This manuscript has been accepted for publication and will appear in a revised form subsequent editorial input by Cambridge University Press in Bird Conservation International published by Cambridge University Press.

Aerts R., Spranghers S., Sekercioglu C. (2016) Conservation of ecosystem services does not secure the conservation of birds in a Peruvian shade coffee landscape. **Bird Conservation International**

DOI: [10.1017/S0959270916000149](https://doi.org/10.1017/S0959270916000149)

Full copyright in all forms and media in the said contribution, including in any supplementary materials that we have authored in support of the online version, has been assigned to the BirdLife International. Moral rights were conferred on the authors by the UK Copyright Act in 1988. Permission was obtained to reproduce illustrative material not in our copyright (bird illustrations in Figure 2). The authors retain the non-transferable right to post the accepted manuscript of the article on the personal or departmental web page and in the Institutional Repository (Lirias) of the institution in which the first author worked at the time the article was first submitted (University of Leuven) provided the posting is accompanied by the statements on this cover page. Conditions of re-use are posted online

<https://www.cambridge.org/core/journals/bird-conservation-international/information/transfer-copyright>

Conservation of ecosystem services does not secure the conservation of birds in a Peruvian shade coffee landscape

RAF AERTS ^{1,2,a,*}, SARAH SPRANGHERS ¹, and ÇAĞAN H. ŞEKERCİOĞLU ^{2,3}

¹ Division Forest, Nature and Landscape, University of Leuven, Celestijnenlaan 200E-2411, BE-3001 Leuven, Belgium

² Department of Biology, University of Utah, 257 South 1400 East, Salt Lake City, Utah 84112, USA.

³ College of Sciences, Koc University, Rumelifeneri, Sariyer 34450, Istanbul, Turkey.

^a Current address: Division Ecology, Evolution and Biodiversity Conservation, University of Leuven, Kasteelpark Arenberg 31-2435, BE-3001 Leuven, Belgium

*Corresponding author: raf.aerts@kuleuven.be

Running head: Bird function in shade coffee

Summary

Agricultural intensification in shade coffee farms has strong impacts on the structure and diversity of the agroforest, with negative consequences for forest specialist birds, understory insectivores and their associated ecosystem services. Utilizing variable distance transect counts, we sampled the bird community in a multiple-certified yet changing shade coffee landscape in the Peruvian East Andean foothills, to evaluate bird functional diversity and to assess potential impacts of coffee production on avian ecosystem services. We used bird count data to calculate relative abundances of functional groups. To account for incomplete detection, we also calculated expected species richness per functional group, and to evaluate the effect of future species losses, we derived reduced bird communities by subsampling our data using a Monte Carlo procedure. We compared the relative abundances of functional groups based on preferred diets in the observed, expected and reduced bird communities to global functional signatures of tropical bird assemblages of forest, agroforests and agriculture. The birds in the shade coffee landscape were predominantly birds of secondary and disturbed forest habitats, indicating, as expected, strong human impact on the forest structure. Yet, the diet signatures of the observed, expected and simulated bird communities were not significantly different from global diet signatures of forest and agroforest bird communities of mixed tropical landscapes. Our results suggest that avian ecological function can be conserved at bird community level despite intensive human ecosystem use and associated losses of forest specialist and other less resilient bird species. These results underscore that forest management strategies or certification audits focused solely at ecosystem services may be insufficient to support conservation of rare or threatened bird species and that shade coffee systems can in no way replace the role of protected natural forests.

Keywords:

agroforestry, diet signature, ecosystem services, Neotropical ornithology, tropical forest

Introduction

The increasing global demand for coffee is driving intensification of coffee cultivation in coffee agroecosystems worldwide (Jha *et al.* 2014), with negative impacts on their biodiversity and associated ecosystem services (De Beenhouwer *et al.* 2013). In shade coffee landscapes, birds have a diverse range of ecological functions and many species deliver important ecosystem services (Sekercioglu 2006a,b, Sekercioglu *et al.* 2016). Pest control services by birds are well-documented in coffee farms (e.g., Kellerman *et al.* 2008, Johnson *et al.* 2010, Karp *et al.* 2013, Maas *et al.* 2015) and are a strong motivation to adopt the land sharing approach to conservation (*sensu* Phalan *et al.* 2011) in this system (Railsback and Johnson 2014). Birds may also disperse seeds and facilitate regeneration on fallow land or other land not used for coffee cultivation (Pejchar *et al.* 2008, Martin *et al.* 2012).

Intensification in such coffee landscapes usually involves deforestation (for conversion of shade coffee to sun-grown coffee or other cash crops), a severe reduction in canopy cover (Hundera *et al.* 2013) or significant changes in the species composition of the shade trees, for instance to provide wood products next to coffee (Rice 2008). These management interventions change the biotic and structural diversity of the forest and this is expected to have negative impacts on forest birds (Calvo and Blake 1998, see Komar 2006 for a review), in particular forest specialist birds, large frugivores and understory insectivores (Bregman *et al.* 2014, Burivalova *et al.* 2015, Buechley *et al.* 2015). Intensification of coffee production may therefore cause a shift in a bird community typical of forest to one of agroforest or agricultural land, comprising relatively fewer insectivorous bird species and more frugivorous and nectarivorous species (Komar 2006, Tschardtke *et al.* 2008). As the primary diet of bird species is an important proxy for ecological function (Sekercioglu 2006a, 2012), shifts in the preferred diets of birds following anthropogenic changes to the forest may signal important shifts in ecosystem services, including avian pest control. Bird surveys that assess functional

guilds and compare these to reference data may therefore be useful to document impacts of agricultural intensification in tropical landscapes, to evaluate coffee farms for certification or to support impact assessments for finance mechanisms such as environmental certification or REDD+ (Harrison *et al.* 2012, Torres 2014).

Our objective was to assess the impact of coffee cultivation on the bird functional diversity in a multiple certified yet changing shade coffee landscape in the Peruvian East Andean foothills. To that end we sampled the bird community utilizing variable distance transect counts and we compared the relative abundances of detected functional groups to global functional signatures of tropical bird assemblages of forest, agroforest and agriculture. We expected that the functional signature differed from a forest signature because of ongoing forest disturbance and increasing intensity of coffee production.

Methods

Study site

The study area, located in the San Pedro de Puntina Punco district of the Sandia Province of the Puno Region in southeastern Peru (14° 6.80'S, 69° 2.85'W), lies on the eastern slopes of the Andes and has an altitude between 900 and 1500 m. The landscape forms the transition zone between the High Andes and the Amazon Basin and is characterized by steep slopes and deep valleys. The study area belongs to the Tambopata catchment, which drains into the Madre de Dios, and ultimately the Amazon. Soils in the upper Tambopata catchment are dystric cambisols (USDA: typic dystrochrept) and on the steep slopes lithosols (USDA: orthents). These soils have low active clay content, low cation exchange capacity, low water availability and high sensitivity for erosion. Like many other tropical soils, these soils are acidic and poor in nutrients, with especially low levels of available phosphorus (Driessen and

Dudal 1991). The climate is subtropical with a humid to very humid regime. The mean annual precipitation is 1500-2500 mm and the mean annual temperature is 26 °C. The study area lies within the buffer zone of the Bahuaja-Sonene National Park and the potential natural vegetation is sub-Andean humid montane forest. Coffee agroforestry is the main land use in this agricultural landscape. Disturbed secondary montane evergreen forest (locally known as ‘*puruma*’) occurs only patchily. Coffee (*Coffea arabica* L.) is grown under different shade coffee management systems with varying degrees of intensity (see Hernandez-Martinez *et al.* 2009 for a classification of coffee agroecosystems with a range of intensities). Traditional ‘rustic’ shade-grown coffee is a low intensity management system with a diverse, semi-natural canopy comprising *Ocotea*, *Cabralea*, *Guarea* and *Inga* species and is similar to (secondary) forest, but with the understory thinned and replaced by coffee. Traditional polyculture systems are systems with coffee under a variety of native and introduced, commercially valuable trees, including fruit-bearing and timber trees, such as *Citrus* and *Juglans* species. Commercial polyculture shade-grown coffee is an intensively managed production system in which most of the canopy is removed and replaced by a homogenous canopy dominated by *Inga* species. The individual coffee farms are members of coffee cooperatives that have been triple certified, that is, certified for coffee that is organic (USDA, JAS and EU organic, Bio Latino), shade grown with biodiversity conservation (Rainforest Alliance Certified, Bird Friendly) and fairly traded (Fair Trade Certified). Despite certification, deforestation is prevalent, mainly for cultivation of sun-grown coffee and coca but also for road construction and timber exploitation (Figure 1).

Figure 1. Forest and deforestation in a shade coffee landscape in the buffer zone of the Bahuaja-Sonene National Park in Peru: (A) secondary subandean humid montane forest, (B) shade coffee (background) and sun grown coffee (foreground), (C) deforestation for sun grown coffee, (D) deforestation for coca cultivation

Data collection

Birds were surveyed in August 2011 using variable distance transect counts. We used three 4-8 km long trails that ran through shade-grown coffee stands, orchards and secondary forest (see online supplementary data for a Google Earth KML of the trails). Each of a total of 12 surveys comprised a long, slow walk, taking 4 to 7 hrs between 07h30 in the morning and 16h00 in the afternoon, in both directions of one of the three trails. During each survey, the observer made a list by recording each new species encountered for that given survey. Birds were recorded continuously during the surveys (i.e. there were no intervals during which no species were recorded, as in point counts) and to a variable distance from the trails – the

distance was basically limited by the density of the understory vegetation. A species can only be recorded once in each list but may be recorded in subsequent lists. Generally, such surveys are repeated until a minimum of ten lists have been produced (Bibby *et al.* 1998). To summarize the data, presences and absences over the 12 surveys were converted to relative frequencies, which can be used as an index of relative abundance. The rationale behind the technique is that the probability to be recorded in surveys increases with a species' abundance, assuming no large differences in species' detectability. This method is an unadjusted count method particularly suitable for monitoring (Gregory *et al.* 2004). The procedure is related to timed-species counts (TSC, Freeman *et al.* 2003) and McKinnon lists (McKL, Mackinnon and Phillips 1993) but the method differs from these techniques in that the effort is not bound by fixed survey duration (as in TSC) or a predetermined number of species to be recorded per list (McKL). Because the detectability of birds that are both inconspicuous (small, camouflaged, silent, dull-coloured or otherwise cryptic) and present in low abundances is probably very low, we expected that such species could be underrepresented in our transect counts.

Preferred habitats and preferred diets of recorded birds were obtained from a world bird ecology database with standardized entries on the ecology of all bird species of the world (Sekercioglu 2012). Detailed data on bird species habitat preference and range within Peru was obtained from a field guide (Shulenberg *et al.* 2007).

Data analysis

We calculated the *Chao2* expected species richness based on incidence data to estimate total bird species richness of the studied shade coffee landscape. We used an ordination method (non-metric multidimensional scaling, NMDS) to assess whether individual lists of bird

species varied with environmental gradients that may be present in the study area and locally affect bird communities. NMDS was run using the Sørensen distance measure, six starting dimensions, 500 iterations, an instability criterion of 10^{-7} and a rotation for maximum variance.

We constructed functional signatures of preferred habitats and preferred diets of the sampled bird community. A functional signature of a set of bird species is the distribution of relative frequencies over a number of functional groups. For instance, for habitat preference, the functional signature of a set of observed bird species could be: 50% forest bird species, 30% woodland bird species and 20% grassland bird species. The habitat signatures were constructed using the relative frequencies of the following habitat classes: forest, woodland, shrub, savanna and grassland. The diet signatures were constructed using the following diet classes: fruit, invertebrates, nectar, omnivore, scavenger, seed, fish and vertebrates.

We focused on preferred diet, which is a proxy for ecological function, to compare our data to global patterns in bird ecological function in mixed tropical landscapes. To account for incomplete detection, we calculated *Chao2* expected species richness per functional (dietary) group. To evaluate the effect of future species losses, we derived ten reduced bird communities by subsampling our data using a Monte Carlo procedure. Each reduced bird community consisted of data from only two randomly selected surveys out of our 12 surveys. We constructed three reference bird communities of 100 bird species each of which the preferred diets corresponded to the global diet signatures of bird communities inhabiting forest, agroforest and agriculture in mixed tropical landscapes, respectively (Tscharntke *et al.* 2008). The diet signatures of the different communities (observed, expected, reduced, references) were then statistically compared by use of the phi-statistic ϕ , which is a χ^2 -based measure of association for nominal $\times$ nominal data (communities $\times$ preferred diets). The phi-statistic tests the null hypothesis that the distribution of frequencies of ‘diets’ (fruit,

invertebrates, nectar, etc.) does not differ between two different ‘lists’ (e.g. observed community vs. reference community in tropical forest).

The *Chao2* expected richness estimators for the whole community and for the dietary groups were calculated using EstimateS version 9 (Colwell 2013). NMDS was performed in PC-ORD 6.0 (MjM Software, Gleneden Beach, Or.). Phi-statistics were calculated in IBM SPSS Statistics 20 (IBM Corp., Armonk, NY).

Results

In total, 86 bird species were recorded (Appendix Table 1) in this agricultural landscape, including one vulnerable (Military Macaw *Ara militaris*) and two near threatened species (Orange-breasted Falcon *Falco deiroleucus* and Black-capped Parakeet *Pyrrhura rupicola*). The mean *Chao2* expected richness was 126 species (95% asymmetric confidence interval 104–178 species). In a two-dimensional ordination space, neither counts nor species were divided into clearly distinguishable clusters (Figure 2), which indicates that the bird survey sampled bird species of one bird community occupying the studied landscape and that there were no strong underlying environmental gradients that caused large differences between individual surveys.

The observed bird species were mainly forest generalist species of forest edges and second growth ($n = 67$). The most frequently recorded species of forest edges and secondary growth were Dusky-green Oropendola *Psarocolius atrovirens* (relative frequency over all transect counts $f_r = 1.00$), Ruddy Ground-dove *Columbina talpacoti* ($f_r = 1.00$), Crested Oropendola *Psarocolius decumanus* ($f_r = 0.83$), Silver-beaked Tanager *Ramphocelus carbo* ($f_r = 0.83$) and Bananaquit *Coereba flaveola* ($f_r = 0.58$) (Appendix Table 1; Figure 2). We recorded only few forest specialists ($n = 19$). The most frequently recorded forest specialist

species were Andean Cock-of-the-rock *Rupicola peruvianus* ($f_r = 0.42$), Fork-tailed Woodnymph *Thalurania furcata* ($f_r = 0.42$), Military Macaw *Ara militaris* ($f_r = 0.42$) and Paradise Tanager *Tangara chilensis* ($f_r = 0.42$) (Appendix Table 1; Figure 2). The recorded birds had their main distribution in Amazonia and the eastern slopes of the Andes ($n = 59$) and in the Andes and the outlying ridges ($n = 25$).

Figure 2. Non-metrical multidimensional scaling (NMDS) ordination of 12 variable distance transect counts (large dots) based on presence/absence data of observed bird species (small dots) in a shade coffee agroecosystem in the buffer zone of the Bahuaja-Sonene National Park in Peru. Numbered bird species are 1. Dusky-green Oropendola, 2. Ruddy Ground-dove, 3. Crested Oropendola, 4. Silver-beaked Tanager, 5. Bananaquit, 6. Andean Cock-of-the-rock, 7. Fork-tailed Woodnymph, 8. Military Macaw, 9. Paradise Tanager, 10. Blue Dacnis, 11. Masked Tityra, 12. Social Flycatcher, 13. Squirrel Cuckoo, 14. Blue-gray Tanager, and 15. Blue-headed Parrot. Illustrations adapted from Dean & Wainwright (2005) Peru – Aves del Bosque, Rainforest Publications. Reproduction permission of illustrations granted.

Figure 3. Patterns in the relative frequencies of (A) habitat preferences and (B) diet preferences of birds in shade coffee farms in sub-Andean humid montane forest in SE Peru (86 bird species).

Figure 4. Relative bird species richness (percentage of all bird species) based on primary diet, which is a proxy for ecological function, (A) in forest, agroforest and open agriculture habitat in mixed tropical landscapes (data and primary diet legend after Tscharrntke *et al.* 2008) and (B) in coffee farms in subandean humid montane forest in SE Peru. The bird communities in (B) are the observed community (12 counts, 86 species), the average of 10 reduced communities (25-41 species) and a community based on the *Chao2* expected richness per diet (120 species).

The habitat signature indicated a bird community dominated by forest birds (74%) complemented by birds of degraded habitats (woodland, 12%, shrubland, 11%) (Figure 3A). The diet signature indicated a bird community dominated by insectivores (48%) and frugivores (33%) (Figure 3B). The diet signatures of the observed and expected bird communities differed significantly from the global tropical diet signature in agriculture (observed: $\phi = 0.478$, $P < 0.001$; expected: $\phi = 0.488$, $P < 0.001$) but not from either global tropical forest (observed: $\phi = 0.207$, $P = 0.340$; expected: $\phi = 0.155$, $P = 0.621$) or global tropical agroforest diet signatures (observed: $\phi = 0.172$, $P = 0.599$; expected: $\phi = 0.219$, $P = 0.157$) (Figure 4). The reduced datasets consisted of bird communities of 25-41 bird species (on average 34 species, i.e. 39.5% of the observed number of species). None of the diet signatures of the reduced datasets differed significantly from either global tropical forest (mean ϕ (SE) = 0.247 (0.014), mean P (SE) = 0.451 (0.069)) or global tropical agroforest diet signatures (mean ϕ (SE) = 0.223 (0.013), mean P (SE) = 0.573 (0.071)) and all differed significantly from the global tropical diet signature in agriculture (mean ϕ (SE) = 0.494 (0.018), mean P (SE) < 0.001 (<0.001)).

Discussion

The expected number of birds, based on our 86 detected species, was 104–178 species. This number is comparable to the 180 bird species recorded in shaded coffee plantation in Chiapas, Mexico (Greenberg *et al.* 1997). Imperfect detection commonly leads to underestimations of diversity in tropical studies (Banks-Leite *et al.* 2014). As it is practically impossible to achieve full species lists no matter how intensive the survey (Bibby 2004), we expected to underestimate species richness and thus relative abundances of species groups with very low detection probabilities, for instance, small understory insectivores. Compared to the observed bird community, the expected bird community indeed had a higher proportion of insectivores

(Figure 4B). Such insectivore species are particularly affected by canopy thinning by farmers who reduce shade to increase yield in coffee agroforests (Philpott and Bichier 2012).

However, cryptic forest understory insectivores almost never leave the forest and are rarely observed in coffee agroforests, whereas agroforest insectivorous bird species are more easily observed. Therefore, our potentially missing of cryptic forest understory insectivores has a small impact on the estimates of changes in avian ecosystem services.

Human disturbance and agricultural activities in the study area have transformed the forest to a landscape mosaic of forest, agroforest and non-forest habitat patches. Fragments of secondary forest, open habitats and fields are embedded in a matrix predominantly composed of rustic and polyculture shade-grown coffee agroforests. As forest specialists are known to be particularly susceptible to decreasing forest cover, forest fragmentation and edge effects, and are prone to local extinction following habitat loss (Sodhi *et al.* 2011, Newbold *et al.* 2014), habitat generalist species were expected to outnumber forest species in the study area. Yet with nearly three out of four species (74%) being forest species, the habitat signature (Figure 3) indicated a forest bird community. However, the birds recorded were predominantly forest generalists, i.e. bird species of forest edges and second growth, with only a limited set of forest specialist species. The bird assemblage thus showed that the forest habitat was secondary and probably degraded, despite the triple certification that should promote conservation of forest biodiversity (see also Tscharntke *et al.* 2015). The primary risk to the threatened birds that were recorded (Military Macaw, Orange-breasted Falcon and Black-capped Parakeet) is, according to the IUCN Red List, habitat loss, caused by deforestation, forest fragmentation and forest degradation. Populations of Military Macaw and Black-capped Parakeet are also threatened by domestic trade and hunting (see also Pires *et al.* 2015). Deforestation and forest degradation caused by agricultural intensification in the studied shade coffee farms mean that the recorded threatened species are particularly at risk

and that future species losses of these threatened species and other sensitive species may be expected (see also Peres *et al.* 2010, Moura *et al.* 2013). Improving shade management in the coffee farms in function of the habitat requirements for such species may enhance habitat quality and help to avoid further species losses (see also Eisermann *et al.* 2011). But even so, certified agroforestry systems like shade coffee cannot be seen as substitutes for natural forest. Because of the human activity these habitats are inherently disturbed, and therefore at best supplemental habitat to protected natural forest areas. Protection of large undisturbed forest areas is critically important, even when existing certification schemes that address shade coffee systems attempt to maintain these agricultural land uses as habitat-friendly as possible.

The diet signatures of the observed and expected bird communities were dominated by insectivores and frugivores (Figure 3B, Figure 4B). These functional signatures were very similar to the global diet signatures of both forest and agroforest bird communities (Figure 4). They differed significantly from the diet signature of tropical agriculture bird communities, which contain relatively more granivores and fewer frugivores (Figure 4A, Tschardt *et al.* 2008). The similarity between the observed diet signatures and the global tropical forest and agroforest signatures suggests that the current bird community still functions as a forest or agroforest bird community, and is able to deliver comparable ecosystem services even though most birds are species of forest edges and second growth. Even more strikingly, diet signatures of communities with simulated species losses (comprising less than 40% of the observed species) were also similar to the global tropical forest and agroforest signatures. These results emphasize that management strategies only focused on conserving ecosystem services may be insufficient to support conservation of rare or threatened species. In a recent meta-analysis of crop-visiting bee communities, Kleijn *et al.* (2015) demonstrated that only a limited set of all known bee species delivers pollination services. Agricultural policies that

focus on pollination services by bees therefore do not benefit all wild bees, but only those common species that perform the bulk of pollination. Likewise, when evaluating coffee farms for certification, especially for their bird conservation value, indicators for ecosystem services should not be used in isolation and the presence/absence of globally threatened and range-restricted bird species should also be taken into account.

Conclusions

The diet signature recorded by bird surveys is a flexible method to address the urgency to monitor avian ecosystem services and biodiversity effects of agricultural transitions in the tropics. However, it should not be used in isolation as a relatively limited set of bird species may be responsible for the majority of the avian ecosystem services. Diet signatures can be useful to evaluate coffee farms for biodiversity-friendly certification, but only in combination with indicators that convey information on overall community species richness, functional redundancy and, preferably, population sizes, along with indicators that accurately assess the conservation status of rare and threatened birds that may not be important for delivering ecosystem services.

Despite the ongoing habitat modifications that accompany agricultural intensification in the studied coffee landscape, the bird community that was recorded demonstrated a functional composition that was more similar to a forest community than an agricultural community. Our results support the notion that agriculture can contribute to the conservation of biodiversity and ecosystem services in dynamic landscapes (Tschamntke *et al.* 2005), but also that management strategies or certification audits focused solely at ecosystem services may be insufficient to support conservation of rare or threatened bird species.

Supplementary Material

The supplementary materials for this article can be found at journals.cambridge.org/bci

Acknowledgements

We wish to thank the Central Agricultural Cooperative of the Valleys of Sandia (CECOVASA) for facilitating the research and the University of Utah for hosting the postdoctoral exchange visit (J-1) of R.A. We also wish to acknowledge Evan Buechley, Jordan Herman and Joshua Horns for their valuable comments.

Financial support

This work was supported by the Research Foundation – Flanders (FWO); VLIR-UOS KLIMOS; the University of Utah; and the Leopold III Fund for Exploration and Conservation of Nature.

Conflict of interest

None.

References

- Banks-Leite, C., Pardini, R., Boscolo, D., Righetto Cassano, C., Püttker, T., Santos Barros, C. and Barlow, J. (2014) Assessing the utility of statistical adjustments for imperfect detection in tropical conservation science. *J. Appl. Ecol.* 51:849-859.
- Bibby, C.J., Jones, M. and Marsden, S. (1998) Expedition Field Techniques: Bird Surveys. Expedition Advisory Centre of the Royal Geographical Society and BirdLife International. 134 pp.
- Bibby, C.J. (2004) Bird diversity survey methods. In Bird Ecology and Conservation. A Handbook of Techniques (W.J. Sutherland, I. Newton, and R.E. Green, Editors). Oxford University Press, Oxford, UK. pp. 1-15.
- Bregman, T.P., Sekercioglu, C.H. and 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.
- Buechley, E.R., Sekercioglu, C.H., Atickem, A., Gebremichael, G., Ndungu, J.K., Mahamued, B.A., Beyene, T., Mekonnen, T. and Lens, L. (2015) Importance of Ethiopian shade coffee farms for forest bird conservation. *Biol. Conserv.* 188:50-60.
- Burivalova, Z., Lee, T.M., Giam, X., Sekercioglu, C.H., Wilcove, D.S. and Koh, L.P. (2015) Avian responses to selective logging shaped by species traits and logging practices. *Proc. Roy. Soc. B* 282:20150164. doi:10.1098/rspb.2015.0164
- Calvo, L. and Blake, J. (1998) Bird diversity and abundance on two different shade coffee plantations in Guatemala. *Bird Conserv. Intl.* 8:297-308.

- Colwell, R.K. (2013) EstimateS: Statistical estimation of species richness and shared species from samples. Version 9. User's Guide and application published at:
<http://purl.oclc.org/estimates>
- De Beenhouwer, M., Aerts, R. and Honnay, O. (2013) A global meta-analysis of the biodiversity and ecosystem service benefits of coffee and cacao agroforestry. *Agric. Ecosyst. Environ.* 175:1-7.
- Driessen, P.M. and Dudal, R.(Editors) (1991) The major soils of the world. Lecture notes on their geography, formation, properties and use. Agricultural University Wageningen and Katholieke Universiteit Leuven, Wageningen and Leuven, The Netherlands and Belgium.
- Eisermann, K., Arbeiter, S., López, G., Avendaño, C. and De León Lux, J. (2011) Distribution, habitat use, and implications for the conservation of the globally threatened Azure-rumped Tanager *Tangara cabanisi* in Guatemala. *Bird Conserv. Intl.* 21:423-437.
- Freeman, S.N., Pomeroy, D.E. and Tushabe H. (2003) On the use of timed species counts to estimate avian abundance indices in species-rich communities. *Afr. J. Ecol.* 41:337-348.
- Greenberg, R., Bichier, P. and Sterling, J. (1997) Bird populations in rustic and planted shade coffee plantations of eastern Chiapas, Mexico. *Biotropica* 29:501-514.
- Gregory, R.D., Gibbons, D.W. and Donald, P.F. (2004) Bird census and survey techniques. In Bird Ecology and Conservation. A Handbook of Techniques (W.J. Sutherland, I. Newton, and R.E. Green, Editors). Oxford University Press, Oxford, UK. pp. 17-55.

- Harrison, M.E., Boonman, A., Cheyne, S.M., Husson, S.J., Marchant, N.C. and Struebig, M.J. (2012) Biodiversity monitoring protocols for REDD+: can a one-size-fits-all approach really work? *Trop. Conserv. Sci.* 5:1-11.
- Hernandez-Martinez, G., Manson, R.H. and Hernandez, A.C. (2009) Quantitative classification of coffee agroecosystems spanning a range of production intensities in central Veracruz, Mexico. *Agric. Ecosyst. Environ.* 134:89-98.
- Hundera, K., Aerts, R., Fontaine, A., Van Mechelen, M., Gijbels, P., Honnay, O. and Muys, B. (2013) Effects of coffee management intensity on composition, structure, and regeneration status of Ethiopian moist evergreen Afromontane forests. *Environ. Manag.* 51:801-809.
- Jha, S., Bacon, C.M., Philpott, S.M., Mendez, V.E., Laderach, P. and Rice, R.A. (2014) Shade coffee: update on a disappearing refuge for biodiversity. *Bioscience* 64:416-428.
- Johnson, M.D., Kellermann, J.L. and Stercho, A.M. (2010) Pest reduction services by birds in shade and sun coffee in Jamaica. *Anim. Conserv.* 13:140-147.
- Karp, D.S., Mendenhall, C.D., Sandi, R.F., Chaumont, N., Ehrlich, P.R., Hadly, E.A. and Daily, G.C. (2013) Forest bolsters bird abundance, pest control and coffee yield. *Ecol. Lett.* 16:1339-1347.
- Kellermann, J.L., Johnson, M.D., Stercho, A.M. and Hackett, S.C. (2008) Ecological and economic services provided by birds on Jamaican Blue Mountain coffee farms. *Conserv. Biol.* 22:1177-1185.
- Kleijn, D., Winfree R., Bartomeus, I. *et al.* (2015) Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. *Nature Communications* 6:7414. doi: 10.1038/ncomms8414

- Komar, O. (2006) Ecology and conservation of birds in coffee plantations: a critical review. *Bird Conserv. Intl.* 16:1-23.
- Maas, B., Karp, S.D., Bumrungsri, S. *et al.* (2016) Bird and bat predation services in tropical forests and agroforestry landscapes. *Biol. Rev.* DOI:10.1111/brv.12211
- Martin, E.A., Viano, M., Ratsimisetra, L., Laloe F. and Carriere, S.M. (2012) Maintenance of bird functional diversity in a traditional agroecosystem of Madagascar. *Agric. Ecosyst. Environ.* 149:1-9.
- MacKinnon, S. and Phillipps, K. (1993) A Field Guide to the Birds of Borneo, Sumatra, Java and Bali, Oxford University Press, Oxford, 491 pp.
- Moura, N.G., Lees, A.C., Andretti, C.B., Davis, B.J.W., Solar, R.R.C., Aleixo, A., Barlow, J., Ferreira, J. and Gardner, T.A. (2013) Avian biodiversity in multiple-use landscapes of the Brazilian Amazon. *Biol. Conserv.* 167:339-348.
- Newbold, T., Hudson, L.N., Phillips, H.R.P. *et al.* (2014) A global model of the response of tropical and sub-tropical forest biodiversity to anthropogenic pressures. *Proc. Roy. Soc. B* 281:20141371.
- Pejchar, L., Pringle, R.M., Ranganathan, J., Zook, J.R., Duran, G., Oviedo, F. and Daily, G.C. (2008) Birds as agents of seed dispersal in a human-dominated landscape in southern Costa Rica. *Biol. Conserv.* 141:536-544.
- Peres, C.A., Gardner, T.A., Barlow, J., Zuanon, J., Michalski, F., Lees, A.C., Vieira, I.C.G., Moreira, F.M.S and Feeley, K.J. (2010) Biodiversity conservation in human-modified Amazonian forest landscapes. *Biol. Conserv.* 143:2314-2327.
- Phalan, B., Onial, M., Balmford, A. and Green, R.E. (2011) Reconciling food production and biodiversity conservation: land sharing and land sparing compared. *Science* 333:1289-1291.

- Philpott, S.M., and Bichier, P. (2012) Effects of shade tree removal on birds in coffee agroecosystems in Chiapas, Mexico. *Agric. Ecosyst. Environ.* 149:171-180.
- Pires, S.F., Schneider, J.L., Herrera, M. and Tella, J.L. (2015) Spatial, temporal and age sources of variation in parrot poaching in Bolivia. *Bird Conserv. Intl.* DOI: 10.1017/S095927091500026X
- Railsback, S.F., and Johnson, M.D. (2014) Effects of land use on bird populations and pest control services on coffee farms. *Proc. Natl. Acad. Sci. USA* 111:6109-6114.
- Rice, R.A. (2008) Agricultural intensification within agroforestry: the case of coffee and wood products. *Agric. Ecosyst. Environ.* 128:212-218.
- Schulenberg, T.S., Stotz, D.F., Lane, D.F., O'Neill, J.P. and Parker III, T.A. (2007) Birds of Peru. Revised and updated version. Princeton University Press, Princeton, NJ, USA.
- Sekercioglu, C.H. (2006a) Ecological significance of bird populations. In Handbook of the Birds of the World, volume 11. (J. del Hoyo, A. Elliott, and D.A Christie, Eds) Lynx Press and BirdLife International. Barcelona and Cambridge, Spain and UK. pp. 15-51.
- Sekercioglu, C.H. (2006b) Increasing awareness of avian ecological function. *Trends Ecol. Evol.* 21:464-471.
- Sekercioglu, C.H. (2012) Bird functional diversity and ecosystem services in tropical forests, agroforests and agricultural areas. *J. Ornithol.* 153:S153-S161.
- Sekercioglu, C.H., Wenny D. and Whelan, C.J. (2016) Why Birds Matter: Avian Ecological Function and Ecosystem Services. University of Chicago Press. Chicago.
- Sodhi, N.J., Sekercioglu, C.H., Barlow, J. and Robinson, S.K. (2011) Tropical bird extinctions. In Conservation of Tropical Birds (N.J. Sodhi, C.H. Sekercioglu, J. Barlow, and S.K. Robinson, Eds.). Wiley-Blackwell, Chichester, West Sussex, UK. pp. 45-67.

- Torres, A.B. (2014) Potential for integrating community-based monitoring into REDD plus. *Forests* 5:1815-1833.
- Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C. (2005) Landscape perspectives on agricultural intensification and biodiversity-ecosystem service management. *Ecol. Lett.* 8:857-874.
- Tscharntke, T., Sekercioglu, C.H., Dietsch, T.V., Sodhi, N.S., Hoehn, P. and Tylianakis, J.M. (2008) Landscape constraints on functional diversity of birds and insects in tropical agroecosystems. *Ecology* 89:944-951.
- Tscharntke, T., Milder, J.C., Schroth, G., Clough, Y., DeClerck, F., Waldron, A., Rice, R., Ghazoul, J. (2015) Conserving biodiversity through certification of tropical agroforestry crops at local and landscape scales. *Cons. Lett.* 8:14-23.

Appendix Table 1. Relative frequencies (RF). preferred habitat and preferred diet of bird species recorded in 12 variable distance transect counts in a coffee agroecosystem in sub-Andean montane forest in SE Peru

Species	RF	Preferred habitat ¹	Preferred primary diet ²
Dusky-Green Oropendola (<i>Psarocolius atrovirens</i>)	1.00	forest edge	Invertebrate
Ruddy Ground Dove (<i>Columbina talpacoti</i>)	1.00	forest edge	Seed
Turkey Vulture (<i>Cathartes aura</i>)	0.92	open habitat. field. pasture	Scavenge
Crested Oropendola (<i>Psarocolius decumanus</i>)	0.83	forest edge and second growth	Fruit
Silver-Beaked Tanager (<i>Ramphocelus carbo</i>)	0.83	forest edge and second growth	Fruit
Bananaquit (<i>Coereba flaveola</i>)	0.58	forest edge	Nectar
Squirrel Cuckoo (<i>Piaya cayana</i>)	0.58	humid and semihumid forest	Invertebrate
Purplish Jay (<i>Cyanocorax cyanomelas</i>)	0.50	river edge. second growth. forest edge	Omnivore
Andean Cock-Of-The-Rock (<i>Rupicola peruvianus</i>)	0.42	humid montane forest	Fruit
Bluish-Fronted Jacamar (<i>Galbula cyanescens</i>)	0.42	treefall gaps and edges	Invertebrate
Fork-Tailed Woodnymph (<i>Thalurania furcata</i>)	0.42	interior and canopy of humid forest	Nectar
Magpie Tanager (<i>Cissopis leverianus</i>)	0.42	forest edge and second growth	Fruit
Military Macaw (<i>Ara militaris</i>)	0.42	humid montane forest	Fruit
Paradise Tanager (<i>Tangara chilensis</i>)	0.42	forest and second growth	Fruit
Rufous-Rumped Foliage Gleaner (<i>Philydor erythrocerum</i>)	0.42	forest	Invertebrate
Swallow-Tailed Kite (<i>Elanoides forficatus</i>)	0.42	above forest canopy	Invertebrate
Black Antbird (<i>Cercomacra serva</i>)	0.33	second growth	Invertebrate
Blue-Crowned Trogon (<i>Trogon curucui</i>)	0.33	forest edge and second growth	Invertebrate
Blue-Necked Tanager (<i>Tangara cyanicollis</i>)	0.33	forest edge	Fruit
House Wren (<i>Troglodytes aedon</i>)	0.33	open	Invertebrate
Masked Crimson Tanager (<i>Ramphocelus nigrogularis</i>)	0.33	second growth near water	Fruit
Masked Tityra (<i>Tityra semifasciata</i>)	0.33	Forest	Invertebrate
Yellow-Browed Sparrow (<i>Ammodramus aurifrons</i>)	0.33	edges. pastures	Invertebrate
Black-Capped Parakeet (<i>Pyrrhura rupicola</i>)	0.25	forest	Fruit
Blue Dacnis (<i>Dacnis cayana</i>)	0.25	forest. forest edge and second growth	Fruit
Blue-Headed Parrot (<i>Pionus menstruus</i>)	0.25	humid forest and forest edge	Seed
Orange-Breasted Falcon (<i>Falco deiroleucus</i>)	0.25	hills	Vertebrate
Plumbeous Kite (<i>Ictinia plumbea</i>)	0.25	humid forest and forest edge	Invertebrate
Purple Honeycreeper (<i>Cyanerpes caeruleus</i>)	0.25	forest	Fruit
Social Flycatcher (<i>Myiozetetes similis</i>)	0.25	forest edge and second growth	Invertebrate
Speckled Chachalaca (<i>Ortalis guttata</i>)	0.25	river edge. second growth. forest edge	Fruit

Three-Striped Warbler (<i>Basileuterus tristriatus</i>)	0.25	humid montane forest	Invertebrate
Bay-Headed Tanager (<i>Tangara gyrola</i>)	0.17	forest	Fruit
Bicolored Hawk (<i>Accipiter bicolor</i>)	0.17	forest	Vertebrate
Black-And-White Seedeater (<i>Sporophila luctuosa</i>)	0.17	grass	Seed
Blue-And-White Swallow (<i>Pygochelidon cyanoleuca</i>)	0.17	broken forest and towns	Invertebrate
Blue-Gray Tanager (<i>Thraupis episcopus</i>)	0.17	forest	Fruit
Buff-Throated Saltator (<i>Saltator maximus</i>)	0.17	forest edge and openings	Invertebrate
Channel-Billed Toucan (<i>Ramphastos vitellinus</i>)	0.17	forest	Fruit
Chestnut-Eared Aracari (<i>Pteroglossus castanotis</i>)	0.17	forest and second growth	Fruit
Golden-Bellied Euphonia (<i>Euphonia chrysopasta</i>)	0.17	humid forest and forest edge	Fruit
Gray-Fronted Dove (<i>Leptotila rufaxilla</i>)	0.17	forest edge	Seed
Hooded Siskin (<i>Carduelis magellanica</i>)	0.17	grass	Seed
Little Cuckoo (<i>Coccyua minuta</i>)	0.17	forest edge and thicket	Invertebrate
Long-Tailed Hermit (<i>Phaethornis superciliosus</i>)	0.17	understory of lowland forest	Nectar
Palm Tanager (<i>Thraupis palmarum</i>)	0.17	palms	Fruit
Short-Tailed Pygmy-Tyrant (<i>Myiornis ecaudatus</i>)	0.17	forest edge	Invertebrate
Stripe-Chested Antwren (<i>Myrmotherula longicauda</i>)	0.17	forest edge	Invertebrate
White-Winged Tanager (<i>Piranga leucoptera</i>)	0.17	humid montane forest	Invertebrate
Black-Backed Grosbeak (<i>Pheucticus aureoventris</i>)	0.08	forest edge	Invertebrate
Blue-Naped Chlorophonia (<i>Chlorophonia cyanea</i>)	0.08	humid montane forest	Fruit
Bronze-Green Euphonia (<i>Euphonia mesochrysa</i>)	0.08	humid montane forest	Fruit
Cerulean-Capped Manakin (<i>Lepidothrix coeruleocapilla</i>)	0.08	humid forest understory	Fruit
Chestnut-Backed Antshrike (<i>Thamnophilus palliatus</i>)	0.08	forest edge and openings	Invertebrate
Chestnut-Tipped Toucanet (<i>Aulacorhynchus derbianus</i>)	0.08	humid montane forest	Fruit
Chestnut-Vented Conebill (<i>Conirostrum speciosum</i>)	0.08	riverine forest edge	Invertebrate
Crimson-Crested Woodpecker (<i>Campephilus melanoleucos</i>)	0.08	forest edge and second growth	Invertebrate
Dull-Colored Grassquit (<i>Tiaris obscurus</i>)	0.08	forest edge	Seed
Emerald Toucanet (<i>Aulacorhynchus prasinus</i>)	0.08	humid montane forest	Fruit
Epaulet Oriole (<i>Icterus cayanensis</i>)	0.08	forest edge	Invertebrate
Giant Cowbird (<i>Molothrus oryzivorus</i>)	0.08	forest edge	Fruit
Golden-Bellied Warbler (<i>Basileuterus chrysogaster</i>)	0.08	humid montane forest	Invertebrate
Gray-Capped Flycatcher (<i>Myiozetetes granadensis</i>)	0.08	forest edge and second growth	Invertebrate
Guira Tanager (<i>Hemithraupis guira</i>)	0.08	forest	Invertebrate
Long-Tailed Tyrant (<i>Colonia colonus</i>)	0.08	forest edge and clearings	Invertebrate
Masked Tanager (<i>Tangara nigrocincta</i>)	0.08	forest and forest edge	Fruit
Olivaceous Woodcreeper (<i>Sittasomus griseicapillus</i>)	0.08	forest understory	Invertebrate
Ornate Antwren (<i>Epinecrophylla ornata</i>)	0.08	thickets	Invertebrate
Plain Xenops (<i>Xenops minutus</i>)	0.08	understory of lowland forest	Invertebrate
Plumbeous Pigeon (<i>Patagioenas plumbea</i>)	0.08	forest interior	Fruit
Red-Billed Scythebill (<i>Campylorhamphus trochilirostris</i>)	0.08	humid forest understory	Invertebrate
Red-Stained Woodpecker (<i>Veniliornis affinis</i>)	0.08	forest interior	Invertebrate

Short-Crested Flycatcher (<i>Myiarchus ferox</i>)	0.08	forest edge and second growth	Invertebrate
Streaked Flycatcher (<i>Myiodynastes maculatus</i>)	0.08	forest edge and clearings	Invertebrate
Thick-Billed Euphonia (<i>Euphonia laniirostris</i>)	0.08	river edge	Fruit
Variable Antshrike (<i>Thamnophilus caerulescens</i>)	0.08	forest edge and openings	Invertebrate
Vermilion Flycatcher (<i>Pyrocephalus rubinus</i>)	0.08	open scrub	Invertebrate
White-Backed Fire-Eye (<i>Pyriglena leuconota</i>)	0.08	forest edge	Invertebrate
White-Bellied Woodstar (<i>Chaetocercus mulsant</i>)	0.08	forest edge	Nectar
White-Browed Hermit (<i>Phaethornis stuarti</i>)	0.08	forest	Nectar
White-Crested Elaenia (<i>Elaenia albiceps</i>)	0.08	forest	Invertebrate
White-Flanked Antwren (<i>Myrmotherula axillaris</i>)	0.08	forest understory and second growth	Invertebrate
White-Throated Quail-Dove (<i>Geotrygon frenata</i>)	0.08	humid montane forest	Seed
White-Winged Becard (<i>Pachyramphus polychopterus</i>)	0.08	forest edge	Invertebrate
Yellow-Bellied Tanager (<i>Tangara xanthogastra</i>)	0.08	forest, forest edge and second growth	Fruit
Yellow-Browed Tody-Flycatcher (<i>Todirostrum chrysocrotaphum</i>)	0.08	forest and second growth	Invertebrate

^{1,2} Preferred habitat and preferred diet in the analyses follow the world bird ecology database

(Sekercioglu 2012). The information in this table was complemented by information in Schulenberg *et al.* (2007).

A Supplementary data file can be found with the published article online: KML file for Google Earth of the trails used for the bird survey