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Bird diversity in cacao farms and forest fragments of western Panama

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Abstract *Theobroma cacao* plantings, when managed under the shade of rainforest trees, provide habitat for many resident and migratory bird species. We compared the bird diversity and community structure in organic cacao farms and nearby forest fragments throughout mainland Bocas del Toro, Panama. We used this dataset to ask the following questions: (1) How do bird communities using cacao habitat compare to communities of nearby forest fragments? (2) To what extent do Northern migratory birds use shaded cacao farms, and do communities of resident birds shift their abundances in cacao farms seasonally? (3) Do small scale changes in shade management of cacao farms affect bird diversity? Using fixed radius point counts and additional observations, we recorded 234 landbird species, with 102 species that were observed in both cacao and forest fragments, 86 species that were only observed in cacao farms, and 46 species that were restricted to forest fragments. Cacao farms were rich in canopy and edge species such as tanagers, flycatchers and migratory warblers, but understory insectivores were nearly absent from cacao farms. We observed 27 migratory species, with 18 species in cacao farms only, two species in forest only, and seven species that occurred in both habitats. In cacao farms, the diversity of birds was significantly greater where there was less intensive management of the canopy shade trees. Shade tree species richness was most important for explaining variance in bird diversity. Our study shows that shaded cacao farms in western Panama provide habitat for a wide variety of resident and migratory bird species. Considering current land use trends in the region, we suggest that action must be taken to prevent conversion away from shaded cacao farms to land uses with lower biodiversity conservation value.

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Introduction

Several long-term studies have documented the decline of forest bird populations with the increase of forest loss to agriculture and other human land uses in the American tropics (Stratford and Stouffer 1999; Robinson 2001; Sekercioglu et al. 2002; Sigel et al. 2006). Different types of land use, however, hold profoundly different consequences for bird diversity. In particular, agricultural systems in which crops are grown under the shade of forest trees can maintain habitat for a wide diversity of birds, including some forest birds (Perfecto et al. 1996; Greenberg et al. 1997; Hughes et al. 2002). *Theobroma cacao* crops are generally planted under forest trees in the new world tropics, and high bird diversities have been documented in many cacao landscapes (Greenberg et al. 2000; Reitsma et al. 2001; Estrada and Coates-Estrada 2005; Faria et al. 2006; Gonzales and Harvey 2007, this issue). Thus, cacao appears to provide additional habitat for some bird populations that continue to lose forest habitat.

The vegetation in shaded coffee and cacao farms has simplified structure and taxonomic diversity relative to forest vegetation, and thus may provide habitat for only certain guilds of birds. For example, management regimes in cacao farms include the removal of understory herbs and shrubs, thinning of canopy trees, removal of lianas and epiphytes, and replacement of naturally occurring trees with planted species that provide useful fruits or wood. This simplified system may preclude the use of cacao farms for forest birds that depend on specific foraging niches. The intensity of such management activities has affected levels of biodiversity for several groups of forest fauna (reviewed by Rice and Greenberg 2000). Conservation efforts will be improved by characterizing which species or groups of birds are supported in cacao landscapes, as well as the factors that lead to improved conditions for birds using cacao habitat.

The conservation value of shaded cacao farms in western Panama has not been well documented. Approximately 40% of the land area of the Bocas del Toro Province is protected on paper, but most protection is limited to the highlands of the Parque Amistad Biosphere Reserve. Most lowland forest fragments are privately owned by individuals or indigenous communities, and are under constant threat of logging. This intensifies the importance of the remaining cacao farms for conservation of lowland forest birds in this region. Moreover, a new asphalt road, opened in 1999, connects the previously isolated province with the rest of the country, and the new ease of transport has led to increased production of cattle in the region (pers. obs.). Cacao farms are currently being cleared for cattle production, which has less value for biodiversity conservation (Kaimowitz 1996; Petit et al. 1999; Estrada and Coates-Estrada 2005). Individual farmers, often from indigenous communities, rarely have the capital to purchase their own cattle, but they will clear all or part of their cacao farms with the hope that wealthy ranchers from other parts of Panama will rent the land to graze their cattle (pers. obs.). Cacao holdings have also decreased in the past two decades as an important pathogen, frosty pod disease (*Moniliopthora roreri*) has spread into the region (J. Betia pers. comm.; see also Dahlquist et al. 2007, this issue). Thus, the survival of cacao production in this region faces severe challenges in the coming decades.

Here, we present data on bird diversity from a one year study in western Panama, focusing on the mainland of Bocas del Toro. We use the data to address several questions regarding the conservation value of shaded cacao farms for birds. First, how much and which representatives of the forest bird community are maintained in cacao farms? Second, do Northern migratory birds use shaded cacao farms, and how does this relate to patterns of cacao farm use by resident bird communties? Finally, how do differences in management of crops and shade trees in cacao farms affect bird diversity?

Study sites and methods

Study sites

Our study sites included cacao farms and lowland forest fragments throughout the province of Bocas del Toro, Panama (Fig. 1). The average daily temperature of the region is 26°C and average annual precipitation is 2555 mm (www.worldclimate.com). A mild dry season occurs between the months of January and May. Northern migratory birds can be found in the area between the months of August and May. The cacao harvests occur in January and June, and new leaves and flowers flush during and after the harvest.

Approximately one thousand individual farmers and/or families manage cacao holdings that range from 2–10 ha, and of the cacao produced in the province, approximately 95% is certified organic (J. Betia, pers. comm.). Cacao is generally produced as a central cash crop along with other garden crops, hardwood for timber, and bee-keeping for honey. The most common shade tree in cacao farms is *Cordia alliodora* (Boraginaceae), which can be harvested for timber after 20 years.

We chose study sites by looking for areas where we could find cacao farms and forest fragments within walking distance of each other (up to 4 km apart). Further, we looked for sites where we could walk ~0.5–1 km in continuous habitat (thus our sampling often covered several small adjacent holdings in cacao sites). All farms used shade trees over cacao plantings, with a mean canopy cover of 57% and mean canopy height of 20 m. Cacao crops were trimmed to a maximum height of 4 m and most farmers removed moss and epiphytes from the cacao branches. The farms were all <500 m in altitude and ranged in age between 40 and 100 years old. Lowland wet-tropical forest fragments ranged in size from 10–100 ha, and were privately owned. We asked owners to help us find forest fragments that had not been cleared by their parents or their grandparents. Our criteria for

Fig. 1 Map of study areas in Bocas del Toro Province, Panama. Numbers correspond to the following communities where birds were counted in cacao farms and forest fragments: (1) Bon Llik, (2) Alto Sori, (3) Charagre, (4) Galilea, (5) La Gloria, (6) Charco de Pavo, (7) Nance, (8) Oriente, (9) Valle de Riscó, (10) Quebrada Pastor, (11) Bella Vista, (12) Norteño. Scale: 1 cm = 14 km

choosing fragments was that they were <500 m altitude, they were at least 10 ha, they had a closed canopy consisting of trees 30m in height, and had no obvious logging activity. All owners used these fragments for hunting and probably for that reason large ground birds were nearly absent during our surveys. We estimate that approximately 25% of our forest census points were old growth remnants, while the remainders were old (>50 year) secondary regrowth.

Bird surveys

In order to compare bird species richness and abundance, we sampled 100 points in managed cacao farms and 100 points in forest fragments that ranged ~58 km across the province. The survey points fell along transects within each habitat type (12 transects in cacao farms and 10 forest transects). Within transects, each point was separated by >100 m and at least 50 m from the edge. The first survey occurred during the dry season, January and February of 2004. The survey was repeated at most of the same points in July 2004, during the wet season, with 90 points in cacao farms and 88 in forest fragments. We sampled birds using fixed-radius point counts (25 m radius) to record all visual and aural signs of birds. The point count method is best suited for obtaining a broad sample of bird communities across a patchy landscape (Petit et al. 1994). Two observers were present at each point count (Nichols et al. 2000). The use of double observers allowed us to calculate observer detection probabilities in the two different habitats (Nichols et al. 2000). One observer was present at all point counts while three additional observers rotated as the second observer (see Table 1). Along with point count data, we kept an on-going list of additional sightings outside of points (Electronic Appendix).

Vegetation sampling

To associate gross vegetation features with bird counts in cacao farms, we sampled vegetation using slightly modified methods of James and Shugart (1970). During the dry

Table 1 Probabilities of bird detection by double observers and estimates of bird abundances in cacao farms and forest fragments during the dry and wet seasons

Description	Metric[a]	Dry cacao	Dry forest	Wet cacao	Wet forest	No. points cacao	No. points forest
Mean detection probability							
Observer 1	p_1	0.79	0.87	0.96	0.98	190	188
Observer 2	p_2	–	–	0.96	0.97	90	88
Observer 3	p_3	0.63	0.68	–	–	52	56
Observer 4	p_4	0.58	0.43	–	–	48	44
Overall probability of a bird being detected	$\hat{p}$	0.86	0.94	0.99	0.99	–	–
Estimate of true number of birds	$\hat{N}$	803	750	948	622	–	–
Number of point counts	n	100	100	90	88	–	–
Estimated birds/point	$\hat{N}/n$	8.03	7.5	10.53	7.07	–	–

[a] Metric matches the terminology used for calculations described in Nichols et al. 2000

season only, we collected data on the vegetation characteristics within the 25 m radius circle at each census point. Estimates of canopy cover and structure were made at 5 subpoints within the circle; the center and at approximately 12 m N, S, E and W of the center subpoint. To estimate canopy cover we took readings with a hand-held concave densiometer at each of the 5 subpoints. To estimate canopy structure (depth), at each of the 5 subpoints we recorded the height of the lowest and highest canopy vegetation immediately above the subpoint. We used a digital rangefinder to improve our estimates of canopy height. The difference in the highest and lowest vegetation heights was used to estimate canopy depth at the 5 subpoints within each circle. In cacao farms only, we recorded the number of shade tree species or morphospecies and their heights within the entire 25 m radius circle. We also counted the number of crop plants (cacao, banana, citrus and coffee) in each 25 m radius circle.

Statistical analyses

We compared the number of species and individuals detected per point between forest and cacao points using a non-parametric test based on ranks, the Wilcoxon Mann-Whitney test (StatXact 2004). This test is suitable for comparing populations with different sample sizes. The summary variables for analyses were the number of total bird individuals per point and total bird species per point. Additionally we separated the number of migrants and residents (by individuals and species) per point. We compared these variables in separate analyses for the wet and dry season.

We used formulas from Nichols et al. (2000) to calculate observe detetction probabilities in the two habitats and seasons. The mean detection probabilities are:

$$\hat{p}_1 = \frac{x_{11}x_{22} - x_{12}x_{21}}{x_{11}x_{22} + x_{22}x_{21}}, \quad \hat{p}_2 = \frac{x_{11}x_{22} - x_{12}x_{21}}{x_{11}x_{22} + x_{11}x_{12}}, \text{and}$$

$$\hat{p} = 1 - \frac{x_{12}x_{21}}{x_{22}x_{11}}$$

where $\hat{p}_1$ is the probability for observer 1, $\hat{p}_2$ is the probability for observer 2 and $\hat{p}$ is the overall mean detection probability. The variable x_{ij} is the number of individuals counted by observer i (1, 2) at point counts where observer j (1, 2) was the primary observer. With these probabilities, we could calculate $\hat{N}$, the natural estimator for population size in the sampled area:

$$\hat{N} = \frac{x_{..}}{\hat{p}},$$

where $x_{..} = x_{11} + x_{21} + x_{22} + x_{21}$.

We examined the data for shifts in the resident community of birds using cacao farms between the dry and wet seasons. For each resident species, we summed detections by season and transect to reduce the number of zeroes in the dataset (n = 12 transects per season). We categorized each species as ‘‘common’’ or ‘‘rare’’ in cacao by whether the species was observed in $\geq$10 transects or <10 transects across both seasons. By this definition, there were 22 common species and 86 rare species. For 22 common resident species, we compared the wet and dry season counts per transect in a paired analysis. We excluded one dry season cacao transect because it could not be repeated in the wet season.

As most species counts did not meet the assumptions of parametric tests, we used a Wilcoxon-rank sign test to conservatively assess differences for each common resident species by season. For the rare resident species, we simply describe presence and absence by season.

To determine whether bird diversity was related to vegetation management in cacao farms, we used multiple regression models (general linear models, Systat 2004) with five vegetation parameters as independent variables (% canopy cover, canopy depth, shade tree height, no. of shade tree species, and cacao density). These variables were chosen following a vegetation management index developed in coffee farms (Mas and Dietsch 2003). We used a subset of the bird count data to create two dependent variables, which we call ''bird species richness and bird abundance,'' by eliminating from the bird counts all bird species that were never observed in forest (Electronic Appendix). This process discarded many species which were present in cacao farms but are generally labeled ''agricultural generalists,'' in the literature (Greenberg et al. 1997; Reitsma et al. 2001). Even though agricultural generalists were observed in cacao farms, these species do not depend on forest-like habitat for foraging and were never seen in forest fragments. Normality and independence assumptions were met for the dependent variables in the multivariate models and we did not observe significant correlations among the vegetation variables.

Results

Using fixed-radius point counts and additional observations, we recorded 234 bird species, with 188 species in cacao farms, and 148 species in forest fragments. We counted 102 species that were observed in both habitat types, so that 86 and 46 species were restricted to cacao farms and forest, respectively (Electronic Appendix). Limiting the counts to systematic point counts with double observers, we observed 2937 individuals comprising 133 species in cacao farms and 120 species in forest fragments. We used sample-based rarefaction curves to calculate 95% confidence intervals of 118–148 bird species in cacao farms and 109–131 in forest fragments. We observed seasonal differences in diversity and abundance between the two habitats: bird diversity was similar in cacao and forest during the dry season (bird abundance WMW T = 4916, $P = 0.84$, bird species richness WMW T = 4905, $P = 0.82$, Table 1, Fig. 2), but diversity was greater in cacao farms during the wet season (bird abundance WMW T = 5154, $P < 0.001$, bird species richness WMW T = 5700, $P < 0.001$, Table 1, Fig. 2).

We further explored differences between specific feeding guilds and bird families in cacao farms and forest fragments by mapping their overall frequencies (Fig. 3A, B). In cacao farms, the most abundant feeding guild designation was canopy frugivore-insectivores, represented by the tanagers and tyrant flycatchers (Thraupinae and Tyrannidae, Fig. 3A, B). In forest fragments, understory insectivores were most abundant, represented by antbirds (Formicariidae and Thamnophilidae, Fig. 3A, B). Within cacao farms, most observations of birds were in the canopy layer, but we observed 27 species that were also foraging in the foliage of cacao trees (Table 2). In addition, we saw 23 bird species that were constructing nests in cacao farms (Table 2).

During the dry season census, we observed 27 migratory species, with 18 species in cacao farms only, two species in forest only, and seven species that occurred in both habitats (Electronic Appendix). The mean abundance of over-wintering migrant birds per point was much greater in cacao farms relative to forest fragments (1.1 ± 0.1 vs. 0.3 ± 0.1 individuals per point, WMW, T = 7267, $P < 0.001$).

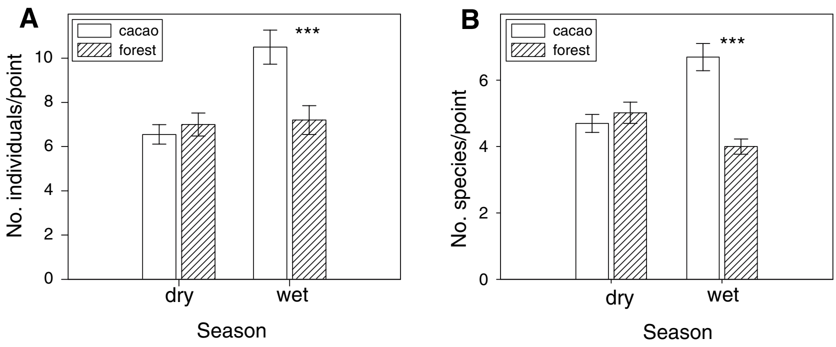

Fig. 2 Seasonal changes in avian abundance and diversity in cacao farms and forest fragments of Bocas del Toro, Panama. (**A**) Mean (SE) number of birds observed per point in cacao farms (open bars) and forest fragments (shaded bars). Data are uncorrected for detection probabilities (as in Table 1). (**B**) Mean (SE) number of bird species observed per point in cacao farms and forest fragments. The sample sizes are the same in panels A and B: cacao dry season, $N = 100$, forest dry season, $N = 100$, cacao wet season, $N = 90$, forest wet season, $N = 88$. ***signifies that $P < 0.001$ in a Wilcoxon Mann-Whitney test, which compared within season values only

The resident bird community using cacao farms changed between the dry and wet season censuses. Of 22 commonly observed resident species, 10 species increased their abundance in cacao farms during the wet relative to the dry seasons (Wilcoxon-signed rank test, 5 comparisons were significant $P < 0.05$ and 5 were marginally significant $P < 0.10$). The resident species that significantly increased their abundance in cacao farms during the wet season were: *Thraupis episcopus* and *Todirostrum cinereum*, (characteristic of agricultural landscapes), *Hylophilus decurtatus* (characteristic of forested landscapes), and *Zimmerius vilissimus a*nd *Tangara larvata* (found in both open habitats and forest canopy). No common resident species decreased abundance in cacao farms in the wet relative to dry seasons. Among rare resident species, we recorded 39 species that were absent in cacao during the dry season but present in wet season census. Understory frugivores, specifically White-collared manakins (*Manacus candei*), was one guild that only appeared in cacao farms during the wet season.

Canopy cover, canopy depth and canopy height were lower in cacao farms relative to forest fragments by 40, 66 and 32%, respectively (Table 3). The most common shade species in cacao farms was *Cordia alliodora*, which accounted for an average of 42% of the shade tree stems per point (Table 3). The next four most common species each accounted for approximately 4% of stems (Table 3). Ninety-seven morphospecies comprised the remaining shade tree stems.

In cacao farms, we observed that bird diversity and abundance were significantly related to shade management practices. The overall model testing bird species richness against canopy cover, depth, cacao density, shade tree species diversity, and shade tree height was significant ($F_{5,93} = 4.3$, $P = 0.001$, Adjusted $r^2 = 0.15$). All vegetation variables were positively correlated to bird species richness. However, only shade tree species diversity explained a significant amount of the variation in bird species richness ($t = 2.9$, $P = 0.005$). Shade tree height explained a marginally significant amount of the variation in bird species richness ($t = 1.6$, $P = 0.10$). The overall model testing bird abundance against the vegetation variables was also significant ($F_{5,93} = 2.9$, $P = 0.02$, Adjusted $r^2 = 0.10$). All vegetation variables were positively correlated to bird abundance. Only shade tree species richness explained a significant amount of variation in bird abundance ($t = 2.4$, $P = 0.02$).

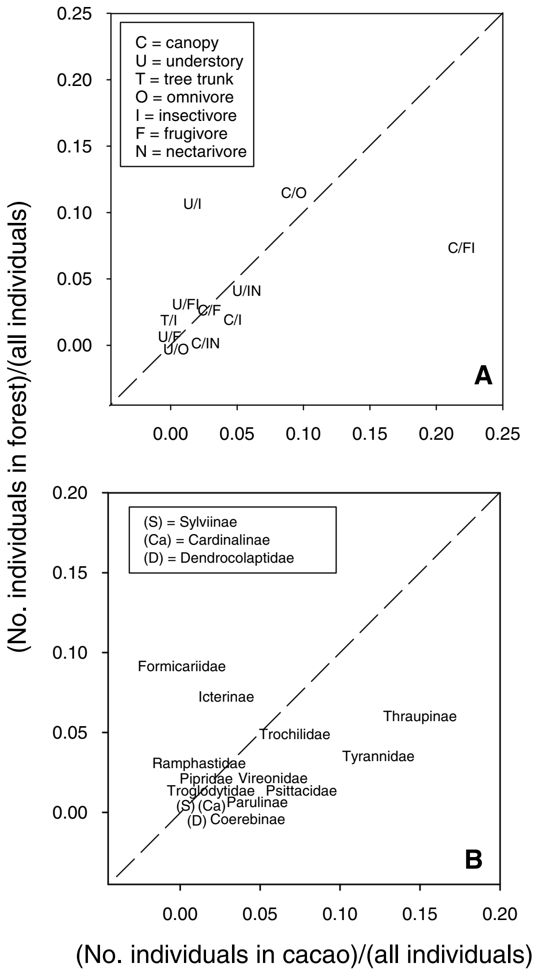

Fig. 3 A comparison of bird feeding guilds and families in cacao farms and forest fragments of Bocas del Toro, Panama. (**A**) The composition of feeding guilds in cacao farms and forest fragments. Each axis represents the number of individual birds (across all points) in cacao or forest, divided by the number of all individuals observed in the study. The dashed line is the one-to-one line, representing equal representation in both habitats. For example, canopy frugivores (C/F) were observed an equal percentage of the time in cacao farms as in forest fragments, but understory insectivores (U/I) were observed much more frequently in forest fragments. Fifty-four percent of the observations were in cacao and 46% were in forest fragments. Feeding guilds with <10 observations in the guild were removed for this figure, with removed datapoints accounting for less than 2% of the overall total. (**B**) The composition of bird families in cacao farms and forest fragments. Axes and dashed line represent the same as in panel 3A

Discussion

The question of which species can or cannot survive in a particular landscape is central to conservation decisions. Although cacao landscapes maintain habitat for a high diversity of resident and migratory birds in western Panama, our observations suggest that some bird guilds are forest dependent and cannot be supported in cacao landscapes. In particular, we found very few understory insectivores in cacao farms, a similar finding to previous reports from shaded agrosystems (Canaday 1996; Faria et al. 2006; Waltert et al. 2005; Gonzalez and Harvey 2007, this issue). The understory herb layer in most cacao farms is actively trimmed to facilitate access to crop plants and prevent overgrowth (pers. obs.). Many understory insectivores depend on having this particular layer of foliage intact for successful foraging. Further, birds that follow army ant swarms are absent in cacao farms, which are generally too small and fragmented to support large ant colonies (Roberts et al. 2000). Thus, preserving cacao habitat may be especially useful for the conservation of

Table 2 Bird species using the cacao layer for foraging and gathering nesting material

Species, common name (no. observations)[a]
Foraging in cacao layer
Amazilia tzacatl Rufous-tailed Hummingbird (24)
Todirostrum cinereum Common Tody-Flycatcher (9)
Amazilia amabilis Blue-chested Hummingbird (8)
Mionectes oleaginous Ochre-bellied Flycatcher (8)
Phaethornis superciliosus Long-tailed Hermit (8)
Dendroica pensylvanica Chestnut-sided Warbler (6)
Glaucis aenea Bronzy Hermit (5)
Phaethornis longuemareus Little Hermit (4)
Zimmerius vilissimus Paltry Tyrannulet (4)
Florisuga mellivora White-necked Jacobin (3)
Habia fuscicauda Red-throated Ant-Tanager (3)
Observed with nesting material in cacao farms
Coereba flaveola Bananaquit
Heliothryx barroti Purple-crowned Fairy[b]
Phaethornis superciliosus Long-tailed Hermit
Chloroceryle aenea American Pygmy Kingfisher
Chaetura cinereiventris Gray-Rumped Swift
Campylorhynchus zonatus Band-backed Wren
Thraupis episcopus Blue-gray Tanager
Myiozetetes granadensis Gray-capped Flycatcher
Tangara inornata Plain-colored Tanager
Aratinga finschi Crimson-fronted Parakeet
Amazilia tzacatl Rufous-tailed Hummingbird[b]
Cacicus uropygialis Scarlet-rumped Cacique
Patagioenas nigrirostris Short-billed Pigeon
Todirostrum cinereum Common Tody-flycatcher
Ciccaba nigrolineata Black-and-white Owl
Psarocolius montezuma Montezuma Oropendula
Pachyramphus polychopterus White-winged Becard
Tangara larvata Golden-hooded Tanager
Glaucis aenea Bronzy Hermit[b]
Amazilia amabilis Blue-chested Hummingbird
Florisuga mellivora White-necked Jacobin[b]
Cyanocorax affinis Black-chested Jay
Zimmerius vilissimus Paltry Tyrannulet

[a] 16 additional species were observed foraging in the cacao layer with <3 observations per species

[b] These species built nests in cacao trees; other species were only observed with nesting material

migratory species, while preserving larger tracts of forest habitat may decrease population declines of understory insectivores.

Several previous studies have documented seasonal shifts in bird communities within a region, generally driven by food abundance (Levey and Stiles 1994; Loiselle and Blake 1991; Greenberg et al. 1997). We observed evidence for a shift in bird community structure moving from the dry to wet seasons. Many resident birds appeared to increase their use of the cacao landscape during the wet period relative to the dry period. One potential

Table 3 Vegetation characteristics and crop densities at points where birds were surveyed in cacao farms and forest fragments

Vegetation variables[a]	Cacao farms, Mean (SE)	Forest fragments, Mean (SE)
% Canopy cover	57.2 (1.9)	95.9 (0.3)
Canopy depth (m)	7.4 (0.5)	21.8 (0.6)
Canopy height (m)	20.3 (0.4)	29.9 (0.7)
No. shade trees/point	20.3 (0.5)	–
No. shade tree species/point	7.9 (0.3)	–
Crops		
No. cacao trees/point	86.2 (2.6)	–
Cacao height (m)	4.3 (0.1)	
No. banana trees/point	30.1 (2.6)	–
No. coffee plants/point	5.6 (2.7)	–
No. citrus trees/point	0.6 (0.2)	–
Common shade tree species (% of all stems/point)		
Cordia alliodora	42.5 (2.5)	–
Inga sp.	4.4 (0.6)	–
Luehea seemannii	3.7 (0.6)	–
Cedrela sp.	3.6 (0.6)	–

[a] All variables were measured at the bird census 100 points in each habitat type during the dry season bird census

explanation is that during the wet season, residents are released from competition with Northern migrants, which were present only during the dry season census. The wet season census also coincided with a period of high nesting activity for the resident bird community. Adult birds feeding nestlings may be using cacao habitat to supplement the prey they find in forest habitats, or may be shifting into cacao habitat specifically for nesting.

The description of a seasonal shift for residents into an agroforest system is one novel aspect of our study, but these results should be taken as preliminary because they describe only one year of data. A further problem with this analysis may be differences in detection probability between the seasons. Resident birds may be easier to detect during their breeding season than non-breeding season, due to increased activity of attracting mates, nest-building, and feeding young. Our calculations of detection probability in different seasons support this notion, with a higher overall probability in the wet season (Table 1). Correcting for this difference, however, still results in higher estimated abundances in cacao farms during the wet relative to dry seasons (Table 1).

In previous studies of shaded agrosystems, greater species diversity of forest organisms has been found where management of canopy vegetation is least intense (Greenberg et al. 1997; Mas and Dietsch 2003; Andersson and Gradstein 2005; Cruz-Angon and Greenberg 2005). At one extreme, where cacao is grown in sparse shade of only a couple of tree species in Indonesia, cacao farms support low bird diversity compared to primary and secondary forest (Waltert et al. 2004). In contrast, most cacao is grown under diverse shade in Central America. Similar to Reitsma et al. (2001) in Costa Rica, we found evidence for greater bird diversity with increasing shade tree species diversity. We note, however, that the vegetation management metrics we used explained a small proportion of the variation in the overall models for bird density and diversity. Nonetheless, these data suggest that farms can attract more birds by planting or maintaining a wide diversity of forest tree species for shade.

The diversity of forest organisms using shaded agroforests is likely to be highly dependent on the landscape matrix in which the agroforests exist. For example, Greenberg et al. (2000) found low bird diversity in Mexican cacao farms, and suggested that distance from forest was an important factor. While Reitsma et al. (2001) found no correlation between bird diversity in cacao farms and distance to forest edge in Costa Rica, Faria et al. (2006) documented greater bird diversity in Brazilian cacao farms that were surrounded by forest than in farms where agriculture dominated the landscape. As our bird survey did not explicitly address questions concerning the landscape matrix, this represents an area for future investigation in western Panama.

Conclusions

Although our study focused on comparisons of cacao and forest, previous studies in Central America suggest that forest bird diversity is much higher in shaded cacao and coffee farms relative to other land uses, such as cultivation of bananas, timber or cattle (Greenberg et al. 1997; Petit et al. 1999; Estrada and Coates-Estrada 2005; Gonzalez and Harvey 2007, this issue). In addition to providing habitat for resident and migratory birds, shaded agrosystems provide ecosystem services to humans that will improve environmental quality and economic gain over the long term. Currently, organic cacao production in western Panama is threatened by economically important pathogens and conversion of cacao landscapes into cattle fields. Making cacao production more economically sustainable to farmers will require the recognition by additional stakeholders of the biodiversity value and other ecosystem services provided by cacao landscapes. For example, government officials and non-governmental organizations can work to preserve biodiversity in cacao landscapes by providing incentives to farmers that will offset the losses due to pathogens. Equally important are the support of research and educational programs (e.g. CATIE in Costa Rica), that detail the best practices to improve pathogen control as well as the ecosystem services provided by biodiversity in cacao landscapes.

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