

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

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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, understorey insectivores and their associated ecosystem services. Utilising 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. 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.

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 (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 understorey 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, Tscharrntke *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 utilising 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 south-eastern Peru (14°6.80'S, 69°2.85'W), lies on the eastern slopes of the Andes and has an altitude between 900 and 1,500 m. The landscape forms the transition zone between the High Andes and the Amazon Basin and is characterised 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 dystic 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 1,500–2,500 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* 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*, *Cabrlea*, *Guarea* and *Inga* species and is similar to (secondary) forest, but with the understorey 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).

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 material for a Google Earth KML of the trails). Each of a total of 12 surveys comprised a long, slow walk, taking 4–7 hrs between 07h30 in the morning and 16h00 in the afternoon, in both directions, along 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 understorey 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 summarise 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 of being 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

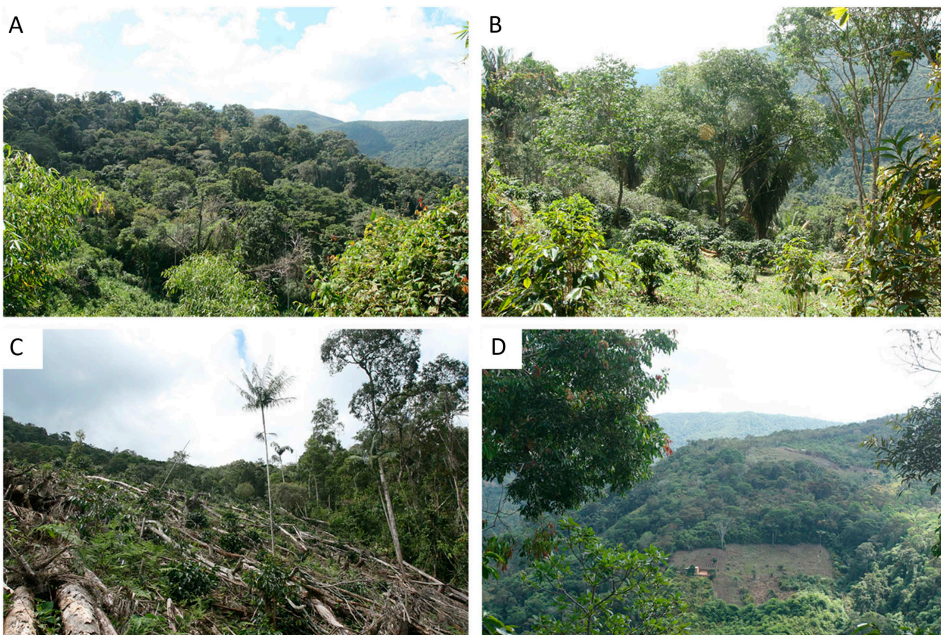


Figure 1. Forest and deforestation in a shade coffee landscape in the buffer zone of the Bahuaja-Sonene National Park in Peru: (A) secondary subandean humid montane forest, (B) shade coffee (background) and sun grown coffee (foreground), (C) deforestation for sun grown coffee, (D) deforestation for coca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

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 standardised entries on the ecology of all bird species of the world (Sekercioglu 2012). Detailed data on bird species habitat preference and range within Peru were obtained from a field guide (Schulenberg *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 (Table S1 in the supplementary material) 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 secondary 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* ($f_r = 0.58$) (Table S1; 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* ($f_r = 0.42$) (Table S1; 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 ($n = 25$).

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: $\phi = 0.478$, $P < 0.001$;

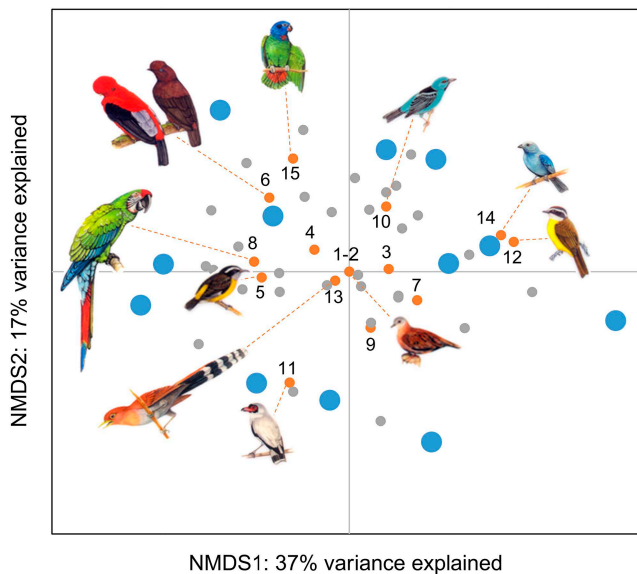


Figure 2. Non-metrical multidimensional scaling (NMDS) ordination of 12 variable distance transect counts (large dots) based on presence/absence data of observed bird species (small dots) in a shade coffee agroecosystem in the buffer zone of the Bahuaja-Sonene National Park in Peru. Numbered bird species 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. Republication permission of illustrations granted.

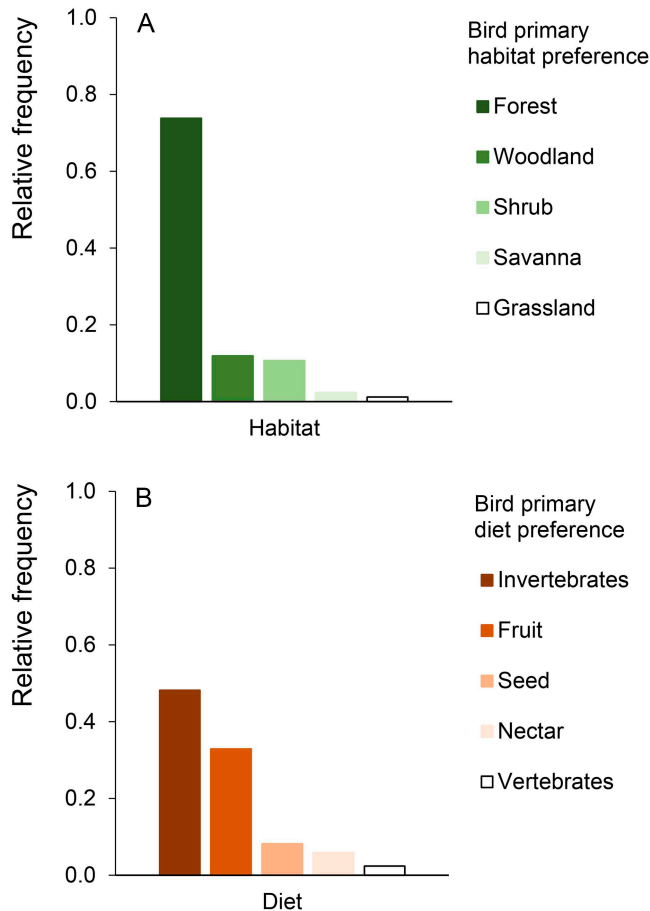


Figure 3. Patterns in the relative frequencies of (A) habitat preferences and (B) diet preferences of birds in shade coffee farms in sub-Andean humid montane forest in SE Peru (86 bird species).

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

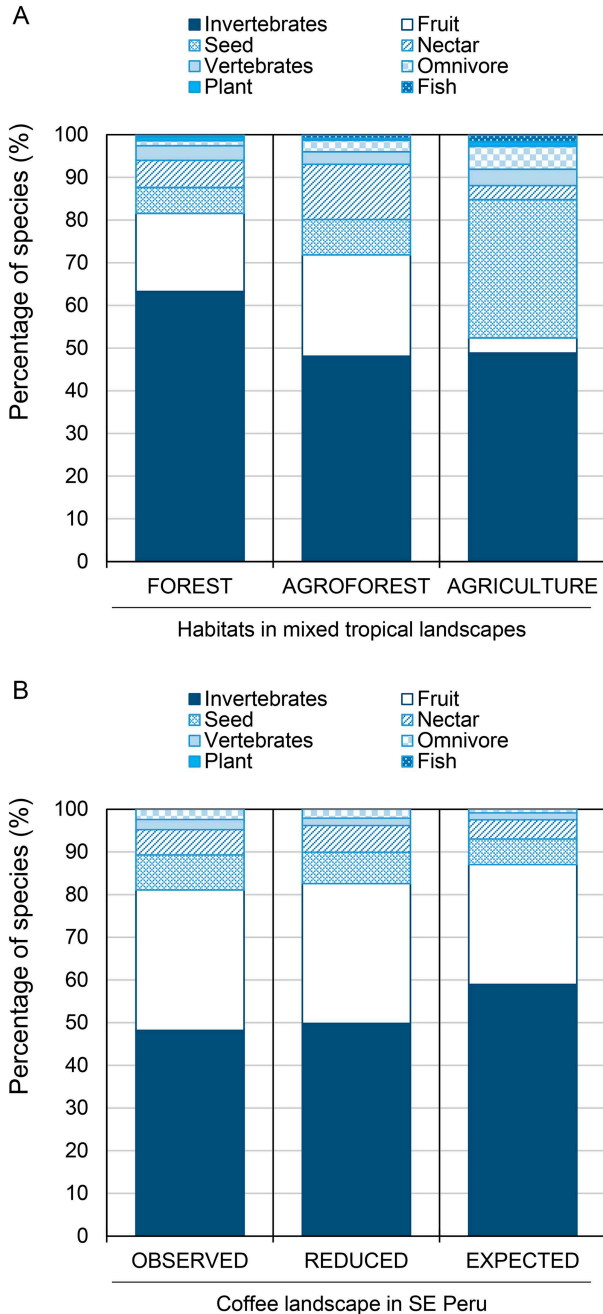


Figure 4. Relative bird species richness (percentage of all bird species) based on primary diet, which is a proxy for ecological function, (A) in forest, agroforest and open agriculture habitat in mixed tropical landscapes (data and primary diet legend after Tscharncke *et al.* 2008) and (B) in coffee 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).

and thus relative abundances of species groups with very low detection probabilities, for instance, small understorey 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 understorey 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 cryptic forest understorey 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 secondary 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, Tscharntke *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 secondary 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 emphasise 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 of monitoring 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 (Tschardt *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

To view supplementary material for this article, please visit <https://doi.org/10.1017/S0959270916000149>

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