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## Original Research Article

## Bird community response to landscape and foliage arthropod variables in sun coffee of central Kenyan highlands

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## ABSTRACT

Land conversion represents a serious threat to terrestrial biodiversity and effective conservation in human-dominated landscapes requires an understanding of the relationship between spatial heterogeneity and biodiversity. Coffee is the most valuable tropical export in the world with the capacity to affect biodiversity on a large scale, and much of the world's coffee is grown in open plantations (sun coffee), where little research has documented how landscape structure or food availability affect bird diversity. We examined the effects of both landscape characteristics and foliage arthropod abundance on bird species richness, total bird abundance and the abundance of foraging guilds in sun coffee plantations of central Kenyan highlands. Variation in the local landscape appeared to have little effect on bird abundance, while the foliage arthropod community, particularly number of arthropod orders, may have a strong impact on omnivore and insectivore abundance in sun coffee. These results do not mean small scale fragments or landscape composition is unimportant to bird communities in our region for several reasons, including the high model uncertainty that may indicate an important missing variable, the habitat complexity and presence of large forest reserves around our study sites, and the single scale at which our variables were tested. Our results indicate that farm managers wanting to increase bird abundance, especially omnivores and insectivores, should consider balancing the need to eradicate coffee pests and leaving an intact arthropod community that likely increases these guilds. Further study is needed to validate these patterns, which may have strong implications for bird biodiversity in agricultural settings across other areas in eastern Africa.

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## 1. Introduction

Habitat loss from human land use and agricultural land conversion represent the greatest threats to terrestrial biodiversity (Seppelt et al., 2016). With global crop demand projected to increase 70% between 2005 and 2050 (Fao, 2009), meeting future agricultural demand will pose serious threats to natural habitat. Moreover, land conversion for agriculture will continue to fragment landscapes, which could have serious consequences for biodiversity. For conservation to work in human-dominated landscapes, it will be especially important to understand the relationship between spatial heterogeneity and biodiversity (Chao et al., 2005; Tscharrntke et al., 2005; Fahrig et al., 2011).

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Coffee can influence biodiversity on a large scale, as it is the most valuable tropical export crop in the world, cultivated on 10 million acres worldwide (FAO, 2012) with a value of approximately US \$90 billion (Jaramillo et al., 2011). The majority of coffee is still grown on smallholder farms (Jha et al., 2014) in areas of tropical forest, and thus is often found in highly fragmented landscapes with high biodiversity. Coffee can also be grown under a variety of different management practices at the scale of both individual farms and landscapes, making it an ideal agricultural system in which to examine the effects of the surrounding landscape on biodiversity. Over the past twenty years, coffee has received enormous attention as a crop that can potentially integrate human livelihood with biodiversity conservation (Jha et al., 2014).

One way to integrate crop production with conservation is through managing habitat to foster ecosystem services provided by biodiversity (Swift et al., 2004, Millennium Ecosystem Assessment, 2005). Birds have gained attention as important providers of ecosystem services (Wenny et al., 2011; Şekerçioğlu et al., 2016), and strong evidence suggests that bird community characteristics, such as diversity and composition, affect the provisioning of services such as pest control (Perfecto et al., 2004; Van Bael et al., 2008; Philpott et al., 2009). While much emphasis has been placed on birds in shade coffee, less work has focused on the bird community in sun coffee farms, and on how this community may be affected by local and landscape resources (Komar 2006).

As mobile organisms, birds may deliver ecosystem services locally, but their behavior and population dynamics are often affected by the spatial distribution of resources at multiple scales (Kremen et al., 2007). To better understand how a coffee farm can support birds foraging in the crop layer, it is vital to understand the influence of local resources such as proximity to natural habitats, local vegetation, and local food supply at multiple scales. Previous research has found that both the surrounding landscape (Karp et al., 2013; Railsback and Johnson, 2014; Milligan et al., 2016) and local vegetation (Perfecto et al., 2004; Johnson et al., 2010; Milligan et al., 2016) can have a strong influence on the provisioning of ecosystem services such as pest control. Control of insect pests by birds can also be greatly affected by local food supply of non-pest insects, particularly when insect pest populations are too variable in time or space to support predator populations by themselves (Railsback and Johnson, 2014), and few studies in coffee have examined the connection between the bird community and local food resources at a fine scale (Johnson, 2000a; Komar 2006; Smith et al., 2012; Sherry et al., 2016). In this study, we examined the effects of (1) landscape characteristics and (2) foliage arthropod abundance on insect-eating bird (insectivore and omnivore) abundance in structurally similar coffee farms in central Kenya. While the conservation value of coffee has been much studied worldwide, little research has been conducted in Africa, where coffee originated. Despite the fact that Africa accounts for roughly 20% of land dedicated to global coffee production (FAO, 2012), only a handful of studies have examined bird communities or pest removal in the region's coffee farms (De Beenhouwer et al., 2013; Classen et al., 2014; Buechley et al., 2015; Smith et al., 2015; Milligan et al., 2016).

## 2. Methods

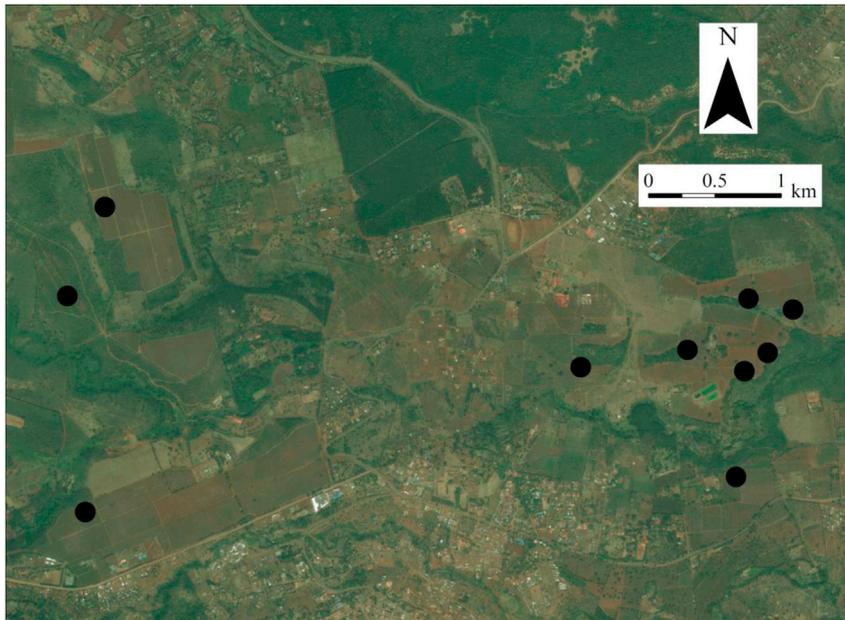
### 2.1. Study location

We conducted this study in Nyeri County, located in the agriculturally productive highlands of central Kenya. The surrounding landscape has seen a 30–60% increase in agricultural area between 1975 and 2000 (Brink and Eva, 2009). Coffee is a major crop grown on both large plantations and small-scale farms situated within a larger non-coffee habitat matrix. Sun coffee (coffee with almost no canopy cover; Moguel and Toledo, 1999) is the predominant cultivation type and farming practices include spraying fungicide (one or two times per year) and spot spraying bushes or blocks of coffee with insecticides when pest infestations occur.

Field work took place in the dry season during a 4 week period in December 2012 and January 2013 and a 6 week period in December 2013 and January 2014. We monitored 10 sites spread over three different farms ( $n = 4$  in 2012–13,  $n = 6$  in 2013–14): Dedan Kimathi University of Technology (DKUT) Farm (120 ha), Jungle Estate (51 ha), and Hill Estate (334 ha) (Fig. 1). A site consisted of two transects of mist nets (Fig. 2) and all sites were a minimum of 250 m apart to preserve independence. Coffee farms in this area of Kenya can be large (e.g., >100 ha), so each farm contained multiple sites. All sites within a single farm were located within different coffee blocks, which were discrete areas within a larger farm separated from other blocks by roads and/or hedgerows and usually managed differently from neighbouring blocks.

### 2.2. Bird variables

To quantify the bird community relevant to farmers, we used mist nets to sample birds using the crop layer, where they have the potential to provide pest removal services (IACUC Protocol #13/14.W.39-A). We did not use point counts because they often miss secretive, quiet birds that may be less visible in thick coffee agriculture (Wang and Finch, 2002; Dunn and Ralph, 2004; Blake and Loiselle, 2009). Each site was sampled for three consecutive days, roughly from 6:00–10:00, depending on weather. We identified captured birds to species (taxonomy based on Checklist of the Birds of Kenya, 4th edition, 2009, EANHS), and age or sex if possible, fitted each with a metal leg band supplied by the National Museums of Kenya, and recorded basic morphometrics. Each site contained two transects of mist nets a minimum of 100 m apart. Each transect consisted of six mist nets placed at 0 m, 10 m, 25 m, 50 m, 75 m and 100 m from a forest fragment edge (Fig. 2). Total abundance over the 3 days was used to quantify the overall bird community and estimate total species richness.



**Fig. 1.** Map of 10 sun coffee study sites around the town of Nyeri, Kenya, showing patchwork of fragments, urbanization, and coffee plantations.

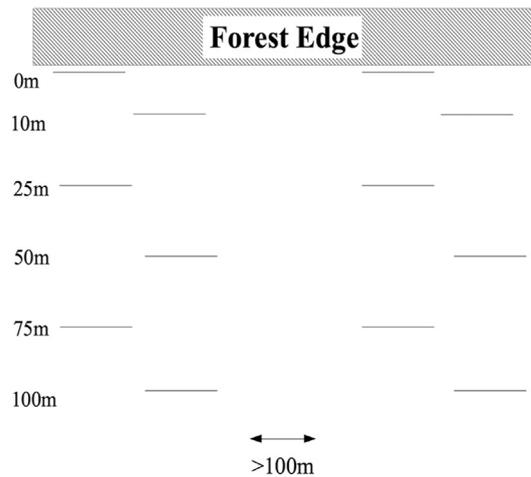
To investigate if feeding guilds responded differently to landscape characteristics, we classified each species into a single dietary guild (i.e., insectivore, granivore, frugivore, nectarivore, or omnivore) based on the first and second major diet preferences following [Kissling et al. \(2007\)](#). We then re-classified 12 species (mostly Sunbirds: Nectariniidae) to either nectarivores or omnivores based on foraging observations by S. MacDonald and published data from East Africa ([Borghesio and Laiolo, 2004](#); [Ndang'ang'a et al., 2013](#)). Because only two frugivore species and three nectarivore species were caught, totalling 20 and 23 individuals respectively, we did not specifically analyse these guilds for community patterns, but included them in analyses of total abundance.

### 2.3. Vegetation variables

To measure local vegetation characteristics, we sampled the coffee and shade tree vegetation in a 5 m radius plot around each mist net. For the coffee layer, we estimated percent coffee (the proportion of the sample plot covered by coffee bushes), and percent cover and height of the weedy understory (height <1.5 m) and midstory (height 1.5–5 m). Volume of midstory and understory were calculated for each net by multiplying their average height by area covered within the plot. Although our study was conducted on sun coffee plantations, all plots abutted fragments and several plantations had a few scattered shade trees, which could exert a proportionally large influence on how birds used the farm. We therefore included measurements of these shade trees to account for this potential variation. Measurements of shade trees included canopy cover (measured using a densiometer), an estimate of shade tree density using point-quarter methods ([Krebs, 1989](#)), and distance to nearest tree (measured using a rangefinder) in each quadrant, along with its total height, average canopy depth (measured from top of the tree to the first large patch of canopy nearest the ground), and average trunk height (total height minus canopy depth). A tree was defined as a woody, non-coffee plant greater than 5 m tall. Because our study sites did not include shade coffee, we did not make any conclusions about the importance of vegetation variables and included them only to account for variation between sites; i.e., we modelled effects of landscape and arthropod variables after first accounting for local vegetation effects (see analysis below). For detail effects of local vegetation on bird communities in both sun and shade coffee, see [Smith et al. \(2015\)](#).

### 2.4. Landscape variables

Adjacent forest fragments differed in both size and quality, but all consisted of secondary growth with a mixture of native and non-native trees. To investigate if the size of conterminous forest affects the bird community, we digitized the adjacent forest fragments using imagery in GoogleEarth by identifying all contiguous areas dominated by trees. We then imported shapefiles into ArcMap 10.1 to estimate the area of each adjacent fragment. Our experimental design also allowed us to test the effect of distance from fragment edge on the bird community, with nets abutting fragments and regularly spaced at intervals out to 100 m into the coffee. To examine differences in the larger non-coffee habitat matrix, we further calculated the proportion of different landcover types within a 125 m buffer around each site. A radius of 125 m was used because it



**Fig. 2.** Arrangement of mist nets in sun coffee, with two lanes per site separated by 100 m and abutting forest fragment edges. Nets were offset from the center line to capture birds in different flight paths over short distances.

represents a larger scale habitat perspective and includes multiple home ranges of small passerines or flocks (see [Siffczyk et al., 2003](#), [Kumstátová et al., 2004](#), [Githiru, 2003](#) for examples of species caught in our study). We digitized landcover layers in GoogleEarth based on the colour and texture of satellite images and personal field observations. The resulting layers were divided into the following landcover types: brush, trees, grassland, coffee, water, and other. We calculated the percentage of each landcover type within a 125 m buffer in Program R (Version 3.0.1) using the rgeos package. Percent grassland, water, and “other” categories were not used in analysis because these categories comprised <5% of total cover on almost all plots. Collectively, landscape-scale predictor variables tested included size of and distance to nearest fragment, and proportion of coffee, brush, or trees within a 125 m radius buffer.

### 2.5. Arthropod variables

In order to estimate local food resources, we took 2–3 samples of the arthropod community at each net location, done in the afternoon following mist-netting at the site. Following the methods described by [Johnson \(2000b\)](#) we surveyed the arthropod community at each net by quickly bagging a ~.5 m long branch sample from a coffee plant, clipping the branch, shaking it within the bag to dislodge insects, then examining insects within the bag and branch. We identified arthropods to order in the field and recorded the number and length of individuals in each order. Predictor variables included arthropod abundance, average size, and order number at a given net. Arthropod data from five nets were lost, so the mean of the other nets ( $n = 67$ ) were used to allow for statistical comparisons ([Nakagawa and Freckleton, 2011](#)). Due to time constraints, we were unable to use pitfall traps to analyse the ground-level insect community, meaning we restrict our findings to “foliage arthropods” (arthropods present on vegetation, discluding those found at ground level). However, in a simultaneous foraging study, only 22% of 176 total observation of insectivores were ground-sampled, and only 3 of the 35 insectivore species frequently were observed foraging on the ground, suggesting ground-foraging insectivores made up a relatively small proportion of our data (unpublished data, S. MacDonald).

### 2.6. Model development and selection

This study included two similar analyses that addressed separate but related questions examining the underlying influences on bird communities in Kenyan coffee farms. Arthropod variables were only measured during the 2013–14 field season. Therefore, a landscape variable analysis was conducted using both years of data (2012–2013 and 2013–2014), and a similar analysis was performed only with data from 2013 to 14 that included both landscape and arthropod variables. We quantified the bird community at the level of an individual net and captures for each net were summed over the three days. We used raw capture data because capture probability was impractical to calculate per net due to small sample sizes and high variability at the level of individual nets. Additionally, our raw capture data was shown to have a relatively high correlation coefficient ( $r = 0.55$ ) with predicted abundances at the site scale when incorporating capture probability ([Smith et al., 2015](#)). In the first analysis, response variables describing the bird community included species richness, total abundance and the abundance of the three major guilds (omnivores, granivores, and insectivores), while in the arthropod analysis, only total bird abundance relevant to arthropods (omnivores plus insectivores) and the abundance of insectivores were examined.

To determine the relative influence of different variables on bird abundance, we used generalized linear mixed models with a Poisson response variable in the lme4 package in Program R (Version 3.4.1). Site and transect were included as nested

random effects to account for any differences between sites that were not measured. Net hours were not included as a random effect because total net hours varied little from the mean of 11.8 per net (95% CI: 11.68–11.93). In addition to random effects, all models included a variable (1|Unit) to estimate overdispersion (Kéry, 2010). All variables that were collinear, as determined based on variance inflation factors (VIFs) greater than 10, were not included in the same model (Hair et al., 1998). We used hierarchical model selection to examine the influence of the surrounding landscape and arthropod community on bird communities after first controlling for local vegetation characteristics. For each analysis, we first built a top vegetation model to which we then added arthropod and landscape variables to build a set of candidate models that were compared using Akaike's Information Criterion corrected for small sample size (AICc). To build a top vegetation model, we compared AICc of models with a single variable, and included in subsequent analyses either all variables for which the cumulative weight of the individual models reached at least 70% or excluded variables that had a large drop in model weight compared to the top model. Once we chose a top model including only vegetation variables, we then added landscape variables or both landscape and arthropod variables, depending on the analysis. We model averaged final model sets to yield coefficient estimates and then assessed model fit by computing both marginal (fixed effect) and conditional (fixed plus random effects)  $R^2$  values following the method outlined by Nakagawa and Schielzeth (2013), using package MuMIn. Variables were considered important if their model-averaged 95% confidence intervals did not overlap zero.

### 3. Results

A total of 1284 birds of 77 species were captured over 1416 net hours over both field seasons. An average of 10.70 birds and 5.80 species were caught per individual net. Guild sample sizes for the landscape variable analysis included 198 insectivores, 656 omnivores, 390 granivores, 23 frugivores, and 20 nectarivores (15%, 51%, 30%, 2%, and 2% of total, respectively). Sample sizes for the year that included arthropod analyses (2013–2014 only) were 679 total birds and 127 insectivores (19% of total).

#### 3.1. Effects of landscape on bird communities

The surrounding landscape had little effect on total bird abundance, species richness, or the abundance of either omnivores or insectivores in sun coffee (Table 1). For these four response variables, none of the landscape variables improved the AICc over the local vegetation model. However, model weights were rather evenly spread over the top three models, which included proportion brush and either fragment size or distance, depending on the response variable. When slope coefficients were model-averaged, no variables were considered important, with all 95% confidence intervals overlapping zero. Marginal and conditional  $R^2$  values for top models suggested that while the model fit the data reasonably well, there remained substantial variation unexplained by the variables in the top model (Table 2).

In contrast to other measures of the bird community, granivore abundance was influenced by landcover variables which improved model fit compared to the vegetation-only model. The top model ( $\Delta AICc = 0$ , model weight = 0.39) predicting granivore abundance included vegetation variables and adjacent fragment size, which was negatively correlated with abundance (Table 1). When coefficients were model-averaged, only adjacent fragment size was important. However, model fit was similar to other analyses, suggesting that substantial variation remained unexplained by the variables in the top model (Table 2).

#### 3.2. Effects of both landscape and arthropod variables on bird communities

Our results suggest that the arthropod community likely has an influence on the larger insect-eating bird community (omnivores plus insectivores) in sun coffee. In this analysis, arthropod order richness and proportion brush were in the top two models, receiving 68% of model weight (Table 3). When coefficients were model-averaged, both arthropod order richness and proportion brush were important, with 95% confidence intervals not overlapping zero. The marginal  $R^2$  for the top model was the highest of all analyses, suggesting this predictor variable yielded the best model fit.

In the analysis predicting insectivore abundance, arthropod community variables were in the top two models, accounting for 60% of model weight (Table 4). The single strongest model ( $\Delta AICc = 0$ , model weight = 0.39) included vegetation variables and arthropod size. When coefficients were model-averaged, important variables included arthropod length and number of order, both of which were positively correlated with abundance. The marginal  $R^2$  for the top model was higher than any from the landscape-scale analyses (Table 2), suggesting this predictor variable explained more variation than those in the landscape analyses.

### 4. Discussion

Variation in the local landscape appears to have little effect on bird abundance in Kenyan sun coffee farms. Factors such as the size of or distance to an adjacent forest fragment and the surrounding landcover types were not strong predictors of total bird and individual guild abundances, with the exception of a small negative effect of adjacent fragment size on granivore abundance. In contrast, the single-season arthropod analysis suggested the arthropod community, especially number of orders, may have a stronger impact on the larger bird community that eats insects (insectivore and omnivore abundance).

**Table 1**

AICc model selection table for abundance, species richness, and abundance of granivores, omnivores, and insectivores in sun coffee farms in Kenya. "Veg" represents the most parsimonious local vegetation variables to which we added the 5 landscape-scale variables. Only adjacent fragment size for granivore abundance was important, with model averaged 95% confidence intervals not overlapping 0.

Abundance Model	K	AICc	$\Delta$ AICc	$w_i$	Cum.Wt	LL
Veg	5	770.94	0	0.29	0.29	-380.2
Veg + Prop_brush	6	771.56	0.63	0.21	0.51	-379.41
Veg + Fragment_size	6	772.04	1.11	0.17	0.68	-379.65
Veg + Prop_coffee	6	772.6	1.67	0.13	0.8	-379.93
Veg + Prop_trees	6	773.12	2.19	0.1	0.9	-380.19
Veg + Distance	6	773.15	2.21	0.1	1	-380.2
<sup>a</sup> Veg = Canopy Height						
Species Richness Model	K	AICc	$\Delta$ AICc	$w_i$	Cum.Wt	LL
Veg	5	608.24	0	0.26	0.26	-298.86
Veg + Prop_brush	6	608.64	0.4	0.21	0.47	-297.95
Veg + Fragment_size	6	608.9	0.66	0.18	0.65	-298.08
Veg + Prop_coffee	6	609.56	1.32	0.13	0.78	-298.41
Veg + Distance	6	609.65	1.41	0.13	0.91	-298.45
Veg + Prop_trees	6	610.38	2.14	0.09	1	-298.82
<sup>a</sup> Veg = Canopy Height						
Granivore Model	K	AICc	$\Delta$ AICc	$w_i$	Cum.Wt	LL
Veg + Fragment_size	8	509.72	0	0.38	0.38	-246.21
Veg + Distance	8	510.77	1.05	0.22	0.6	-246.74
Veg	7	511.92	2.2	0.13	0.73	-248.46
Veg + Prop_coffee	8	512.02	2.3	0.12	0.85	-247.36
Veg + Prop_brush	8	512.43	2.71	0.1	0.95	-247.57
Veg + Prop_trees	8	513.6	3.88	0.05	1	-248.15
<sup>a</sup> Veg = Canopy Cover, Percent Coffee, Canopy Height						
Omnivore Model	K	AICc	$\Delta$ AICc	$w_i$	Cum.Wt	LL
Veg	5	643.19	0	0.32	0.32	-316.33
Veg + Prop_brush	6	643.76	0.57	0.24	0.55	-315.51
Veg + Distance	6	645.12	1.92	0.12	0.67	-316.19
Veg + Prop_coffee	6	645.28	2.09	0.11	0.78	-316.27
Veg + Prop_trees	6	645.33	2.14	0.11	0.89	-316.29
Veg + Fragment_size	6	645.34	2.15	0.11	1	-316.3
<sup>a</sup> Veg = Canopy Height						
Insectivore Model	K	AICc	$\Delta$ AICc	$w_i$	Cum.Wt	LL
Veg	4	421.23	0	0.3	0.3	-206.44
Veg + Fragment_size	5	421.93	0.7	0.21	0.52	-205.7
Veg + Prop_brush	5	422.42	1.19	0.17	0.68	-205.94
Veg + Prop_coffee	5	423.19	1.96	0.11	0.8	-206.33
Veg + Distance	5	423.39	2.17	0.1	0.9	-206.43
Veg + Prop_trees	5	423.41	2.18	0.1	1	-206.44
<sup>a</sup> Veg = Percent Coffee						

**Table 2**

The marginal and conditional  $R^2$  values for the top models using landscape or arthropod plus landscape variables to explain bird communities in sun coffee in Kenya. Marginal  $R^2$  indicate amount of variation explained by fixed effects, and conditional  $R^2$  the fixed plus random effects.

	Marginal R2	Conditional R2
Landscape Analysis		
Total Abundance	0.05	0.63
Species Richness	0.04	0.63
Granivore Abundance	0.03	0.57
Omnivore Abundance	0.06	0.50
Insectivore Abundance	0.03	0.30
Arthropod and Landscape Analysis		
Abundance	0.12	0.49
Insectivore Abundance	0.07	0.35

**Table 3**

Support for the final set of models predicting abundance of omnivores and insectivores in the arthropod analysis. Vegetation variables include: midstory volume, percent canopy cover and tree height.

Model	K	AICc	$\Delta$ AICc	$w_i$	Cum.Wt	LL
Veg + Arth_orders	8	420.04	0	0.47	0.47	-200.88
Veg + Prop_brush	8	420.81	0.77	0.32	0.78	-201.26
Veg	7	424.56	4.52	0.05	0.83	-204.4
Veg + Prop_grass	8	425.15	5.11	0.04	0.87	-203.43
Veg + Arth_length	8	425.27	5.23	0.03	0.9	-203.49
Veg + Arth_numbers	8	426.03	5.99	0.02	0.93	-203.87
Veg + Prop_coffee	8	426.13	6.09	0.02	0.95	-203.92
Veg + Prop_tree	8	426.33	6.29	0.02	0.97	-204.02
Veg + Distance	8	426.5	6.46	0.02	0.99	-204.11
Veg + Fragment_size	8	427.07	7.03	0.01	1	-204.39

**Table 4**

Support for the final set of models predicting insectivore abundance in the arthropod analysis. Vegetation variables include: tree density, tree height and volume of understory vegetation.

Model	K	AICc	$\Delta$ AICc	$w_i$	Cum.Wt	LL
Veg + Arth_length	7	265.93	0	0.39	0.39	-125.09
Veg + Arth_orders	7	267.21	1.28	0.21	0.6	-125.73
Veg	6	268.89	2.95	0.09	0.69	-127.8
Veg + Prop_brush	7	269.12	3.19	0.08	0.77	-126.69
Veg + Distance	7	269.9	3.97	0.05	0.82	-127.08
Veg + Arth_numbers	7	270.03	4.1	0.05	0.87	-127.14
Veg + Prop_coffee	7	270.57	4.63	0.04	0.91	-127.41
Veg + Fragment_size	7	271.06	5.13	0.03	0.94	-127.65
Veg + Prop_grass	7	271.12	5.19	0.03	0.97	-127.68
Veg + Prop_tree	7	271.18	5.25	0.03	1	-127.72

However, due to small sample size, further study should be conducted to tease apart the bottom-up effects of arthropod availability from the effects of the surrounding landscape on bird communities.

Although landscape-scale variation had little effect on bird abundance or species richness in sun coffee in our study, our findings should not be construed to suggest that the retention of small forest fragments and other non-coffee habitat within large sun coffee farms is not beneficial to birds. Similar to our results, a previous study in East Africa found no effect of distance from forest fragments on guild diversity (Otieno et al., 2011). However, these results diverge from other studies showing landscape-scale factors, such as whether sites were adjacent to large fragments and their proximity to be the most important variables explaining bird species richness or abundance in India (Raman, 2006; Anand et al., 2008). Due to the nature of our study sites, distance from fragments was only considered to 100 m and surrounding landcover types to 125 m. The high model uncertainty in our landscape-scale analyses may suggest an important variable is missing from models, including these same variables on a larger scales. A site-level vegetation analysis of our study system (Smith et al., 2015) found understory volume and canopy cover were extremely important in predicting bird abundance. Additionally, larger scale factors such as the moderate size of plantations (all <200 m across), plantations being highly interspersed with forests or grasslands, and all sites being within 10 km of Aberdares National Park (a large old growth forest) may be important. The complex configuration of fragments and farms in our study area may support relatively high abundances of more species than a simpler landscape configuration (Seppelt et al., 2016), meaning that non-coffee habitat could still be important for bird communities. Future studies should examine landscape composition and configuration on a larger scale to evaluate additional effects of the habitat matrix on bird communities.

The composition of the bird community is likely part of the reason we did not detect a change in community from forest edges into coffee plantations. In our study, the bird community in sun coffee had a high proportion of granivores and agriculture-generalists, which could have masked other specialist groups, such as edge species, that may use the landscape more selectively. The paucity of nectarivores and frugivores (<45 captures total), is noteworthy and is perhaps related to lack of many fruit and nectar resources on sun coffee farms; few birds eat coffee fruits, and coffee flowers are insect pollinated (Raw and Free, 1977). However, the relative lack of individual frugivores and nectarivores is partly related to their narrow classification by Kissling et al. (2007; only 2 and 3 of our 70 captured species, respectively) whose omnivore guild included many species that commonly consume fruits and/or nectar. The minimal effect of adjacent fragments might also be explained by the few forest-generalist species using the coffee. Smith et al. (2015) found that 40% of birds in sun coffee were forest visitors, while only 1.5% were forest specialists.

While our results are preliminary, the local arthropod community appears to have an influence on birds that consume insects in Kenyan sun coffee, which could reflect important bottom-up influences on bird abundance. The number of arthropod orders was an important predictor of insectivore and omnivores, and insectivores alone. This could suggest that diversity is more important than overall abundance and reflect the generalist nature of the insect-eating bird community in

Kenyan sun coffee. Insecticides that suppress general insect abundance and order richness likely reduce the number of total insect-eating birds and insectivores feeding within coffee, producing a trade-off where more insecticides mean fewer pests but also fewer pest-eating birds.

In conclusion, our results suggest that the retention of small forest fragments and other non-coffee habitat within large sun coffee farms had little influence on the bird community. However, these results should be treated tenuously, as our high model uncertainty suggests an important variable may be missing, such as these same variables at larger scales. Additionally, these same small fragments can hold value in other ways, such as pest predation, which is often higher adjacent to fragments (Pywell et al., 2015; Gras et al., 2016; Milligan et al., 2016). Our results further suggest that foliage arthropods may help predict the insect-eating bird community abundance, especially insectivores; farm managers attempting to increase bird numbers should contemplate balancing the needs for destroying coffee pests with retaining healthy non-pest arthropod populations, for example, by avoiding blanket pesticide spraying and using spot-spraying of concentrated outbreaks. As only a small percentage of land in East Africa is protected in parks (Western et al., 2009; Norton-Griffiths and Said, 2010), bird and biodiversity conservation at large in this region must involve agricultural landscapes. As crop demand globally is expected to rise 70% in the next 45 years (Fao, 2009), further studies of landscape designs and other factors, like food sources, that allow bird populations to persist around agriculture are urgently needed.

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