta-based overstorey agroforestry system in semi-arid Kenya: II. Crop growth and system performance. Forest Ecology and Management 139:187-201.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. Andrew Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. Bailey, and J. E. Hines. 2017. Occupancy estimation and modeling: Inferring patterns and dynamics of species occurrence. 2nd edition. Academic Press, Amsterdam, Netherlands.

Maundu, P. and B. Tengäs. 2005. Useful trees and shrubs for Kenya. World Agroforestry Centre-Eastern and Central Africa Regional Programme, Nairobi, Kenya.

Mehrabi, Z., E. C. Ellis, and N. Ramankutty. 2018. The challenge of feeding the world while conserving half the planet. Nature Sustainability 1:409–412.

Milligan, M. C. 2014. Quantifying pest control services by birds and ants in Kenyan coffee farms. Master's thesis, Humboldt State University, Arcata, California.

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. Conservation Biology 13:11–21.

Muchiri, M. N. 2004. Grevillea robusta in agroforestry systems in Kenya. Journal of Tropical Forest Science 16:396-401.

Murithi, C. W., C. K. Ong, J. Craigon, B. M. Mati, V. W. Ngumi, and C. R. Black. 2009. Gas exchange and water use efficiency of trees and maize in agroforestry systems in semi-arid Kenya.

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 201809259.

Narango, D. L., D. W. Tallamy, K. J. Snyder, and R. A. Rice. 2019. Canopy tree preference by insectivorous birds in shade-coffee farms: Implications for migratory bird conservation. Biotropica 51:387-398.

Negash, L. 1995. Native trees of Ethiopia: Biology, uses and propogation techniques. SLU Reprocentralen, Umea, Sweden.

Norton-Griffiths, M., and C. Southey. 1995. The opportunity costs of biodiversity conservation in Kenya. Ecological Economics 12:125-139.

Osorio, N. 2002. The global coffee crisis: a threat to sustainable development. International Coffee Organization, London. Johannesburg, South Africa.

Pendergast, M. 2010. Uncommon Grounds: The history of coffee and how it transformed our world. Revised edition. Basic Books, New York, New York.

Perfecto, I., and J. Vandermeer. 2010. The agroecological matrix as alternative to the land- sparing/agriculture intensification model. Proceedings of the National Academy of Sciences 107:5786–5791.

Perfecto, I., and J. Vandermeer. 2015. Coffee agroecology: A new approach to understanding agricultural biodiversity, ecosystem services and sustainable development. 1st edition. Routledge, Abingdon, United Kingdom.

Perfecto, I., J. Vandermeer, G. L. Bautista, G. Ibarra Nunñez, R. Greenberg, P. Bichier, and S. Langridge. 2004. Greater predation in shaded coffee farms: The role of resident Neotropical birds. Ecology 85:2677–2681.

Perfecto, I., J. Vandermeer, and S. M. Philpott. 2014. Complex ecological interactions in the coffee agroecosystem. Annual Review of Ecology, Evolution, and Systematics 45:137- 158.

Perfecto, I., J. Vandermeer, and A. Wright. 2009. Nature's Matrix: Linking Agriculture, Conservation and Food Sovereignty. 1st edition. Routledge, Abingdon, United Kingdom.

Petit, L. J., and D. R. Petit. 2003. Evaluating the importance of human-modified lands for neotropical bird conservation. Conservation Biology 17:687–694.

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.

Philpott, S. M., and P. Bichier. 2012. Effects of shade tree removal on birds in coffee agroecosystems in Chiapas, Mexico. Agriculture, Ecosystems & Environment 149:171-180.

Philpott, S. M., O. Soong, J. H. Lowenstein, A. L. Pulido, D. T. Lopez, D. F. Flynn, and F. DeClerck. 2009. Functional richness and ecosystem services: bird predation on arthropods in tropical agroecosystems. Ecological applications 19:1858–1867.

Pinard, F., E. Joetzjer, R. Kindt, and K. Kehlenbeck. 2014a. Are coffee agroforestry systems suitable for circa situm conservation of native trees? A case study from Central Kenya. Biodiversity and Conservation 23:467–495.

Pinard, F., J. M. Boffa, and E. Rwakagara. 2014b. Scattered shade trees improve low-input smallholder Arabica coffee productivity in the northern Lake Kivu region of Rwanda. Agroforestry Systems 88:707-718.

Pyke, G. H. 1984. Optimal foraging theory: A critical review. Ann. Rev. Ecol. Syst.

15:523-575.

Raman, T. R. S. 2006. Effects of habitat structure and adjacent habitats on birds in tropical rainforest fragments and shaded plantations in the Western Ghats, India. Biodiversity and Conservation 15:1577–1607.

Rahn, E., P. Vaast, P. Läderach, P. J. A. Van Asten, L. Jassogne, and J. Ghazoul. 2018. Exploring adaptation strategies of coffee production to climate change using a process- based model. Ecological Modelling 371:76-89.

Railsback, S. F. and M. D. Johnson. 2014. Effects of land use on bird populations and pest control service on coffee farms. Proceedings of the National Academy of Sciences 1320957111.

Romero-Alvarado, Y., L. Soto-Pinto, L. García-Barrios, and J. F. Barrera-Gaytán. 2000. Coffee yields and soil nutrients under the shades of *Inga* sp. vs. multiple species in Chiapas, Mexico. Agroforestry Systems 54:215-224.

Sage, R. D. 1982. Wet and dry-weight estimates of insects and spiders based on length. The American Midland Naturalist 108:407-411.

Schemske, D. W., G. G. Mittelbach, H. V. Cornell, J. M. Sobel, and K. Roy. 2009. Is there a latitudinal gradient in the importance of biotic interactions? Ann. Rev. Ecol. Syst. 40:245-269.

Schooler, S. L. 2019. Shade trees preserve avian insectivore biodiversity on coffee farms in a warming climate. Master's thesis, Humboldt State University, Arcata, California.

Sekercioglu, C. H., P. R. Ehrlich, G. C. Daily, D. Aygen, D. Goehring, and R. F. Sandi. 2002. Proc. Nat. Acad. Sci. 99:263-267.

SelecTree. 2020. "Grevillea robusta Tree Record." CalPoly SelecTree Database (1995-2020). <https://selectree.calpoly.edu/tree-detail/grevillea-robusta>. Accessed 31 July 2020.

Sherry, T.W., M. D. Johnson, K. A. Williams, J. D. Kaban, C. K. McAvoy, A. M. Hallauer, S. Rainey, and S. Xu. 2016. Dietary opportunism, resource partitioning, and consumption of coffee berry borers by five species of migratory wood warblers (Parulidae) wintering in Jamaican shade coffee plantations. *Journal of Field Ornithology*, *87*(3), pp.273-292.

Soto-Pinto, L., I. Perfecto, J. Castillo-Hernandez, and J. Caballero-Nieto. 2000. Shade effect on coffee production at the northern Tzeltal zone of the state of Chiapas, Mexico. Agriculture, Ecosystems and Environment 80:61-69.

Southwood, T. R. E., V. C. Moran, and C. E. J. Kennedy. 1982. The richness, abundance, and biomass of the arthropod communities on trees. Journal of Animal Ecology 51:635-649.

Smith, C. J., M. D. Johnson, B. R. Campos, and C. M. Bishop. 2012. Variation in aggression of Black-throated Blue Warblers wintering in Jamaica. Condor 114:831-839.

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.

Smith, C., M. C. Milligan, M. D. Johnson, and P. Njoroge. 2018. Bird community response to landscape and foliage arthropod variables in sun coffee of central Kenyan highlands. Global Ecology and Conservation 13:e00378.

Stevenson, T., and J. Fanshawe. 2002. The Birds of East Africa: Kenya, Tanzania, Uganda, Rwanda, Burundi. 1st edition. Princeton University Press, Princeton, New Jersey.

Tallamy, D. W. 2004. Do alien plants reduce insect biomass? Conservation Biology 18(6):1689-1692.

Teketay, D. 1999. History, botany and ecological requirements of coffee. Walia 20:28–50.

Teodoro, A., A.-M. Klein, and T. Tscharntke. 2008. Environmentally mediated coffee pest densities in relation to agroforestry management, using hierarchical partitioning analyses. Agriculture, Ecosystems & Environment 125:120-126.

Tilman, D., C. Balzer, J. Hill, and B. L. Befort. 2011. Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences 108:20260–20264.

Tingor, R. L. 2015. Colonrial Transformation of Kenya: The Kambu, Kikuyu, and Maasai from 1900-1939. Princton University Press, Princeton, New Jersey.

Van Bael, S. A., S. M. Philpott, R. Greenberg, P. Bichier, N. A. Barber, K. A. Mooney, and D. S. Gruner. 2008. Birds as predators in tropical agroforestry systems. Ecology 89:928–934.

Vandermeer, J., and I. Perfecto. 1997. The agroecosystem: a need for the conservation biologist's lens. Conservation Biology 11:591–592.

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.

Whelan, C. J. 2001. Foliage structure influences foraging of insectivorous forest birds: An experimental study. Ecology 82:219.

Whelan, C. J., D. F. Tomback, D. Kelly, and M. D. Johnson. 2016. Trophic interaction networks and ecosystem services. Page 368 *in*. Why Birds Matter: Avian Ecological Function and Ecosystem Services. University of Chicago Press, Chicago, Illinois.

World Bank. 2018. DataBank. <http://databank.worldbank.org/data/home.aspx>. Accessed 6 Sep 2018.

APPENDICES

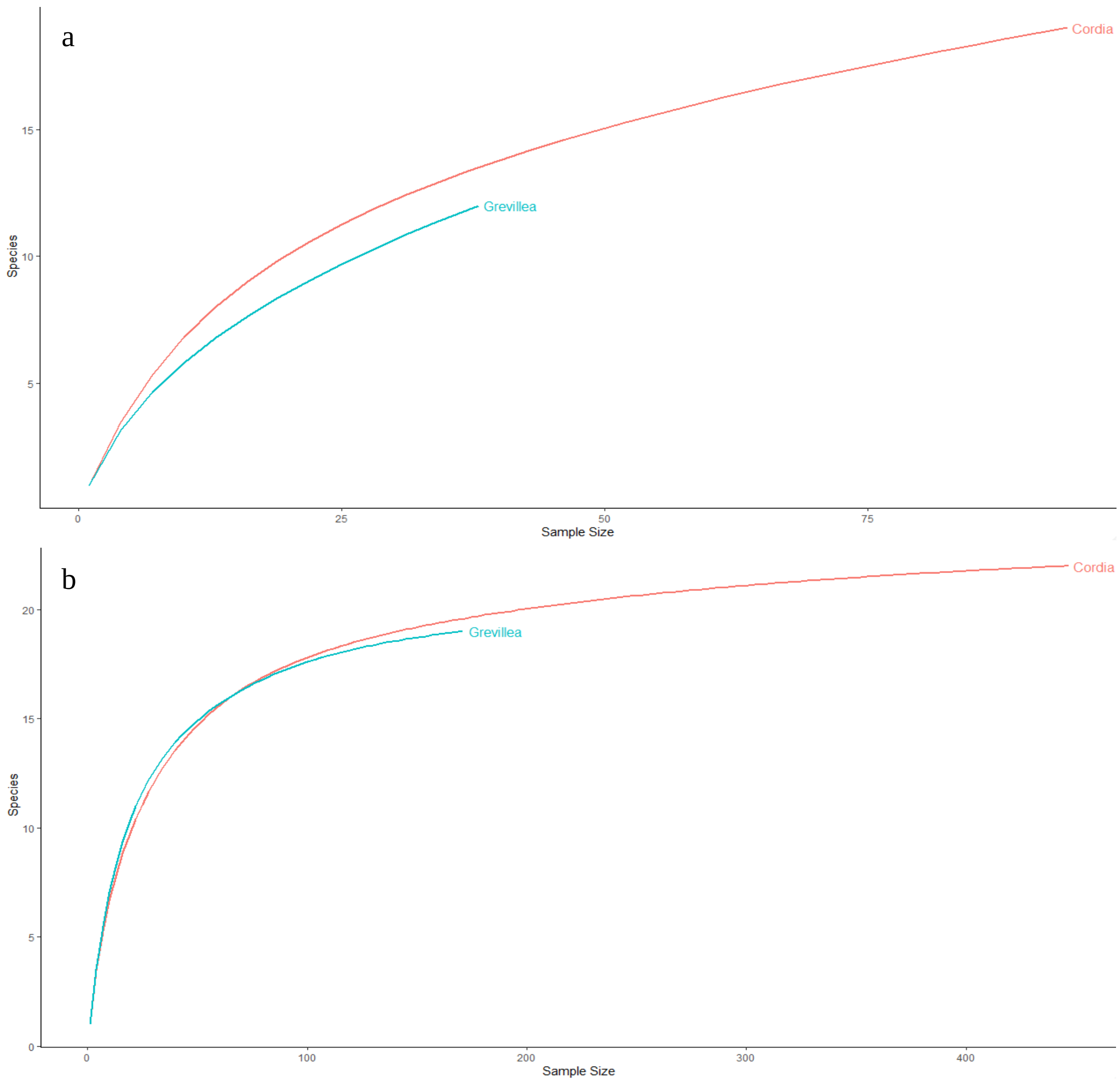
Appendix A. Detected abundances of all detected bird species for each vegetation level on coffee farms in Kiambu County, Kenya, winter 2018-2019. Birds were detected at the canopy level using 10-minute focal tree observations and at the understory level using mist nets.

Common Name	Latin Name	Vegetation Level			
		Canopy-Cordia	Understory-Cordia	Canopy-Grevillea	Understory-Grevillea
Dusky Turtle-Dove	*Streptopelia lugens*	1	0	0	0
Ring-necked Dove	*Streptopelia capicola*	0	0	2	0
Red-eyed Dove	*Streptopelia semitorquata*	0	0	1	0
African Green Pigeon	*Treron calvus*	1	0	0	0
Speckled Mousebird	*Colius striatus*	0	0	0	1
African Pygmy-Kingfisher	*Ispidina picta*	0	4	0	5
Cinnamon-chested Bee-Eater	*Merops oreobates*	2	0	2	0
Eurasian Bee-Eater	*Merops apiaster*	0	1	0	0
Yellow-rumped Tinkerbird	*Pogoniulus chrysoconus*	1	0	1	0
Spot-flanked Barbet	*Tricholaema lacrymosa*	0	1	0	0
Green-backed Honeyguide	*Prodotiscus zambesiae*	0	0	1	0
Cardinal Woodpecker	*Chloropicus fuscescens*	1	0	0	0
Brown-backed Woodpecker	*Chloropicus obsoletus*	0	1	0	0
Chinspot Batis	*Batis molitor*	6	4	7	2
African Paradise-Flycatcher	*Terpsiphone viridis*	6	8	6	10
Northern Fiscal	*Lanius humeralis*	0	1	0	0
White-bellied Tit	*Melaniparus albiventris*	2	8	0	4
Red-faced Crombec	*Sylvietta whytii*	1	9	2	7
Yellow-breasted Apalis	*Apalis flavida*	7	8	6	5
Wire-tailed Swallow	*Hirundo smithii*	0	0	0	1
Common Bulbul	*Pycnonotus barbatus*	30	37	49	21
Willow Warbler	*Phylloscopus trochilus*	43	7	4	7
Eurasian Blackcap	*Sylvia atricapilla*	6	7	2	6
Garden Warbler	*Sylvia borin*	1	1	0	1

Common Name	Latin Name		Vegetation	Level	
Pale White-Eye	*Zosterops flavilateralis*	18	4	21	1
Kikuyu White-Eye	*Zosterops kikuyuensis*	22	46	31	20
Abyssinian Thrush	*Turdus abyssinicus*	9	2	11	3
African Dusky Flycatcher	*Muscicapa adusta*	0	0	0	2
Pale Flycatcher	*Agricola pallidus*	13	4	2	2
White-eyed Slaty-Flycatcher	*Melaenornis fischeri*	5	2	0	5
Cape Robin-Chat	*Cossypha caffra*	11	14	1	8
Ruppell's Robin-Chat	*Cossypha semirufa*	0	0	0	3
Collared Sunbird	*Hedydipna collaris*	3	4	0	0
Green-headed Sunbird	*Cyanomitra verticalis*	1	1	1	0
Amethyst Sunbird	*Chalcomitra amethystina*	3	0	1	1
Scarlet-chested Sunbird	*Chalcomitra senegalensis*	5	1	3	9
Bronze Sunbird	*Nectarinia kilimensis*	31	21	9	14
Variable Sunbird	*Cinnyris venustus*	46	13	13	12
Baglafecht Weaver	*Ploceus baglafecht*	19	12	5	12
Spectacled Weaver	*Ploceus ocularis*	2	0	3	0
Speke's Weaver	*Ploceus spekei*	0	1	0	0
Village Weaver	*Ploceus cucullatus*	1	12	3	1
Yellow-bellied Waxbill	*Coccopygia quartinia*	0	2	0	2
Common Waxbill	*Estrilda astrild*	0	0	0	1
Red-cheeked Cordonbleu	*Cuculus solitarius*	5	7	1	8
Purple Grenadier	*Granatina ianthinogaster*	0	3	0	5
Red-billed Firefinch	*Lagonosticta senegala*	1	11	2	5
Bronzed Manakin	*Spermestes cucullata*	5	4	1	0
Village Indigobird	*Vidua chalybeata*	2	1	0	0
Kenya Rufous Sparrow	*Passer rufocinctus*	2	2	2	3
Western Yellow Wagtail	*Motacilla flava*	0	1	0	0
Tree Pipit	*Anthus trivialis*	10	10	2	11
African Citril	*Crithagra citrinelloides*	30	20	51	19
Reichenow's Seedeater	*Crithagra reichenowi*	17	1	5	0
White-bellied Canary	*Crithagra dorsostriata*	1	1	0	0

Common Name	Latin Name		Vegetation	Level	
Brimstone Canary	*Crithagra sulphurata*	4	3	5	0
Streaked Seedeater	*Crithagra striolata*	14	54	19	48
Golden-breasted Bunting	*Emberiza flaviventris*	6	7	1	5

Appendix B. Two pairs of curves generated from rarefying the foraging survey data. Plot (a) shows the rarefaction curves generated from trees which had full vegetation variables sampled (n = 146), while plot (b) shows the curves generated from the full sample of trees (n = 353). The curve flattened more thoroughly with the inclusion of all trees, suggesting an adequate survey effort.

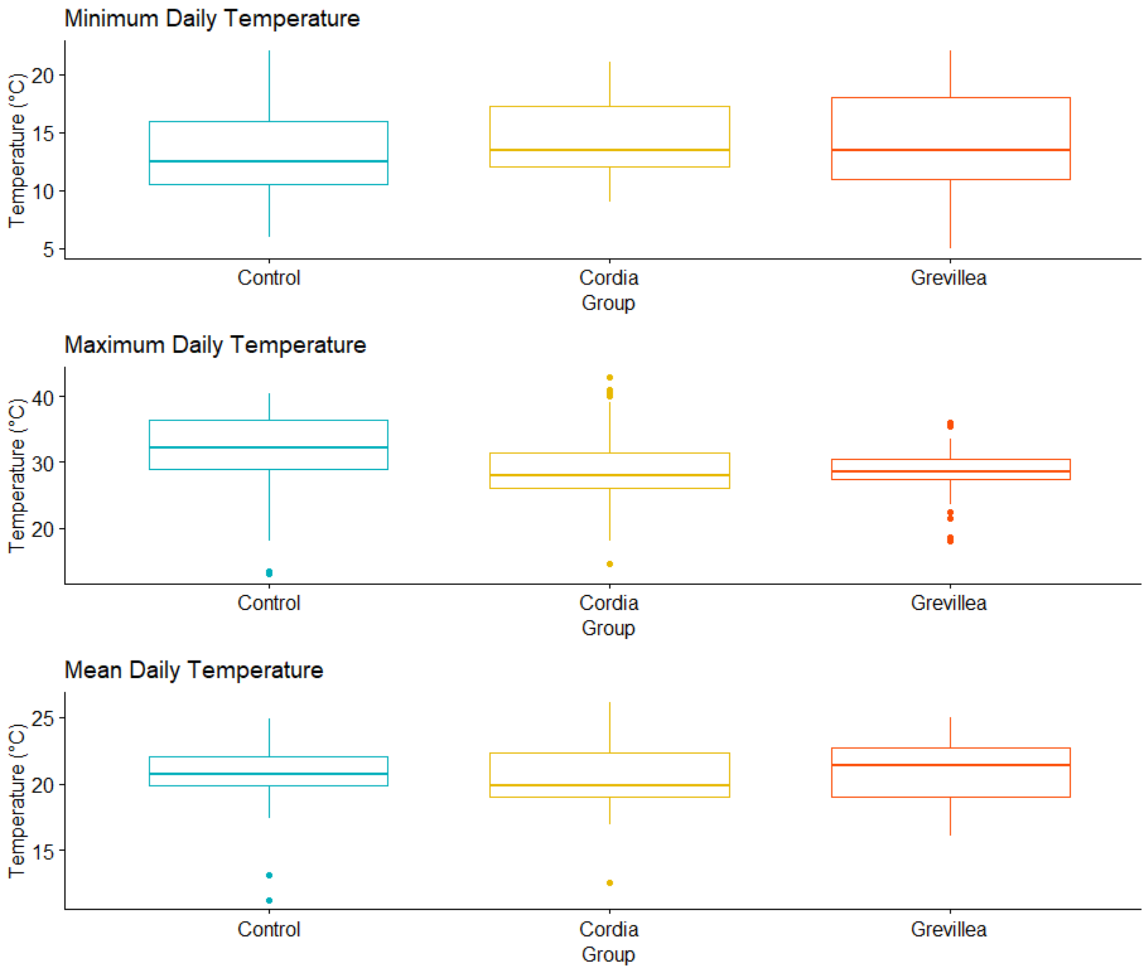


Appendix C. Tukey HSD results of temperature data (minimum, maximum, and mean daily temperatures) collected under Cordia and Grevillea trees, as well as an unshaded control, on coffee farms in Kiambu County, Kenya, winter 2018-2019.

Response Variable	**Group Comparison**	**Difference**	**95% CI LL**	**95% CI UL**	**P_{adj}**
Minimum Daily Temperature	Cordia-Control	1.264	0.310	2.218	0.005**
	Grevillea-Control	0.811	-0.217	1.840	0.153
	Grevillea-Cordia	-0.453	-1.483	0.576	0.555
Maximum Daily Temperature	Cordia-Control	-3.191	-4.299	-2.084	0.000**
	Grevillea-Control	-3.526	-4.721	-2.331	0.000**
	Grevillea-Cordia	-0.334	-1.530	0.861	0.788
Mean Daily Temperature	Cordia-Control	-0.283	-0.810	0.244	0.418
	Grevillea-Control	0.243	-0.326	0.812	0.574
	Grevillea-Cordia	0.526	-0.043	1.096	0.077

**Statistically significant ($p_{adj} < 0.05$)

Appendix D. Box plots of minimum, maximum, and mean daily temperatures of Cordia and Grevillea as well as an unshaded control, on coffee farms in Kiambu County, Kenya, winter 2018-2019.



Appendix E. AICc results of the competing general linear model set which included tree species, tree height, diameter at breast height (dbh), average coffee flower score, canopy cover, and understory cover as predictors to insectivorous bird species richness and abundance in the crop layer of coffee farms in Kiambu County, Kenya, winter 2018-19. Refer to Table 2-3 for column definitions.

Response Variable	Model	K[a]	$Log_e(L)$[b]	AIC_c[c]	Delta AIC_c[d]	Wi[e]
Richness	**Coffee Flower Score + Canopy Cover + (1|Site)**	**4**	**-253.93**	**516.13**	**0.00**	**0.29**
	Coffee Flower Score + Canopy Cover + Understory Cover + (1|Site)	5	-253.03	516.48	0.34	0.24
	dbh + Coffee Flower Score + Understory Cover + Understory Cover + (1|Site)	6	-252.28	517.16	1.02	0.17
	Coffee Flower Score + (1|Site)	3	-255.77	517.71	1.57	0.13
	Species + dbh + Coffee Flower Score + Canopy Cover + Understory Cover + (1|Site)	7	-251.57	517.94	1.81	0.12
	Species + Height + dbh + Coffee Flower Score + Canopy Cover + Understory Cover + (1|Site)	8	-251.47	519.98	3.84	0.04
	Canopy Cover + (1|Site)	3	-261.99	530.14	14.01	0.00
	1 + (1|Site)	2	-265.20	534.47	18.34	0.00
	Understory Cover + (1|Site)	3	-264.97	536.09	19.96	0.00
	Species + (1|Site)	3	-265.02	536.20	20.07	0.00
	dbh + (1|Site)	3	-265.03	536.22	20.09	0.00
	Height + (1|Site)	3	-265.06	536.28	20.15	0.00
Abundance	**Coffee Flower Score + Canopy Cover + Understory Cover + (1|Site)**	**5**	**-349.11**	**708.64**	**0.00**	**0.35**
	dbh + Coffee Flower Score + Canopy Cover + Understory Cover + (1|Site)	6	-348.09	708.79	0.15	0.68
	Height + dbh + Coffee Flower Score + Canopy Cover + Understory Cover + (1|Site)	7	-347.60	710.02	1.38	0.18
	Coffee Flower Score + Canopy Cover + (1|Site)	4	-351.61	711.50	2.86	0.94

Response Variable	**Model**	**K[a]**	**$Log_e(L)$[b]**	**AIC_c[c]**	**Delta AIC_c[d]**	**Wi[e]**
	Species + Height + dbh + Coffee Flower Score + Canopy Cover + Understory Cover + (1|Site)	8	-347.55	712.16	3.52	0.06
	Coffee Flower Score + (1|Site)	3	-357.84	712.84	13.20	0.00
	Canopy Cover + (1|Site)	3	-359.61	725.40	16.76	0.00
	Species + (1|Site)	3	-367.18	725.54	31.90	0.00
	1 + (1|Site)	2	-368.62	741.32	32.68	0.00
	Understory Cover + (1|Site)	3	-367.67	741.51	32.87	0.00
	Tree Height + (1|Site)	3	-368.07	742.31	33.67	0.00
	dbh + (1|Site)	3	-368.59	743.36	34.72	0.00

Appendix F. Results from top models for insectivorous bird species richness and abundance in the crop layer of coffee farms in Kiambu County, Kenya, winter 2018-2019.

Response	**Covariate**	**β**	**SE**	**CI (95%)**
Richness	Intercept	0.005	0.291	-0.581, 0.728
	Av. Coffee Flower Score	-0.899	0.241	-1.393, -0.440
	Canopy Cover	0.038	0.009	-0.0001, 0.0147
Abundance	Intercept	-0.249	0.318	-0.900, 0.871
	Av. Coffee Flower Score	-0.688	0.184	-1.061, -0.333
	Canopy Cover	0.013	0.003	0.006, 0.019
	Understory Cover	0.006	0.003	0.0008, 0.013