Importance of Ethiopian shade coffee farms for forest bird conservation

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Abstract

Coffee is the most important tropical commodity and is grown in high-priority areas for biological conservation. There is abundant literature on the conservation value of coffee farms internationally, but there has been little research on this topic in Africa. Ethiopia is a diverse and little-studied country with high levels of avian endemism, pressing conservation challenges, and where *Coffea arabica* originated. We sampled bird communities in shade coffee farms and moist evergreen Afromontane forest in Ethiopia utilizing standard mist netting procedures at seven sites over three years to evaluate bird species richness, diversity and community structure. Although species diversity did not differ between shade coffee and forest, shade coffee farms had over double the species richness of forest sites and all but one of the nine Palearctic migratory species were captured only in shade coffee. There was a greater relative abundance of forest specialists and understory insectivores in forest, demonstrating that little-disturbed forest is critical for sustaining these at-risk groups of birds. Nonetheless, all species recorded in primary forest control sites were also recorded in shade coffee, indicating that Ethiopian shade coffee is perhaps the most “bird-friendly” coffee in the world. This is an important finding for efforts to conserve forest birds in Africa, and for shade coffee farmers that may benefit from avian pest regulation and biodiversity-friendly coffee certifications.

Keywords: understory insectivore, coffee, agroforest, biodiversity hotspot, ecosystem services, forest specialist, climate change, tropical ecology, ornithology

1 Introduction

1.1 Tropical Forest Declines and Implications for Bird Populations

Increasing human populations and corresponding land use changes are driving a global extinction crisis (Brashares et al., 2001; Pimm et al., 2006; Vitousek et al., 1997). Tropical forests are the most species-rich terrestrial ecosystem on Earth, supporting up to 70% of plant and animal species, and are being lost at an alarming rate (Dirzo and Raven, 2003; Donald, 2004; Laurance and Bierregaard, 1997; Sodhi et al., 2004). In the last decade, approximately 13 million hectares of forest were cut down each year, with most of the losses occurring in the tropics (UNFAO, 2010). Tropical deforestation represents the single greatest threat to global biodiversity (Donald, 2004): it results in rapid transformations in plant and animal communities, which drastically alters ecological processes and impacts human societies (Clough et al., 2009a; Tilman et al., 2001).

Numerous studies attribute forest bird declines to deforestation and the conversion of tropical forests to agricultural habitats, particularly in forest archipelagos in agricultural landscapes (Bregman et al., 2014; Newmark, 1991; Şekercioğlu, 2012a; Sigel et al., 2006; Sodhi et al., 2011; Stratford and Stouffer, 1999). Currently, 23% of bird species are globally threatened or near threatened with extinction (BirdLife International, 2014), with the vast majority of threatened species inhabiting tropical forests (BirdLife International, 2014; Brooks et al., 1999; Lees and Peres, 2006; Sodhi et al., 2004; Turner, 1996).

Understanding the ecological drivers underlying avian distributions is critical to evaluate the overall ecological integrity of ecosystems because birds are highly specialized, occupy a variety of ecological niches, have key ecological functions, and are variably susceptible to disturbance (Komar, 2006; Şekercioğlu, 2006a, 2006b; Anjos et al. **This Issue;** Pollock et al. **This Issue;** Pavlacky et al. **This Issue**). Bird extinction risk increases with ecological specialization (Şekercioğlu, 2011). Shifts in bird relative abundance and/or local extinctions are likely to affect ecological processes, including seed dispersal, pollination, nutrient cycling, and even soil formation (Chapin et al., 1998; Heine and Speir, 1989; Lens et al., 2002; Şekercioğlu et al., in press).

Forest understory insectivores are especially sensitive to forest fragmentation and disturbance, and are thus among the most threatened bird species in the world (Tobias et al., 2013). They have relatively high habitat specificity, dependence on forest interior habitats, and limited mobility (Lens et al., 2002; Şekercioğlu et al., 2002; Tobias et al., 2013). Evaluating where and why they are declining is a conservation priority in the tropics (Tobias et al., 2013).

1.2 Agroforests as Bird Habitat

Preserving biodiversity in habitats that are impacted by human activities is important because (i) these habitats make up an increasingly large portion of the globe (Norris, 2008) and (ii) about one third of world's ~10,000 bird species have been recorded in human-dominated and mostly agricultural habitats (Şekercioğlu et al., 2007). Agriculture accounts for over 37% of global land cover (World Bank, 2012a) and is a major cause of deforestation. Agroforestry—a farming technique that combines a mixture of trees, shrubs, and crops—is particularly valuable for biodiversity conservation, especially when native tree species are present (Fischer and Lindenmayer, 2007; Perfecto et al., 1996; Pimentel et al., 1992). The conservation value of tropical agroforests is being increasingly recognized (Greenberg et al., 2008; Perfecto and Vandermeer, 2008; Tscharntke and Klein, 2005). Landscape management strategies that maximize biological diversity retention, ecological services, and economic profitability should be investigated and promoted (Bengtsson et al., 2005; Railsback and Johnson, 2014; Rosenzweig, 2003).

A number of factors affect bird assemblages in tropical agroforests, including forest patch size, proximity to other habitat types, percent canopy cover, and shade tree composition. For example, agroforests that have intact forest canopies with high shade tree diversity and native tree species harbor relatively high avian diversity (Gove et al., 2008; Perfecto et al., 1996; Greenberg et al., 1997; Van Bael et al., 2007). Shade coffee is among the most bird-friendly of agricultural habitats, often harboring a high diversity of birds, including forest specialists (Komar 2006; Perfecto et al., 1996; Greenberg et al., 1997; Van Bael et al., 2007). However, most avian studies only evaluate species diversity or richness, and often overlook the role of community composition in shaping the ecological and conservation importance of bird species utilizing coffee farms. In particular, there is a need to evaluate the degree of habitat specialization, foraging guild structure, and conservation status of bird communities (Komar, 2006). Furthermore, the majority of this research has taken place in the Neotropics and the ecology of birds in coffee farms in Africa, in particular, needs further investigation (Komar, 2006; Şekercioğlu, 2012a).

1.3 Ethiopia: Importance and Challenges

Ethiopia is a unique, immensely diverse and little-studied country with a high level of avian endemism. It is located along the critical African-Eurasian migratory flyway (Ash et al., 2009; Şekercioğlu, 2012b). Eastern Afromontane and Horn of Africa Global Biodiversity Hotspots cover most of the country (Conservation International, 2014) and the Ethiopian highlands account for over 50% of the Eastern Afromontane eco-region (Figure A1). This eco-region is intermittently distributed, is the least explored and least protected eco-region in Africa, and is a major source of endemism (Gole et al., 2008; Küper et al., 2004; Scholes et al., 2006). Approximately three-quarters of plant species (Gole et al., 2008) and 32 bird species are endemic to the Abyssinian Highlands, which include Ethiopia and a portion of neighboring Eritrea (Ash et al., 2009). Despite minimal visitation by ornithologists and birders, especially the unstable border regions with Somalia, Kenya, North and South Sudan, and Eritrea, an impressive total of over 860 species have been documented (Şekercioğlu, 2012b); ranking Ethiopia among the richest countries in the world in terms of bird diversity. This species list is steadily growing with increasing research and tourism. The combination of bird diversity, endemism, globally important migration routes, and scant research make Ethiopia a top priority in Africa for ornithological research and conservation (Şekercioğlu, 2012b).

While Ethiopia has a tremendous wealth of natural resources and biological diversity, it also faces serious conservation challenges. The country's population growth rate is among the highest in the world—currently estimated at 2.6% per year (World Bank, 2013)—which is causing rapid and widespread conversion of forest habitats for human settlements, charcoal and firewood harvesting, and clearing for agriculture, including tea and coffee plantations (Bekele, 2011; Campbell, 1991; Hurni, 1988). Furthermore, there is limited governmental commitment to wild-land conservation. These factors have led to widespread deforestation in the biologically rich Ethiopian highlands: forest cover was reduced from over 15,100,000 hectares in 1990 to just under 12,300,000 hectares in 2010—a drastic 18.6% decline in 20 years (FAO, 2010).

Global coffee consumption has increased consistently since the early 1980's, at a rate of about 1.2% annually (ICO, 2012a). With an annual value of $100 billion (Donald, 2004), coffee is the second most valuable legal international commodity after oil (O'Brien and Kinnaird, 2003) and is the most important export commodity for many tropical countries (ICO, 2012a). It is produced on approximately 11.5 million hectares of terrain, often in areas of high conservation importance (Donald, 2004). *Coffea arabica*— the most widespread and economically valuable coffee strain—makes up two-thirds of the world's coffee market (Aerts et al., 2011; Labouisse et al., 2008), and is native to southwestern Ethiopia where it has been cultivated for over a thousand years (Aerts et al., 2013; Anthony et al., 2001, 2002).

The agricultural industry accounts for 80% of employment in Ethiopia (United Nations, 2012) and coffee is the primary export crop (ICO, 2012b). From 2000-2010, coffee accounted for an average of 33% of export earnings, the second most of any country (ICO, 2012b). Present day coffee cultivation in Ethiopia ranges from the harvesting of near-wild coffee in forest to shade coffee farms with native tree canopies to monoculture sun coffee farms. While Ethiopia has a long history of shade coffee farming, it is following a recent global trend towards sun coffee production, due to the ease of mechanization which can yield higher production per unit area despite decreased production per plant (Donald, 2004; Gove et al., 2008). Intensive sun coffee farms produce a lower quality crop and often face problems with crop pollination and pest outbreaks due to loss of avian ecological function (Kellermann et al., 2008). These biodiversity losses can cause increased reliance on pesticides, which in turn cause further ecological damage (Donald, 2004). As little forest cover remains in Ethiopia and agriculture is the dominant land use, determining the conservation value of agricultural systems is pressing. In addition to being an important step towards determining avian conservation priorities in the tropics, our study also fills an important gap in the existing literature on birds in coffee farms, in a country with high levels of biodiversity, endemism, deforestation rates, human population growth, and economic dependence on agriculture.

2 Material and Methods

2.1 Site Description

Our study took place in the Oromia Region of southwestern Ethiopia, in the heart of the country's coffee producing region and where *C. arabica* was first domesticated from wild stock (Anthony et al., 2002). Bird community sampling was carried out in two habitat types: shade coffee farms (422 km^2 area; at four localities, Garuke, Eladale, Fetche, and Yebu) and moist evergreen Afromontane forest (920 km^2 area; at three localities, Afalo, Abana Bunna, and Quaccho) (Figure 1).

The shade coffee farms are located within the major coffee-producing agricultural mosaic near the city of Jimma (in Kaffa Province, which gave coffee its name) and are all operated by small-scale local farmers with similar growing strategies. The area of the shade coffee farms ranged from two to ten hectares. These shade coffee farms are agroforest fragments in a patchwork of pastures and agriculture. There is extensive canopy and understory thinning and widespread planting of *C. arabica* at high densities and regularly spaced intervals. The coffee cultivars at all of the sites were from wild stocks of *C. arabica* and there was no documented pesticide or fungicide use on the farms. The shade coffee sites have a simplified structure and reduced shrub and tree species composition when compared with the forest sites. Three forest sites were selected from the closest accessible large contiguous forest patches that occurred within the same elevational range, climactic region, and vegetation zone as our shade coffee sites. Located within the Belete-Gera Regional Forest Priority Area, these sites showed only moderate signs of forest management and human alteration, including some clearing of the understory to promote the growth of wild coffee. The forest was complex structurally and compositionally, including diverse herbs, shrubs, lianas and saplings, with an average canopy height of approximately 20m in the most pristine sections.

Hundera et al., (2013) studied forest composition and structure within our same study sites in detail. They documented a total of 69 woody plant species across all sites, with 44 species found in forest, while 26 to 38 species were found on different shade coffee farms. When comparing forest to shade coffee, there was a 70-95% reduction of seedlings, tree abundance was reduced by 30-68%, and basal area decreased by up to 75%, respectively. Emergent tree species, such as *Pouteria adolfi-friederici*, *Olea welwitschii*, and *Afrocarpus falcatus*, are often the first removed in the conversion from forest to shade coffee. While mean tree and canopy height did not vary significantly between habitats, regeneration of late successional tree species was significantly greater in forest than in shade coffee. Hundera et al., (2013) conclude that cutting of saplings in shade coffee inhibits recruitment of late-successional and secondary tree species.

We determined the elevation and mean annual rainfall for all study localities (Table A1). Elevation was extracted from a high resolution digital elevation model (Hijmans et al., 2005), and rainfall values were determined using a world climate database (WorldClim, 2014). All study sites are located in a 110m elevational band. The sites are at least 5 km apart and the maximum distance between the two most distant localities is 57 km. All sites occur within the Moist

Evergreen Montane Forest vegetation zone and the Warm Temperate 1 and 2 climatic regions as described in Ash et al., (2009). There are distinct weather seasons in the region; a wet season from March to mid-September, with peak rains occurring in April and August, and a dry season from September to February.

2.2 Study Design and Sampling

Birds were sampled at all sites using standard mist-netting procedures as described in Karr (1979). Mist-netting is regarded as an effective method for sampling understory bird communities, as it can detect species that are cryptic and/or less vocal and is repeatable with few observer biases (Karr, 1981). Sampling took place during the dry season, from December to February, over a three-year time frame, from 2010 to 2012. At each site, we positioned twenty 12 x 2.5 m nets within a 1 ha area and at least 50 m from any bordering habitat type. As much as the terrain and vegetation allowed, net placement approximated a square of 60 m on each side. We used the same net lanes throughout the three-year study period. Each site was sampled at least six times every season, with approximately two weeks between each sampling session. A sampling session consisted of opening the nets half an hour before sunrise and keeping the nets open for six continuous hours. The nets were routinely checked at 30-minute intervals so as to promptly remove, process, and release the birds. To process each bird we identified the species, banded it, took standard measurements, and released it (Redman et al., 2009; Stevenson and Fanshawe, 2002).

2.3 Bird Classification

We classified each bird species using four main criteria: (i) migratory status, (ii) forest dependence, (iii) foraging guild, and (iv) habitat strata association. Bird taxonomy follows *Clement's 6th Edition*, updated in 2014 (Clements, 2014).

We first classified each species as either a Palearctic migrant or an Afrotropical resident. We then used the established classification of East African forest birds (Bennun et al., 1996) to create a forest dependence rank. In this work, species are classified as forest specialists (FF), forest generalists (F), and forest visitors (f). For a small number of study species that were not included in Bennun et al., (1996), we followed the authors' methods to classify species, using habitat association information found in Ash et al., (2009), del Hoyo et al., (1992), and Redman et al., (2009).

Bird species' foraging guilds were determined using a dataset containing the ecological traits of all of the bird species in the world (hereafter "Birdbase"), as described in Şekercioğlu et al., (2004). This dataset was initially compiled from an extensive literature survey of 248 sources, is updated regularly, and has been used in numerous ecological studies and meta-analyses of bird populations (e.g. Bregman et al., 2014; Burivalova et al., 2014; Redding et al., 2015; Şekercioğlu, 2012a). Herein, seven food categories are identified (plant material, seeds, fleshy fruits, nectar, invertebrates, carrion, and vertebrates) and ordered by priority in each species' diet on a ten-point scale to determine primary diet and foraging strategy. The species' first diet choice was used to classify it into one of the following guilds that were present in our study: frugivore, nectarivore, granivore, and insectivore. These bird diet classification methods are further described in Kissling et al. (2011). Consulting the Birdbase, Ash et al., (2009), del Hoyo et al., (1992), and Redman et al., (2009), we also categorized each species’ occurrence within the understory, midstory, and canopy.

Using these categories, we identified two additional groups: understory insectivores, and resident understory insectivores. These groups are composed of species that are insectivorous and consistently frequent the understory, with the latter including only Afrotropical resident species. These groups are of particular interest in this study for two main reasons: (i) pan-tropical studies have shown that understory insectivores are highly impacted by forest modifications (e.g. Bregman et al., 2014; Burivalova et al., 2014), making them good indicators of forest health; (ii) understory insectivores have been shown to contribute ecosystem services to coffee farmers in the form of pest-regulation in other regions of the world (Şekercioğlu et al., in press), and may likewise be of economic importance to coffee farmers in Ethiopia. (See Table A2 for a list of species along with their classifications included in the analysis.)

2.4 Data Analysis

We made several modifications to the dataset prior to analysis, to account for limitations and potential biases associated with mist net data (Remsen Jr. and Good, 1996) (see Discussion for full treatment of these issues). We removed species that do not consistently frequent the understory and species that are not reliably caught in mist nets due to their large size, such as raptors, owls, and ravens (Wang and Finch, 2002; see Table A3 for a list of species and the reason they were excluded from the analysis). Individuals were only counted when trapped first (recaptures were excluded from the analysis) to avoid estimation bias from individuals that were recaptured many times (Remsen and Good, 1996). Then, all shade coffee sites and forest sites were combined, so as to compare the two major habitat types.

Using EstimateS 9.1.0 (Colwell, 2013), we calculated estimated species richness S(est), estimated shared species V(est), and Morisita-Horn sample similarity. We used the Chao1 estimator to calculate S(est) for our species relative abundance data. The Morisita-Horn index was used because it has minimal sample size biases and is useful for large species assemblages with many rarely recorded species, as was the case in our study (Magurran, 1988). Rarefaction and extrapolation curves of S(est) were computed with 95% confidence intervals in both habitat types, extrapolating the smaller sample to the number of captures of the larger sample (1,208 individuals), in order to directly compare observed and estimated species richness in both habitats. Using this method, statistically robust extrapolation of samples is possible to directly compare sites with different sample sizes, as was the case in our study (Colwell et al., 2012).

Shannon’s Diversity (H) was compared between forest and shade coffee by fitting a generalized linear mixed effects model using the package lme4 in R (Bates et al., 2008). Average Shannon’s Diversity for each one of the 142 sampling sessions from the seven sites was used as the response variable, site as the random effect and habitat (shade coffee or forest) as the fixed effect. The frequency of breeding birds was determined for both habitats, using the number of individuals in breeding condition, as evidenced by cloacal protuberance or brood patch, divided by the total number of captures (Ralph and Dunn, 2004). The ratio of juvenile to adult birds was then determined. Birds in their first year were classified as juveniles and all birds in their second year or after were classified as adults, with species of undetermined age excluded. Relative abundance was determined from the capture rate (number of birds per net hour), an index which controls for differing effort between habitats (Karr, 1982; Newmark, 1991). To compare relative abundance between habitats, we (i) identified the capture rate of each individual species and each bird classification category and (ii) divided this by the total capture rate in each habitat respectively. We then ran a chi-square analysis in SPSS 21.0 (IBM Corp., 2012) to test for significant differences in relative abundance between habitats.

3 Results

3.1 Bird Captures, Richness and Diversity

A total of 1,692 individuals of 71 species were captured in 18,177 net-hours; 1,281 individuals were captured in shade coffee and 411 in forest. Nine species were excluded from analysis due to their large body sizes and 11 species were excluded because they do not consistently frequent the understory. After these refinements to the dataset were made, 1,605 individuals (94.9% of all individuals captured) of 51 species (71.8% of all species captured) were included in the analysis. All 51 species were captured in shade coffee, while 19 of these were caught in forest. Because shade coffee had more land cover, mist netting effort in shade coffee (13,690 net hours) was more than double the effort in forest sites (4,487 net hours), while the overall capture rate was identical (0.085 and 0.082 birds per net-hour in forest and shade coffee, respectively). Six species had significantly greater relative abundance in forest, as determined from the capture rate: Lemon Dove (*Columba larvata*), African Hill Babbler (*Sylvia abyssinica*), Abyssinian Ground-thrush (*Geokichla piaggiae*), Eastern Olive Sunbird (*Cyanomitra olivacea*), Abyssinian Crimson-wing (*Cryptospiza salvadorii*) and Green-backed Twinspot (*Mandingoa nitidula*). Nine species had significantly greater relative abundance in shade coffee: Tambourine Dove (*Turtur tympanistria*), Yellow-fronted Tinkerbird (*Pogoniulus chrysoconus)*, Willow Warbler (*Phylloscopus trochilus*), Blackcap (*Sylvia atricapilla*), Common Chiffchaff (*Phylloscopus* collybita), Broad-ringed White-eye (*Zosterops poliogastrus*), Abyssinian Slaty-Flycatcher (*Melaernornis chocolatinus*), African Paradise-flycatcher (*Terpsiphone viridis*), and Tree Pipit (*Anthus trivialis*). Palearctic migrants were predominantly found in shade coffee, where they were captured nearly twice as frequently. All but one (Blackcap, *S. atricapilla*) of the nine migratory species were captured only in shade coffee. (See Table A3 for a full list of species included in the analysis with relative abundance values.)

The sites had estimated understory bird species richness S(est) of 51.00 (95% CI [44.49, 57.51]) and 19.25 (95% CI [17.82, 20.67]), for shade coffee and forest, respectively. While sharing an observed 19 species V(obs), estimated shared species Chao V(est) was 20.96. Despite the large difference in species richness between habitats, the Morisita-Horn sample similarity index was 0.728, indicative of a high degree of overlap in bird communities. Species rarefaction and extrapolation curves reached a plateau in forest, while shade coffee curves had a positive slope indicating that continued sampling in this habitat might have yielded additional species (Figure 2). Analysis of Shannon's Diversity Index showed no significant difference in bird diversity between shade coffee farms and forest (Table A4).

3.2 Community Structure Analysis

While there were no significant differences in overall bird diversity values between shade coffee and forest, there were differences in the relative abundance of bird community categories, as determined from the capture rate.

Forest generalists (F) were frequently captured in both habitat types, accounting for 58% of captures in shade coffee and 41% of captures in forest. Forest visitors (f) accounted for over one-third of all captures in shade coffee, whereas they were only one-fifth of captures in forest. There was no significant difference in the composition of these 2 groups between habitats, however. Importantly, though, forest specialists (FF) had a greater relative abundance in forest than in shade coffee by a wide margin; they were captured nearly 5 times as frequently in this habitat (χ^2=9.877, df=1, p=0.001) (Figure 3).

Four foraging guilds were found in our study: frugivore, granivore, insectivore, and nectarivore. Frugivores had a greater relative abundance in shade coffee (χ^2=4.670, df=1, p=0.017), whereas granivores had a greater relative abundance in forest (χ^2=18.900, df=1, p<0.001). Nectarivores constituted less than 1% of all captures, with no significant difference between habitats. Insectivores were by far the most frequently captured in both habitats, comprising 68% of all captures in shade coffee and 64% in forest. There was no significant difference in the overall relative abundance of insectivores between the habitats. However, both understory insectivores (χ^2=14.195, df=1, p<0.001) and resident understory insectivores (χ^2=48.392, df=1, p<0.001) had much greater relative abundance in forest. In contrast, shade coffee sites had much greater relative abundance of Palearctic migrants (χ^2=21.375, df=1, p<0.001) (Figure 3).

There was no significant difference in the frequency of breeding birds (as evidenced by cloacal protuberance or brood patch) between forest and shade coffee, with 27% of all captures in breeding condition in shade coffee and 23% in forest (χ^2=2.476, df=1, p=0.065). The species that most frequently showed signs of breeding in shade coffee were Yellow-fronted Tinkerbird (*P. chrysoconus*), Green-backed Camaroptera (*Camaroptera brachyura*), Broad-ringed White-eye (*Z. poliogastrus*), and Eastern Olive Sunbird (*C. olivacea*). The species that most frequently showed signs of breeding in forest were two of the same species, Broad-ringed White-eye (*Z. poliogastrus*) and Eastern Olive Sunbird (*C. olivacea*), plus African Hill Babbler (*S. abyssinica*) and Abyssinian Crimson-wing (*C. salvadorii*). The juvenile to adult ratio was 0.19 in shade coffee and 0.22 in forest, with no significant difference between sites (χ^2=2.215, df=1, p=0.080).

4. Discussion

4.1 Richness and Diversity

Results from rarefaction show that shade coffee had over double the species richness of forest. Despite this, the Morisita-Horn Sample Similarity Index indicates high community overlap of nearly 73% between the bird communities. There were no significant differences in Shannon's Diversity. Eight of the nine Palearctic migrants in the study were found only in shade coffee. These results are consistent with numerous tropical studies showing that shade coffee farms harbor high bird species richness and diversity, and provide important habitat for temperate migrants (Jones and Ramoni-Perazzi, 2002; Komar, 2006; Perfecto et al., 2003; Sherry, 2000). The fact that every species we captured in forest was also captured in shade coffee indicates that forest specialist birds may rely on shade coffee farms in Ethiopia even more than they do in other regions of the world. This is supported by the result that shade coffee had no significant difference from forest in the frequency of birds in breeding condition or the ratio of juveniles to adults. We captured several forest specialist birds in breeding condition in shade coffee, indicating that this habitat may provide viable breeding habitat for some forest specialists, including Lemon Dove (*C. larvata*), Abyssinian Ground-thrush (*G. piaggiae*), Eastern Olive Sunbird (*C. olivacea*), and Green-backed Twinspot (*M. nitidula*). The lack of chemical use in these traditional shade coffee plantations is also likely to contribute to high bird diversity and abundance. However, the viability of shade coffee as breeding habitat for forest birds in this region requires further study. It is possible that shade coffee farms serve mainly as stepping stones for forest birds searching for more suitable habitat, or that these shade coffee fragments are an ecological trap (Battin, 2004) for forest bird species in a highly fragmented and human-dominated landscape. Long-term studies of population dynamics using capture-mark-recapture methods are needed. Nonetheless, the high species richness, diversity, and presence of forest specialist species in organic shade coffee farms in this region are encouraging findings, illustrating the potential importance of shade coffee farms for bird conservation in Africa.

4.2 Community Structure

Considering species richness alone, however, could be misleading when assessing the importance of shade coffee farms and forest for bird conservation. Results from community structure analysis show that there are significant differences in the relative abundance of bird species between the two habitats, illustrating the importance of little-disturbed Afromontane forest for particular groups of birds. For example, forest had a much higher relative abundance of forest specialists, understory insectivores, and resident understory insectivores. These results corroborate studies from around the world that have shown that understory insectivores are among the most susceptible of groups to forest disturbance and are often the first species to disappear from altered forests (Şekercioğlu et al., 2002; Stouffer and Bierregaard Jr., 1995; Sodhi et al., 2011; Cordeiro et al. **This Issue;** Paclacky et al. **This Issue;** Arcilla et al. **This Issue**).

In order to conserve forest specialists and understory insectivores in the long term, it is necessary to conserve areas of little-disturbed forest in the Afrotropics as well.

With regard to guild structure, insectivores made up a similar proportion of the community in both forest and shade coffee, a result that is unusual (Hernandez et al., 2013; Şekercioğlu, 2012a). This may be explained by the fact that coffee is a native crop within our study area and a larger portion of the invertebrate prey base for insectivores may be maintained in shade coffee farms here. A recent study has shown similar incidence of pests on coffee grown in contiguous forest and forest fragments in this region of Ethiopia (Samnegård and Hambäck, 2014). Also of note is a higher proportion of granivores in forest than in shade coffee. This is an unusual result, as well, as granivores typically prefer disturbed and open habitats. Two granivorous species captured frequently in forest, Abyssinian Crimson-wing (*C. salvadorii*) and Green-backed Twinspot (*M. nitidula*), account for the greater relative abundance of granivores in forest. These two species were among the most commonly captured species in forest, accounting for 18% of all captures in this habitat. Unlike many other tropical studies (Şekercioğlu, 2012a), shade coffee farms in our study did not have high numbers of open country granivores. This is an important result, as granivores can be agricultural pests. Frugivores were more common in shade coffee than in forest, a result consistent with pan-tropical findings (Şekercioğlu, 2012a). An increase in frugivores in shade coffee is perhaps the result of selective thinning of the forest in favor of fruiting trees, a frequent practice in agroforests that helps to increase economic production.

These results indicate an important difference in overall community composition from specialists in forest to generalists in shade coffee. These findings are consistent with previous research (Komar, 2006; Şekercioğlu, 2012a). Generalists are more widespread, relatively common, and less threatened than forest specialists (Şekercioğlu, 2012a). Thus, while the high species richness in shade coffee is an encouraging result, the lower relative abundance of forest specialist species in shade coffee is illustrative of the importance of little disturbed forest for many species.

4.3 Caveats

Mist netting is regarded as likely the best technique for assessing the relative abundance of tropical understory birds because it can detect species that are cryptic and/or less vocal and is repeatable with few observer biases (Karr, 1982; Newmark, 1991). Nonetheless, there are limitations and potential biases associated with mist netting data (Remsen Jr. and Good, 1996). For example, habitat modifications, such as removal of canopy trees and clearing of the understory may alter flight height of species, thereby changing their susceptibility to mist-net capture without changing their relative abundance (Arcilla et al, this issue; Remsen Jr. and Good, 1996). We recognize that the number of captures by species is therefore a result, at least in part, of how susceptible a species is to be caught by mist nets and of the habitat structure where the nets are placed. We have therefore made extensive efforts in this study to control for these potential biases. Accordingly, we restricted our analysis by removing species that do not consistently frequent the understory, and species that are not reliably caught in mist nets due to their large size, such as raptors, owls, and ravens (Wang and Finch, 2002). It should therefore be stressed that our results are restricted to interpreting differences in the understory bird community—not the entire bird community—between these habitats. While there was considerable difference in the structure between our shade coffee and forest sites, the average canopy tree height at our sites did not differ (Hundera et al, 2013). We also recognize that the three-year time period of our study could affect the relative abundance estimates of long-lived versus short-lived species. However, in one of the most rigorous studies of tropical forest bird longevity, results from Korfanta et al. (2004) show that the average life span of forest species in Tanzania's Usambara Mountains is 11.8 years. Taking this into account, we believe that a 3-year study period is relatively short compared to the average longevity of tropical forest species. Furthermore, longevity is positively related to body mass in most terrestrial organisms, including birds (Jones et al., 2003; Laurance, 1991), and we have excluded species of large body size from the analysis, which should help minimize any bias in this regard. Lastly, we believe that audio-visually obtained data, such as from point counts (e.g. Aerts et al., 2008), would substantially add to our understanding of bird community composition in Afromontane forest and shade coffee sites. Accordingly, a multi-year point count study is currently being conducted to improve our understanding of the bird communities in these habitats.

4.4 Agroforests and Conservation

While shade coffee provides important habitat for many bird species, particularly those migrating from temperate regions, it is substantially different from forests and likely does not provide suitable habitat for all forest species. As evidenced in our study sites by the work of Hundera et al., (2013), shade coffee farming practices often involve the clearing of much of the diverse understory and mid-story of saplings, shrubs, and forbs, as well as the selective removal of large canopy trees. Native tree species are often replaced with those of greater economic value, including fruit and timber producers. Importantly, not all agroforests are created equally, and different farming practices can have profound impacts on biodiversity. For example, agroforests with higher percent shade cover and greater shade tree diversity have been shown to host a greater richness and diversity of birds (Clough et al., 2009a). Retaining shade cover and shade tree diversity on coffee farms may help preserve forest specialist birds, as well as insectivores and nectarivores, which can in turn benefit crop production (Johnson et al., 2010; Maas et al., 2009; Şekercioğlu, 2012a; Şekercioğlu et al., in press). Further research on bird communities on coffee farms with different structural and floral components is needed to evaluate how these factors may impact bird communities.

Shade coffee farms may not provide viable habitat for all species found therein. Rather, some species may use these farms as stepping-stones between forest patches. Research globally has shown that "suboptimal" forest habitats, such as agroforests, secondary forest, plantations, and even individual trees can help increase connectivity of forest patches in agricultural landscapes (Berens et al., 2008; Ferraz et al., 2012; Neuschulz et al., 2011; Uezu et al., 2008). Research in northern Ethiopia demonstrated that forest restoration sites with suboptimal habitat can help connect forest fragments and also provide suitable habitat for some forest species (Aerts et al., 2008). Similarly, shade coffee farms in southwestern Ethiopia may help connect populations of species that rely on forests for breeding. Thus, the location of shade coffee farms may be important in determining their ecological value as links between forest patches.

4.5 Climate Change Threats

Climate change is predicted to have profound impacts on biodiversity (Thomas et al., 2004). It may cause as many as 900 bird extinctions over the next century, with the vast majority expected to occur in the tropics (Şekercioğlu et al., 2012). Tropical montane forest birds are among the most threatened of all bird species from climate change (Wormworth and Şekercioğlu, 2011) because they are often sedentary and have small ranges. Our study took place in and near Ethiopia's montane forests, which have a large number of endemic and range-restricted bird species that are expected to experience further range contractions with climate change. The distributions of montane birds in East Africa are predicted to shrink and become more isolated as arid areas expand in the region (Huntley et al., 2006). Human-induced habitat loss is likely to further exacerbate the effects of climate change on forest birds by reducing viable habitat and creating barriers to dispersal (Şekercioğlu et al., 2008). In order to preserve forest birds in Ethiopia—and forest biodiversity in general—reserves should incorporate wide elevational distributions and have high connectivity (Noss, 2001; Şekercioğlu et al., 2012). Shade coffee farms that are strategically located near forest patches may help improve connectivity of forests and help mitigate the predicted extinction crisis. Furthermore, trees help buffer against climate change impacts, by improving water quality, reducing topsoil erosion, and creating microclimates (Bonan, 2008; Şekercioğlu 2010). Encouragingly, there is evidence that Ethiopian farmers recognize these benefits, and are already working to mitigate the effects of climate change on crops by planting trees (Deressa et al., 2009).

Coffee production is also expected to suffer worldwide as a result of climate change. A global model estimates land suitable for growing coffee will decrease by about 50% by 2050 (Bunn et al., 2014). Interestingly, Ethiopia is one of the few locations where the suitability for coffee production is expected to improve. This model shows suitable land for coffee growing in Ethiopia shifting upwards with climate change, from rugged hillsides to the extensive highland plateaus. This scenario presents Ethiopia with a unique opportunity: by investing in shade coffee farming now, it may position itself to control a larger share of the lucrative coffee market in the future, while helping to mitigate the local effects of climate change by planting trees, and simultaneously benefiting the countries rich biodiversity by increasing connectivity of native forests. However, in order to conserve biodiversity, it is also imperative to preserve remaining forest patches with minimal human disturbance.

4.6 Avian Ecosystem Services and “Shade Grown Coffee” Certification

Approximately half of the global human population relies on subsistence or small-scale farming (Donald, 2004). Therefore, changes in ecological processes and ecosystem services can have profound impacts on human livelihood and wellbeing (Şekercioğlu 2010). With a per-capita GDP of $374 USD in 2011 (World Bank, 2012b), Ethiopia is one of the most impoverished nations on Earth. However, it has tremendous opportunities for sustainable development based on its high biological diversity, abundant natural resources, and potential for ecotourism. Shade coffee farming with high canopy cover and shade tree diversity have the potential to benefit not only the local ecology and biodiversity, but also the economy.

Birds provide valuable ecosystem services in agricultural areas, including pollination, predation of pests, seed dispersal, and ecosystem engineering (Şekercioğlu, 2006a, 2006b; Wenny et al., 2011; Şekercioğlu et al., in press). In the Neotropics, birds have been shown to provide economically valuable services to coffee farmers in the form of pest control (Clough et al., 2009b; Dietsch et al., 2007; Greenberg et al., 2000a, 2000b; Johnson et al., 2010; Perfecto et al., 2004; Şekercioğlu, 2006a, 2006b; Van Bael et al., 2008). For example, a study in Jamaica concluded that pest reduction by birds economically benefited coffee farmers by $310 USD per hectare (Johnson et al., 2010). Investigating avian usage of and pest-regulating services in African shade coffee farms is a high priority, in order to compare with extensive findings from other regions of the world (Komar, 2006). Our results show that shade coffee farms in southwestern Ethiopia harbor a diverse and abundant insectivorous bird community. This is an important finding with implications for pest regulation on shade coffee farms. Fifteen coffee insect pests have been documented in the vicinity of our study, including the Coffee Berry Borer (*Hypothemus hampei)* and Coffee Berry Moth (*Prophantis smaragdina),* which can drastically damage coffee crops (Abedeta et al., 2014). Indeed, average Coffee Berry Moth incidence on coffee berries in the region was documented at 24.5%, with peak incidence of over 60% in some seasons (Mendesil and Tesfaye, 2009). Coffee Berry Borer is similarly ubiquitous in the region (Mendesil, 2004). This high prevalence of coffee pests implies that there may be large benefits from avian insectivory on shade coffee farms in Ethiopia. One study within the region documented similar pest infestation rates between shade coffee grown in contiguous forest and forest patches (Samnegård and Hambäck, 2014), however there is need for further investigation of the frequency of pest infestation and avian pest regulation in differing habitats where coffee is grown.

To our knowledge, our study documents the only known location in the world where all forest understory bird species recorded in primary forest control sites were also recorded in shade coffee sites (e.g. Wunderle Jr. and Latta, 1996; Tejeda-Cruz and Sutherland, 2004; Philpott et al., 2008; Waltert et al., 2005; Aguilar-Ortiz, 1982). This is not altogether surprising, because coffee is native to our study region, whereas most studies of bird communities on coffee farms have occurred in the Neotropics, where coffee is an exotic crop. However, there is almost no awareness of this in the global "biodiversity friendly" coffee market. Certifying, publicizing and marketing Ethiopian coffee as “shade-grown” and “bird friendly” has the potential to increase incomes of local coffee farmers and provide them a major financial incentive to maintain traditional shade coffee farms instead of converting them into sun coffee plantations that are poor for biodiversity conservation. Farms in Ethiopia that have “shade grown” certification may receive as much as 15-20% more revenue per unit of crop (Takahashi and Todo, 2013). Furthermore, shade coffee is widely regarded to be of superior quality to sun coffee, and is thus more valuable. These factors should be a significant consideration for local farmers in developing countries attempting to maximize profits (Philpott and Dietsch, 2003).

5. Conclusions

In studies around the world, shade coffee has been shown to support high bird species richness, albeit with fewer forest specialist species, particularly understory insectivores. Our results corroborate these findings. Shade coffee farms in southwestern Ethiopia had over double the species richness of nearby primary forest, while there was a much higher relative abundance of forest specialists, understory insectivores and Afrotropical-resident understory insectivores in primary forest. These groups are among the most extinction-prone of birds globally. There were also some results that contrast with most global findings: (i) there was no difference in the relative abundance of all insectivores between the two habitats, and (ii) there was a greater relative abundance of granivores in primary forest. Our results support the consensus that shade coffee farms are an important habitat for forest bird conservation in the tropics. However, differences in the relative abundance of species in shade coffee and forest habitats indicate that intact forest must also be conserved in order to mitigate declines in forest specialist birds. Conserving all types of forested habitat is increasingly important for biodiversity conservation in the tropics (Gibson et al., 2011; Hernandez et al., 2013).

Humans can benefit in turn from conservation of forests and bird communities. Shade coffee farmers can benefit from valuable ecosystem services provided by forest bird communities, such as pollination and insect regulation. These benefits can be economically significant, and may help contribute to poverty alleviation in Ethiopia—one of the poorest countries in the world. Shade coffee farms located near forest and those that maintain high levels of canopy cover and native tree diversity are particularly likely to benefit from avian ecosystem services. Our results imply that Ethiopian shade coffee is among the most “bird friendly” in the world. By promoting, certifying, and marketing shade coffee, Ethiopia has the potential to substantially increase revenue, while simultaneously helping conserve biodiversity.

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References

Abedeta, C., Getu, E., Seyoum, E., Hindorf, H. 2014. Coffee berry insect pests and their parasitoids in the Afromontane rainforests of southwestern Ethiopia. East African J. Sci. 5, 41–50.

Aerts, R., Berecha, G., Gijbels, P., Hundera, K., Glabeke, S., Vandepitte, K., Muys, B., Roldán-Ruiz, I., Honnay, O. 2013. Genetic variation and risks of introgression in the wild Coffea arabica gene pool in south-western Ethiopian montane rainforests. Evol. Appl. 6, 243–52.

Aerts, R., Hundera, K., Berecha, G., Gijbels, P., Baeten, M., Van Mechelen, M., Hermy, M., Muys, B., Honnay, O. 2011. Semi-forest coffee cultivation and the conservation of Ethiopian Afromontane rainforest fragments. For. Ecol. Manage. 261, 1034–1041.

Aerts, R., Lerouge, F., November, E., Lens, L., Hermy, M., Muys, B. 2008. Land rehabilitation and the conservation of birds in a degraded Afromontane landscape in northern Ethiopia. Biodivers. Conserv. 17, 53–69.

Aguilar-Ortiz, F. 1982. Estudio ecológico de las aves del cafetal. Pages 103-127 in E. Jimenez-Avila and A. Gomez-Pompa, editors. Estudios ecológicos en el sistema cafetalero. Instituto Nacional de Investigaciones sobre Recursos Bioticos, Xalapa, Veracruz, Mexico.

Anjos, L., C. Collins, R. Holt, G. Volpato, E. Lopes, G. Bochio **This Issue**. Can habitat specialization patterns of Neotropical birds highlight vulnerable areas for conservation in the Atlantic rainforest, southern Brazil? Biol. Conserv.

Anthony, F., Bertrand, B., Quiros, O. 2001. Genetic diversity of wild coffee (Coffea arabica L.) using molecular markers. Euphytica 118, 53–65.

Anthony, F., Combes, M., Astorga, C. 2002. The origin of cultivated Coffea arabica L. varieties revealed by AFLP and SSR markers. Theor. Appl. Genet. 104, 894–900.

Arcilla, N., Holbech, L., Kolani, Z. **This issue**. Recent declines of Upper Guinea forest understory birds as indicators of unsustainable logging and illegal forest exploitation in Ghana, West Africa. Biol. Conserv.

Ash, J., Atkins, J., Ash, C.P. 2009. Birds of Ethiopia and Eritrea: an atlas of distribution. A & C Black.

Bates, D., Maechler, M., Dai, B. 2008. The lme4 package.

Battin, J. 2004. When good animals love bad habitats: ecological traps and the conservation of animal populations. Conserv. Biol. 18, 1482–1491.

Bekele, M. 2011. Forest plantations and woodlots in Ethiopia: a platform for stakeholders in African forestry. African For. Forum 1.

Bengtsson, J., Ahnström, J., Weibull, A.-C. 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. J. Appl. Ecol. 42, 261–269.

Bennun, L., Dranzoa, C., Pomeroy, D. 1996. The Forest Birds of Kenya and Uganda. J. East African Nat. Hist. 85, 23–48.

Berens, D.G., Farwig, N., Schaab, G., Bohning-Gaese, K. 2008. Exotic guavas are foci of forest regeneration in Kenyan farmland. Biotropica 40, 104–112.

BirdLife International 2014. Birdlife Data Zone [WWW Document]. URL http://www.birdlife.org/datazone/home (accessed 3.19.14).

Bonan, G. 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Science. 320, 1444–1449.

Brashares, J., Arcese, P., Sam, M.K. 2001. Human demography and reserve size predict wildlife extinction in West Africa. Proc. R. Soc. Biol. Sci. 268, 2473–2478.

Bregman, T.P., Şekercioğlu, Ç.H., Tobias, J.A. 2014. Global patterns and predictors of bird species responses to forest fragmentation: implications for ecosystem function and conservation. Biol. Conserv. 169, 372–383.

Brooks, T., Pimm, S., Oyugi, J. 1999. Time lag between deforestation and bird extinction in tropical forest fragments. Conserv. Biol. 13, 1140–1150.

Bunn, C., Läderach, P., Ovalle Rivera, O., & Kirschke, D. 2014. A bitter cup: climate change profile of global production of Arabica and Robusta coffee. *Climatic Change*. 1-13.

Burivalova, Z., Şekercioğlu, Ç.H., Koh, L.P. 2014. Thresholds of logging intensity to maintain tropical forest biodiversity. Curr. Biol. 24: 1893-1898.

Campbell, J. 1991. Land or peasants?: the dilemma confronting Ethiopia resource conservation. Afr. Aff. 90, 5–21.

Chapin, F., Sala, O., Burke, I., Grime, J. 1998. Ecosystem consequences of changing biodiversity. Bioscience 45–52.

Clements, J.F. 2014. The Clements Checklist of Birds of the World. 6th Edition. Updated 2014. Cornell Laboratory of Ornithology, Cornell University Press, Ithaca.

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

Clough, Y., Faust, H., Tscharntke, T. 2009b. Cacao boom and bust: sustainability of agroforests and opportunities for biodiversity conservation. Conserv. Lett. 2, 197–205.

Colwell, R., Chao, A., Gotelli, N. 2012. Models and estimators linking individual-based and sample-based rarefaction, extrapolation and comparison of assemblages. J. Plant Ecol. 5, 3–21.

Colwell, R.K. 2013. EstimateS: Biodiversity Estimation Software.

Conservation International 2013. The Biodiversity Hotspots - Conservation International [WWW Document]. www.conservation.org. URL http://www.conservation.org/where/priority_areas/hotspots/Pages/hotspots_main.aspx (accessed 12.12.13).

Conservation International 2014. Conservation International: Eastern Afromontane Biodiversity Hotspot [WWW Document]. URL http://www.conservation.org/where/priority_areas/hotspots/africa/Eastern-Afromontane/Pages/default.aspx (accessed 3.1.14).

Cordeiro, N.J., Borghesio, L., Joho, M.P., Monoski, T.J., Mkongewa, V.J., Dampf, C.J., **This Issue**. Forest fragmentation in an African biodiversity hotspot impacts mixed-species bird flocks. Biol. Conserv.

Del Hoyo, J., Elliott, A., Sargatal, J., Cabot, J. 1992-2013. Handbook of the Birds of the World. Lynx Edicions, Barcelona.

Deressa, T.T., Hassan, R.M., Ringler, C., Alemu, T., Yesuf, M. 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob. Environ. Chang. 19, 248–255.

Dietsch, T. V., Perfecto, I., Greenberg, R. 2007. Avian foraging behavior in two different types of coffee agroecosystem in Chiapas, Mexico. Biotropica 39, 232–240.

Dirzo, R., Raven, P. 2003. Global state of biodiversity and loss. Annu. Rev. Environ. Resour. 28, 137–167.

Donald, P. 2004. Biodiversity impacts of some agricultural commodity production systems. Conserv. Biol. 18, 17–37.

FAO 2010. Global Forest Resources Assessment 2010: Main Report. Food and Agriculture Organization of the United Nations.

Ferraz, K., De Barros, M.P.M., De Siqueira, M.F., Alexandrino, E.R., Da Luz, D.T.A., Do Couto, H.T.Z. 2012. Environmental suitability of a highly fragmented and heterogeneous landscape for forest bird species in south-eastern Brazil. Environ. Conserv. 39, 316–324.

Fischer, J., Lindenmayer, D. 2007. Landscape modification and habitat fragmentation: a synthesis. Glob. Ecol. Biogeogr. 16, 265–280.

Gibson et al. 2011. Primary forests are irreplaceable for sustaining tropical biodiversity. Nature 478, 378–381.

Gole, T.W., Borsch, T., Denich, M., Teketay, D. 2008. Floristic composition and environmental factors characterizing coffee forests in southwest Ethiopia. For. Ecol. Manage. 255, 2138–2150.

Gove, A.D., Hylander, K., Nemomisa, S., Shimelis, A. 2008. Ethiopian coffee cultivation-implications for bird conservation and environmental certification. Conserv. Lett. 1, 208–216.

Graham, C.H.C. 2001. Factors influencing movement patterns of keel-billed toucans in a fragmented tropical landscape in southern Mexico. Conserv. Biol. 15, 1789–1798.

Greenberg, R., Bichier, P., Angon, A. 2000a. The impact of avian insectivory on arthropods and leaf damage in some Guatemalan coffee plantations. Ecology 81(6), 1750–1755.

Greenberg, R., Bichier, P., Angon, A.C. 2000b. The conservation value for birds of cacao plantations with diverse planted shade in Tabasco, Mexico. Anim. Conserv. 3, 105–112.

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

Greenberg, R., Perfecto, I., Philpott, S. 2008. Agroforests as model systems for tropical ecology. Ecology 89, 913–914.

Heine, J., Speir, T. 1989. Ornithogenic soils of the Cape Bird Adelie penguin rookeries, Antarctica. Polar Biol. 2, 199–205.

Hernandez, S.M., Mattsson, B.J., Peters, V.E., Cooper, R.J., Carroll, C.R. 2013. Coffee agroforests remain beneficial for neotropical bird community conservation across seasons. PLoS One 8, e65101.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas. Int. J. Climatol. 25, 1965–1978.

Hundera, K., Aerts, R., Fontaine, A., Van Mechelen, M., Gijbels, P., Honnay, O., Muys, B. 2013. Effects of coffee management intensity on composition, structure, and regeneration status of Ethiopian Moist Evergreen Afromontane forests. Environ. Manage. 51, 801–9.

Hurni, H. 1988. Degradation and conservation of the resources in the Ethiopian Highlands. Mt. Res. Dev. 8, 123–130.

IBM Corp. 2012. SPSS Statistical Software, Version 21.0.

ICO 2012a. International Coffee Organization - World Coffee Trade [WWW Document]. URL http://www.ico.org/countries/ethiopia.pdf (accessed 10.12.13).

ICO 2012b. International Coffee Organization: Ethiopia coffee fact sheet [WWW Document]. URL http://www.ico.org/countries/ethiopia.pdf (accessed 10.12.13).

Johnson, M.D., Kellermann, J.L., Stercho, a. M. 2010. Pest reduction services by birds in shade and sun coffee in Jamaica. Anim. Conserv. 13, 140–147.

Jones, J., Ramoni-Perazzi, P. 2002. Species composition of bird communities in shade coffee plantations in the Venezuelan Andes. Ornitol. Neotrop. 397–412.

Jones, K., Purvis, A., Gittleman, J. 2003. Biological correlates of extinction risk in bats. Am. Nat. 16, 601–614.

Karr, J. 1979. On the use of mist nets in the study of bird communities. Inl. Bird Band. 51, 1–10.

Karr, J. 1981. Surveying birds with mist nets. Stud. Avian Biol. 6, 62–67.

Karr, J.R. 1982. Population variability and extinction in the avifauna of a tropical land bridge island. Ecology 63, 1975–1978.

Kellermann, J.L., Johnson, M.D., Stercho, A.M., Hackett, S.C. 2008. Ecological and economic services provided by birds on Jamaican Blue Mountain coffee farms. Conserv. Biol. 22, 1177–85.

Kissling, W., Şekercioğlu, Ç.H., Jetz, W. 2011. Bird dietary guild richness across latitudes, environments and biogeographic regions. Glob. Ecol. Biogeogr. 21, 328–340.

Komar, O. 2006. Ecology and conservation of birds in coffee plantations: a critical review. Bird Conserv. Int. 16, 1.

Korfanta, N., Newmark, W., Kauffman, M. 2004. Long-term demographic consequences of habitat fragmentation to a tropical understory bird community. Ecology 93, 2548–2559.

Küper, W., Sommer, J.H., Lovett, J.C., Mutke, J., Linder, H.P., Beentje, H.J., Rompaey, R.S.A.R. Van, Chatelain, C., Sosef, M., Barthlott, W. 2004. Africa's hotspots of biodiversity redefined. Ann. Missouri Bot. Gard. 91, 525–535.

Labouisse, J.-P., Bellachew, B., Kotecha, S., Bertrand, B. 2008. Current status of coffee (Coffea arabica L.) genetic resources in Ethiopia: implications for conservation. Genet. Resour. Crop Evol. 55, 1079–1093.

Laurance, W. 1991. Ecological correlates of extinction proneness in Australian tropical rain forest mammals. Conserv. Biol. 5, 79–89.

Laurance, W., Bierregaard, R. 1997. Tropical forest remnants: ecology, management, and conservation of fragmented communities. University of Chicago Press.

Lees, A., Peres, C. 2006. Rapid avifaunal collapse along the Amazonian deforestation frontier. Biol. Conserv. 133, 198–211.

Leica Geosystems 2004. ERDAS Imagine Software.

Lens, L., Dongen, S. Van, Norris, K., Githiru, M., Matthysen, E. 2002. Avian persistence in fragmented rainforest. Science. 298(5596), 1236–1238.

Maas, B., Putra, D.D., Waltert, M., Clough, Y., Tscharntke, T., Schulze, C.H. 2009. Six years of habitat modification in a tropical rainforest margin of Indonesia do not affect bird diversity but endemic forest species. Biol. Conserv. 142, 2665–2671.

Magurran, A.E. 1988. Ecological Diversity and Its Measurement. Croom Helm Ltd.

Mendesil, E. 2004. Population dynamics and distribution of the coffee berry borer, hypothenemus hampei (Ferrari) (Coleoptera: Scolytidae) on Coffea arabica L. in Southwestern Ethiopia. SINET Ethiop. J. Sci. 27, 127–134.

Mendesil, E., Tesfaye, A. 2009. The influence of weather on the seasonal incidence of coffee berry moth, Prophantis smaragdina(Butler). J. Asia. Pac. Entomol. 12, 203–205.

Neuschulz, E.L., Botzat, A., Farwig, N. 2011. Effects of forest modification on bird community composition and seed removal in a heterogeneous landscape in South Africa. Oikos 120, 1371–1379.

Newmark, W.D. 1991. Tropical forest fragmentation and the local extinction of understory birds in the Eastern Usambara Mountains, Tanzania. Conserv. Biol. 5, 67–78.

Norris, K. 2008. Agriculture and biodiversity conservation: opportunity knocks. Conserv. Lett. 1, 2–11.

Noss, R.F. 2001. Beyond Kyoto: Forest Management in a Time of Rapid Climate Change. Conserv. Biol. 15, 578–590.

O'Brien, T.T., Kinnaird, M.M. 2003. Caffeine and conservation. Science. 300(5619), 587.

Pavlacky, D.C., Possingham, H.P., Goldizen, A.W., 2014. Integrating life history traits and forest structure to evaluate the vulnerability of rainforest birds along gradients of deforestation and fragmentation in eastern Australia. Biol. Conserv.

Perfecto, I., Mas, A., Dietsch, T., Vandermeer, J. 2003. Conservation of biodiversity in coffee agroecosystems: a tri-taxa comparison in southern Mexico. Biodivers. Conserv. 12, 1239–1252.

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

Perfecto, I., Vandermeer, J. 2008. Biodiversity conservation in tropical agroecosystems: a new conservation paradigm. Ann. N. Y. Acad. Sci. 1134, 173–200.

Perfecto, I., Vandermeer, J., Bautista, G., 2004. Greater predation in shaded coffee farms: the role of resident neotropical birds. Ecology 85, 2677–2681.

Philpott, S. M., Arendt, W. J., Armbrecht, I., Bichier, P., Diestch, T. V, Gordon, C., Greenberg, R., Perfecto, I., Reynoso-Santos, R., Soto-Pinto, L., Tejeda-Cruz, C. Williams-Linera, G., Valenzuela, J., Zolotoff, J. M. 2008. Biodiversity loss in Latin American coffee landscapes: review of the evidence on ants, birds, and trees. Conserv. Biol. 5, 1093–1105.

Philpott, S.M., Dietsch, T. 2003. Coffee and Conservation: a global context and the value of farmer involvement. Conserv. Biol. 17, 1844–1846.

Pimentel, D., Stachow, U., Takacs, D. 1992. Conserving biological diversity in agricultural/forestry systems. Bioscience 354–362.

Pimm, S., Raven, P., Peterson, A., Şekercioğlu, Ç.H., Ehrlich, P.R. 2006. Human impacts on the rates of recent, present, and future bird extinctions. Proc. Natl. Acad. Sci. U. S. A. 103, 10941–10946.

Pollock, H.S., Cheviron, Z. a., Agin, T.J., Brawn, J.D., 2014. Absence of microclimate selectivity in insectivorous birds of the Neotropical forest understory. Biol. Conserv.

Railsback, S. F., & Johnson, M. D. 2014. Effects of land use on bird populations and pest control services on coffee farms. Proc. Natl. Acad. Sci. U. S. A. 111, 6109–6114.

Ralph, C., Dunn, E. 2004. Monitoring bird populations using mist nets. Cooper Ornithological Society.

Redding, D. W., Mooers, A. O., Şekercioğlu, Ç. H., Collen, B. 2015. Global evolutionary isolation measures can capture key local conservation species in Nearctic and Neotropical bird communities. *Proceedings of the Royal Society B: Biological Sciences* 370. In press.

Redman, N., Stevenson, T., Fanshawe, J. 2009. Birds of the Horn of Africa: Ethiopia, Eritrea, Djibouti, Somalia, and Socotra (Princeton Field Guides). Princeton University Press.

Remsen Jr., J., Good, D. 1996. Misuse of data from mist-net captures to assess relative abundance in bird populations. Auk 381–398.

Rosenzweig, M. 2003. Reconciliation ecology and the future of species diversity. Oryx 37, 194–205.

Samnegård, U., Hambäck, P. 2014. Local and regional variation in local frequency of multiple coffee pests across a mosaic landscape in Coffea arabica's native range. Biotropica 46, 276–284.

Scholes, R., Kuper, W., Biggs, R. 2006. Biodiversity, in: Africa Environment Outlook 2: Our Enviornment, Our Wealth. pp. 226–261.

Şekercioğlu, Ç.H. 2006a. Increasing awareness of avian ecological function. Trends Ecol. Evol. 21, 464–71.

Şekercioğlu, Ç.H. 2006b. Ecological significance of bird populations, in: Handbook of the Birds of the World. pp. 15–51.

Şekercioğlu, Ç.H. 2010. Ecosystem functions and services. Pp. 45-72 in *Conservation Biology for All*. Sodhi, N.S. and Ehrlich, P.R. (Eds.). Oxford University Press. Oxford.

Şekercioğlu, Ç.H. 2011. Functional extinctions of bird pollinators cause plant declines. Science. 331(6020), 1019–20.

Şekercioğlu, Ç.H. 2012a. Bird functional diversity and ecosystem services in tropical forests, agroforests and agricultural areas. J. Ornithol. 153, 153–161.

Şekercioğlu, Ç.H. 2012b. Promoting community-based bird monitoring in the tropics: conservation, research, environmental education, capacity-building, and local incomes. Biol. Conserv. 151, 69–73.

Şekercioğlu, Ç.H., Daily, G.C., Ehrlich, P.R. 2004. Ecosystem consequences of bird declines. Proc. Natl. Acad. Sci. U. S. A. 101, 18042–18047.

Şekercioğlu, Ç.H., Ehrlich, P.R., Daily, G.C., Aygen, D., Goehring, D., Sandi, R.F. 2002. Disappearance of insectivorous birds from tropical forest fragments. Proc. Natl. Acad. Sci. U. S. A. 99, 263–267.

Şekercioğlu, Ç.H., Primack, R.B., Wormworth, J. 2012. The effects of climate change on tropical birds. Biol. Conserv. 148, 1–18.

Şekercioğlu, Ç.H., Schneider, S., Fay, J., Loarie, S. 2008. Climate change, elevational range shifts, and bird extinctions. Conserv. Biol. 22, 140–150.

Şekercioğlu, Ç.H., Wenny, D. and Whelan, C.J. (Eds.). In press. *Why Birds Matter*. University of Chicago Press. Chicago.

Sherry, T. 2000. Shade coffee: a good brew even in small doses. Auk 117, 563–568.

Sigel, B.J., Sherry, T.W., Young, B.E. 2006. Avian community response to lowland tropical rainforest isolation: 40 years of change at La Selva Biological Station, Costa Rica. Conserv. Biol. 20, 111–21.

Sodhi, N., Koh, L., Brook, B., Ng, P. 2004. Southeast Asian biodiversity: an impending disaster. Trends Ecol. Evol. 19, 654–660.

Sodhi, N. S., Şekercioğlu, Ç.H., Barlow, J., Robinson, S. K. 2011. Conservation of tropical birds. John Wiley & Sons.

Stevenson, T., Fanshawe, J. 2002. The Birds of East Africa: Kenya, Tanzania, Uganda, Rwanda, Burundi (Princeton Field Guides). Princeton University Press.

Stouffer, P., Bierregaard Jr., R.O. 1995. Use of Amazonian forest fragments by understory insectivorous birds. Ecology 76, 2429–2445.

Stratford, J. A., Stouffer, P.C. 1999. Local extinctions of terrestrial insectivorous birds in a fragmented landscape near Manaus, Brazil. Conserv. Biol. 13, 1416–1423.

Takahashi, R., Todo, Y. 2013. Impact of a shade coffee certification program on forest conservation: a case study from a wild coffee forest in Ethiopia. J. Environ. Manage. 130, 48–54.

Tejeda-Cruz, C., & Sutherland, W. J. 2004. Bird responses to shade coffee production. Anim. Cons., 2, 169–179.

Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., De Siqueira, M.F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., Van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega-Huerta, M. a, Peterson, a T., Phillips, O.L., Williams, S.E. 2004. Extinction risk from climate change. Nature 427, 145–8.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C. 2001. Forecasting agriculturally driven global environmental change. Science. 292(5515), 281–284.

Tobias, J., Şekercioğlu, Ç.H., Vargas, H. 2013. Bird conservation in tropical ecosystems: a review of challenges and opportunities. Pp. 258-276 in *Key*

Topics in Conservation Biology. MacDonald, D. (Ed.). Wiley-Blackwell. Oxford.

Tscharntke, T., Klein, A. 2005. Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. Ecol. Lett. 8, 857–874.

Turner, I. 1996. Species loss in fragments of tropical rain forest: a review of the evidence. J. Appl. Ecol. 200–209.

Uezu, A., Beyer, D.D., Metzger, J.P. 2008. Can agroforest woodlots work as stepping stones for birds in the Atlantic forest region? Biodivers. Conserv. 17, 1907–1922.

United Nations 2012. UNdata: Country Profile: Ethiopia [WWW Document]. URL http://data.un.org/CountryProfile.aspx?crName=Ethiopia (accessed 10.13.12).

Van Bael, S.A., Bichier, P., Ochoa, I., Greenberg, R. 2007. Bird diversity in cacao farms and forest fragments of western Panama. Biodivers. Conserv. 16, 2245–2256.

Van Bael, S.A., Philpott, S.M., Greenberg, R., Bichier, P., Barber, N. a, Mooney, K. a, Gruner, D.S. 2008. Birds as predators in tropical agroforestry systems. Ecology 89, 928–34.

Vitousek, P., Mooney, H., Lubchenco, J., Melillo, J. 1997. Human domination of Earth’s ecosystems. Science. 277(5325), 494–499.

Waltert, M., Bobo, K., & Sainge, N. 2005. From forest to farmland: habitat effects on Afrotropical forest bird diversity. Ecol. Appl. 4, 1351–1366.

Wang, Y., Finch, D. 2002. Consistency of mist netting and point counts in assessing landbird species richness and relative abundance during migration. Condor 104, 59–72.

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

World Bank 2012a. Agricultural land (% of land area) [WWW Document]. URL http://data.worldbank.org/indicator/AG.LND.AGRI.ZS/countries?display=graph (accessed 10.12.12).

World Bank 2012b. GDP per capita (current US$) [WWW Document]. URL http://data.worldbank.org/indicator/NY.GDP.PCAP.CD?order=wbapi_data_v alue_2011+wbapi_data_value+wbapi_data_value-last&sort=asc (accessed 10.12.12).

World Bank 2013. World Development Indicators | The World Bank [WWW Document]. URL http://wdi.worldbank.org/table/3.2 (accessed 6.1.14).

WorldClim 2014. Global Climate Data [WWW Document]. URL http://www.worldclim.org/ (accessed 3.30.14).

Wormworth, J., Şekercioğlu, Ç.H. 2011. *Winged Sentinels: Birds and Climate Change*. Cambridge University Press, Cambridge.

Wunderle Jr., J., & Latta, S. 1996. Avian abundance in sun and shade coffee plantations and remnant pine forest in the Cordillera Central, Dominican Republic. *Ornitología Neotropical* 7, 19–34.

Figures:

Figure 1. Location of four shade coffee farms (+) and three moist evergreen Afromontane forest sites (★) where mist netting took place in southwestern Ethiopia. The map shows regional forest cover from a 30 m resolution LandSat image (WorldClim.org, 2014) and classified using ERDAS Imagine Software (Leica Geosystems, 2004).

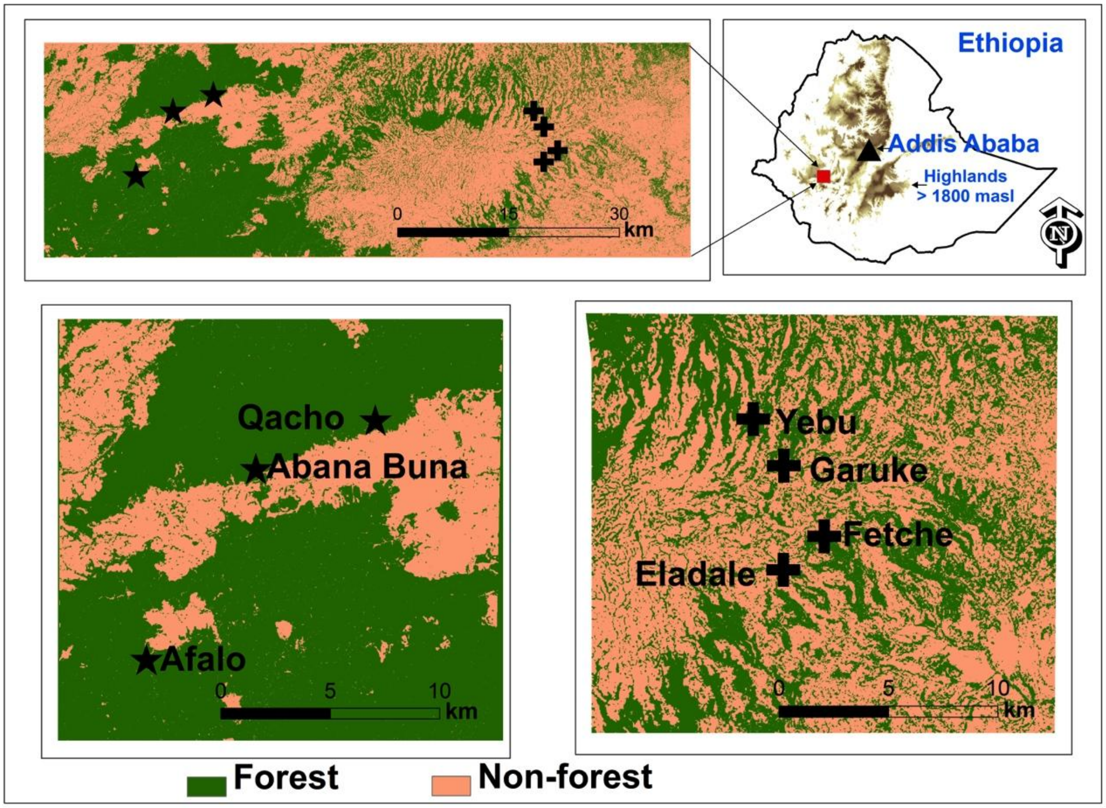


Figure 2. Observed and extrapolated bird species accumulation curves (S(est)) with 95% confidence intervals (CI) for shade coffee farms and moist evergreen Afromontane forest sites in southwestern Ethiopia.

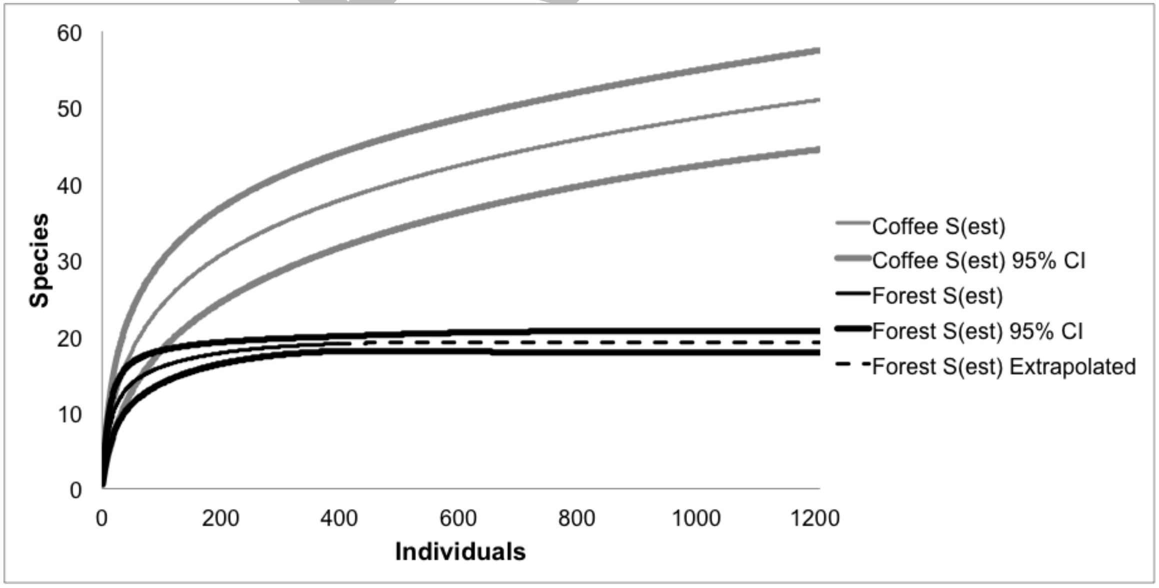
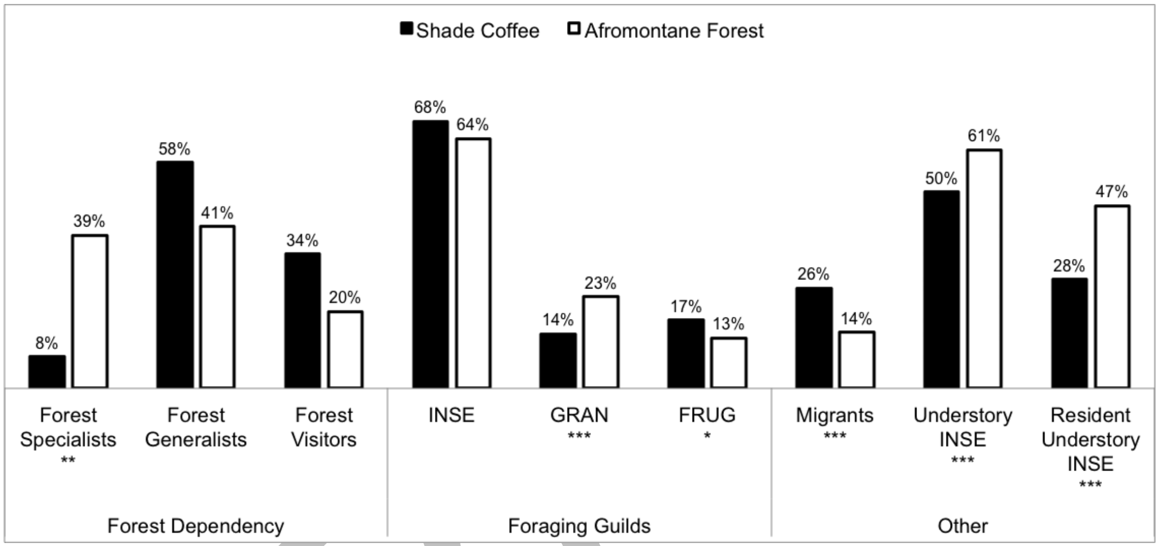


Figure 3. Summary of the differences in bird relative abundance between shade coffee farms and moist evergreen Afromontane forest sites in southwestern Ethiopia. Bars illustrate the relative abundance of each bird classification category, calculated as the capture rate (# of birds/net hour) in each habitat divided by the total capture rate. Asterisks indicate significant differences in the relative abundance of a category between habitats at the p<.05 (*), p<.01 (**), and p<.001 (***) levels, based on chi-square analysis. Nectarivores were not included in the figure because they accounted for only a fraction of a percent of all captures.



Appendices:

Figure A1. The Ethiopian highlands account for more than 50% of the Eastern Afromontane eco-region, as indicated in orange. Image courtesy of Conservation International (2014).

Table A1. Characteristics of four shade coffee and three moist evergreen Afromontane forest mist-netting sites in southwestern Ethiopia. Location was acquired from a handheld GPS on site, elevation was extracted from a high resolution digital elevation model (Hijmans et al., 2005), and rainfall values were determined using a world climate database (WorldClim, 2014).

Site	Habitat	Latitude	Longitude	Elevation (m)	Rainfall (mm)
Eladale	Shade Coffee	7.70363	36.80863	2062	1811
Fetche	Shade Coffee	7.71753	36.75606	2043	1815
Garuke	Shade Coffee	7.74667	36.73917	2060	1834
Yebu	Shade Coffee	7.76583	36.72639	1982	1843
Abana	Forest	7.76339	36.28510	1954	1849
Afalo	Forest	7.68427	36.24030	1957	1854
Qaccho	Forest	7.78384	36.33443	2012	1879

Table A2. A list of all species and classifications used in the analysis. Taxonomy follows the 2014 update of *Clements 6th Edition*. For guild classifications, FRUG = frugivore, GRAN = granivore, INSE = insectivore, and NECT = nectarivore. Migr. = Eurasian migrant, UI = understory insectivore, and RUI = resident understory insectivore. Forest Dependency categories are forest specialist (FF), forest generalist (F), and forest visitor (f) (Bennun et al., 1996). Relative abundance was calculated from the capture rate (# of birds/net hour), an index that controls for differing effort between habitats. The last column denotes species that significantly differed (p<.05) in capture rate between shade coffee and moist evergreen Afromontane forest. Species are listed in descending order of total captures.

Species #	Species English	Species Latin	Guild	Migr.	UI	RUI	Forest Dep.	Coffee Captures	Coffee Capture Rate	Forest Captures	Forest Capture Rate	Total Captures	Total Capture Rate	Sig. Diff. Between Habitats
1	Blackcap	*Sylvia atricapilla*	INSE	X	X		F	232	0.0169	57	0.0127	289	0.0159	X
2	Rueppell's Robin-chat	*Cossypha semirufa*	INSE		X	X	f	135	0.0099	52	0.0116	187	0.0103	
3	Broad-ringed White-eye	*Zosterops poliogastrus*	FRUG				F	131	0.0096	20	0.0045	151	0.0083	X
4	Tambourine Dove	*Turtur tympanistria*	GRAN				F	92	0.0067	15	0.0033	107	0.0059	X
5	Eastern Olive Sunbird	*Cyanomitra olivacea*	INSE		X	X	FF	57	0.0042	40	0.0089	97	0.0053	X
6	Abyssinian Slaty-Flycatcher	*Melaenornis chocolatinus*	INSE				F	84	0.0061	2	0.0004	86	0.0047	X
7	Green-backed Camaroptera	*Camaroptera brachyura*	INSE		X	X	f	68	0.0050	14	0.0031	82	0.0045	
8	Abyssinian Crimson-wing	*Cryptospiza salvadorii*	GRAN				F	16	0.0012	49	0.0109	65	0.0036	X
9	Dusky-brown Flycatcher	*Muscicapa adusta*	INSE		X	X	F	52	0.0038	11	0.0025	63	0.0035	
10	African Paradise-flycatcher	*Terpsiphone viridis*	INSE				f	49	0.0036	5	0.0011	54	0.0030	X
11	Lemon Dove	*Columba larvata*	FRUG				FF	19	0.0014	28	0.0062	47	0.0026	X
12	Abyssinian Ground-thrush	*Geokichla piaggiae*	INSE		X	X	FF	9	0.0007	36	0.0080	45	0.0025	X
13	Willow Warbler	*Phylloscopus trochilus*	INSE	X			f	37	0.0027	0	0.0000	37	0.0020	X
14	Yellow-fronted Tinkerbird	*Pogoniulus chrysoconus*	FRUG				F	34	0.0025	0	0.0000	34	0.0019	X
15	Green-backed Twinspot	*Mandingoa nitidula*	GRAN				FF	11	0.0008	22	0.0049	33	0.0018	X
16	African Hill Babbler	*Sylvia abyssinica*	INSE		X	X	FF	2	0.0001	29	0.0065	31	0.0017	X
17	Black-billed Wood-dove	*Turtur abyssinicus*	GRAN				F	22	0.0016	7	0.0016	29	0.0016	
18	Common Bulbul	*Pycnonotus barbatus*	FRUG				f	21	0.0015	2	0.0004	23	0.0013	X
19	Brown-throated Wattle-eye	*Platsteira cyanea*	INSE				f	15	0.0011	4	0.0009	19	0.0010	
20	Tree Pipit	*Anthus trivialis*	INSE	X	X		f	18	0.0013	0	0.0000	18	0.0010	X
21	Common Chiffchaff	*Phylloscopus collybita*	INSE	X	X		F	14	0.0010	0	0.0000	14	0.0008	X
22	Red-capped Robin-Chat	*Cossypha natalensis*	INSE		X	X	F	10	0.0007	3	0.0007	13	0.0007	
23	Ethiopian Boubou	*Laniarius aethiopicus*	INSE				f	8	0.0006	0	0.0000	8	0.0004	
24	Red-billed Firefinch	*Lagonosticta senegala*	GRAN				f	8	0.0006	0	0.0000	8	0.0004	
25	Variable Sunbird	*Cinnyris venustus*	INSE				f	8	0.0006	0	0.0000	8	0.0004	
26	African Pygmy-kingfisher	*Ispidina picta*	INSE				f	6	0.0004	0	0.0000	6	0.0003	
27	Magpie Starling	*Speculipastor bicolor*	FRUG				f	5	0.0004	1	0.0002	6	0.0003	
28	African Firefinch	*Lagonosticta rubricata*	GRAN				f	4	0.0003	0	0.0000	4	0.0002	
29	Red-eyed Dove	*Streptopelia semitorquata*	GRAN				f	4	0.0003	0	0.0000	4	0.0002	
30	Red-shouldered Cuckooshrike	*Campephaga phoenicea*	INSE				f	4	0.0003	0	0.0000	4	0.0002	
31	Scarlet-chested Sunbird	*Chalcomitra senegalensis*	NECT				f	4	0.0003	0	0.0000	4	0.0002	
32	Common Redstart	*Phoenicurus phoenicurus*	INSE	X	X		F	3	0.0002	0	0.0000	3	0.0002	
33	Streaky Seedeater	*Serinus striolatus*	GRAN				f	3	0.0002	0	0.0000	3	0.0002	
34	Bronze Mannikin	*Spermestes cucullata*	GRAN				f	2	0.0001	0	0.0000	2	0.0001	
35	Common Cuckoo	*Cuculus canorus*	INSE	X			F	2	0.0001	0	0.0000	2	0.0001	
36	Yellow-bellied Waxbill	*Coccopygia quartinia*	GRAN				f	2	0.0001	0	0.0000	2	0.0001	
37	Tacazze Sunbird	*Nectarinia tacazze*	NECT				f	2	0.0001	0	0.0000	2	0.0001	
38	Northern Black-Flycatcher	*Melaenornis edolioides*	INSE		X	X	F	2	0.0001	0	0.0000	2	0.0001	
39	African Citril	*Serinus citrinelloides*	GRAN				f	1	0.0001	0	0.0000	1	0.0001	
40	Baglafecht Weaver	*Ploceus baglafecht*	INSE				f	1	0.0001	0	0.0000	1	0.0001	
41	Blue-spotted Wood-dove	*Turtur afer*	GRAN				f	1	0.0001	0	0.0000	1	0.0001	
42	Cardinal Woodpecker	*Dendropicos fuscescens*	INSE				f	1	0.0001	0	0.0000	1	0.0001	
43	Eurasian Reed-warbler	*Acrocephalus scirpaceus*	INSE	X	X		f	1	0.0001	0	0.0000	1	0.0001	
44	Gray Wagtail	*Motacilla cinerea*	INSE	X	X		F	1	0.0001	0	0.0000	1	0.0001	
45	African Grey Woodpecker	*Dendropicos goertae*	INSE				f	1	0.0001	0	0.0000	1	0.0001	
46	Lesser Whitethroat	*Sylvia curruca*	INSE	X	X		f	1	0.0001	0	0.0000	1	0.0001	
47	Pale Flycatcher	*Bradornis pallidus*	INSE		X	X	f	1	0.0001	0	0.0000	1	0.0001	
48	Red-cheeked Cordonbleu	*Uraeginthus bengalus*	GRAN				f	1	0.0001	0	0.0000	1	0.0001	
49	Red-winged Starling	*Onychognathus morio*	FRUG				F	1	0.0001	0	0.0000	1	0.0001	
50	Swainson's Sparrow	*Passer swainsonii*	GRAN				f	1	0.0001	0	0.0000	1	0.0001	
51	Yellow-breasted Apalis	*Apalis flavida*	INSE				f	1	0.0001	0	0.0000	1	0.0001	

Table A3. List of species excluded from the analysis, including the reason they were excluded, number of captures by habitat, and total number of captures. Species are listed in descending order of the total number of captures.

Species English	Species Latin	Reason Excluded	Coffee Captures	Forest Captures	Total Captures
Narina Trogon	*Apaloderma narina*	Midstory/Canopy Species	14	1	15
African Goshawk	*Accipiter tachiro*	Large Size	11	2	13
Little Sparrowhawk	*Accipiter minullus*	Large Size	3	3	6
Ethiopian Black-headed Oriole	*Oriolus monacha*	Midstory/Canopy Species	5	0	5
Lesser Honeyguide	*Indicator minor*	Midstory/Canopy Species	4	1	5
Northern Puffback	*Dryoscopus gambensis*	Midstory/Canopy Species	5	0	5
White-breasted White-eye	*Zosterops abyssinicus*	Midstory/Canopy Species	5	0	5
Spectacled Weaver	*Ploceus ocularis*	Midstory/Canopy Species	1	3	4
African Emerald Cuckoo	*Chrysococcyx cupreus*	Midstory/Canopy Species	3	0	3
Brown Woodland-warbler	*Phylloscopus umbrovirens*	Midstory/Canopy Species	0	3	3
Black-headed Batis	*Batis minor*	Midstory/Canopy Species	1	0	1
White-cheeked Turaco	*Tauraco leucotis*	Midstory/Canopy Species	1	0	1
Woodland Kingfisher	*Halcyon senegalensis*	Midstory/Canopy Species	0	1	1
African Wood-owl	*Strix woodfordii*	Large Size	1	0	1
European Scops-Owl	*Otus scops*	Large Size	1	0	1
Levant Sparrowhawk	*Accipiter brevipes*	Large Size	1	0	1
Long-crested Eagle	*Lophaetus occipitalis*	Large Size	1	0	1
Scaly Francolin	*Francolinus squamatus*	Large Size	1	0	1
Thick-billed Raven	*Corvus crassirostris*	Large Size	1	0	1
Wattled Ibis	*Bostrychia carunculata*	Large Size	1	0	1

Table A4. Estimates, standard errors (SE), t-values, and p-values from a linear mixed effects model. Average Shannon's Diversity (H) for each one of the 140 nets was used as the response variable, site as the random effect and habitat (shade coffee or moist evergreen Afromontane forest in southwestern Ethiopia) as the fixed effect.

	Estimate	SE	t value	p-value
Intercept	1.2781	0.11	11.64	0.00
Forest	-0.0773	0.18	-0.44	0.68