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Presence and abundance of birds in an Atlantic forest reserve and adjacent plantation of shade-grown yerba mate, in Paraguay

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Abstract. In the Atlantic forest region, there is a need to develop economic activities that can be carried out in buffer zones around parks, with minimal impact on forest bird species. One such possibility is the farming of yerba mate, *Ilex paraguariensis*, under native trees. We compared bird species' presence and abundance between a forest reserve and an adjacent plantation of shade-grown yerba mate, to determine which species might use such plantations. Of the 145 species that were regularly recorded in the forest, 66%, including five globally threatened species, were also regularly recorded in the plantation. Most canopy species and tree trunk insectivores showed similar abundance in both habitats, but forest floor and understory species were absent from the plantation. Within the plantation, higher tree density did not lead to a greater abundance of forest birds. Yerba mate grown under native trees could be used to rehabilitate cleared land and allow recolonization by some Atlantic forest bird species.

Introduction

The Atlantic forest of southeastern Brazil, northeastern Argentina, and eastern Paraguay, is one of the world's top five biodiversity hotspots (Myers et al. 2000) and one of South America's highest priorities for bird conservation (Stotz et al. 1996; Stattersfield et al. 1998). Agriculture, cattle-ranching, and industry have replaced more than 90% of the Atlantic forest, mostly within the last 30 years. The diverse bird community is threatened by high-grade logging (Aleixo 1999), hunting (BirdLife International 2000), habitat loss, and habitat fragmentation (Marsden et al. 2001), all of which have led to local extirpations of formerly common species (Willis 1979; Christiansen and Pitter 1996; Ribon et al. 2003). In total, 61 of the Atlantic forest's 199 endemic bird species are endangered, vulnerable, or extinct in the wild (IUCN 2002; endemism from Stotz et al. 1996). Indeed, this region now contains more critically endangered birds than any other in the neotropics (Stotz et al. 1996).

Protected areas should be the top priority for conserving Atlantic forest birds, but, given the region's large population, private land-ownership, and rapid deforestation, it is also important to find economically viable activities that do not involve total deforestation. For example, existing parks require buffer zones in which economic activities are limited, and, preferably, compatible with conservation. One such activity could be the production of shade-tolerant crops under a tree canopy. Research in Africa, Asia, and Latin America suggests that such shade-grown crops can conserve some species of birds and other wildlife, especially when planted under a diverse canopy of native trees and located near native forest (Moguel and Toledo 1999; Rice and Greenberg 2000).

One of the Atlantic forest region's most widespread crops is the native yerba mate, *Ilex paraguariensis*, whose leaves are used to make mate (hot tea) and terere (cold tea). Although it is almost always produced as a monoculture in full sun, yerba mate can be grown in shade under native trees (Eibl et al. 2000). For certified organic, shade-grown yerba, farmers in Paraguay receive three times the price of traditional, sun-grown yerba, making shade-grown yerba an economically viable option despite slightly lower yields (A. Pryor *in litt.*). Thus, shade-grown yerba mate could be planted in buffer zones or biosphere reserves as a compromise between bird conservation and agriculture.

Despite the potential for yerba mate to be grown under native trees, it is not clear how such plantations would be used by birds in the region. If shade-grown crops are to be used in buffer zones, it is important to identify which forest birds occur in such plantations, and how plantations may be managed to promote bird conservation.

To our knowledge, only one study has examined the potential for shade-grown crops to conserve Atlantic forest birds. In Brazil's coastal Atlantic forest, Alves (1990) found that, with the exception of tinamous (Tinamidae), cracids (Cracidae), antbirds (Formicariidae), and manakins (Pipridae), most bird families present in the forest were also represented in shade-grown cacao plantations.

Here we confirm and extend Alves' (1990) findings in a species-level study of birds in an Atlantic forest reserve and adjacent plantation of shade-grown yerba mate. Our first objective was to compare the presence and abundance of bird species in the forest reserve and adjacent plantation, and to compare differences in presence and abundance between broad groups of birds characterized by typical habitat, strata, and diet. Our second objective was to compare two parts of the plantation that differed in tree density and canopy cover, to determine whether higher tree density in the plantation led to higher total abundance of birds in any of the ecological groups.

Methods

Our study was conducted between 16 October and 5 December 2001 (austral spring) and 19 February and 22 April 2002 (late summer, early autumn) at

Estancia Itabó, Department of Canindeyú, Paraguay (24°30′S 54°38′W, elevation 300 m).

Study site

The study site was located within a 5000 ha tract of Atlantic forest and an adjacent 80 ha plantation of shade-grown yerba mate, and included approximately 50 ha of the forest and 45 ha of the plantation (Figure 1). Fifty hectare plots are considered necessary to avoid missing rare species in diverse tropical forest bird communities (Terborgh et al. 1990). The size and layout of the plantation did not allow for replication of such large plots, and trails were too close together to be independent; thus, we compare the bird community between the entire 50 ha of forest and the entire 45 ha of plantation.

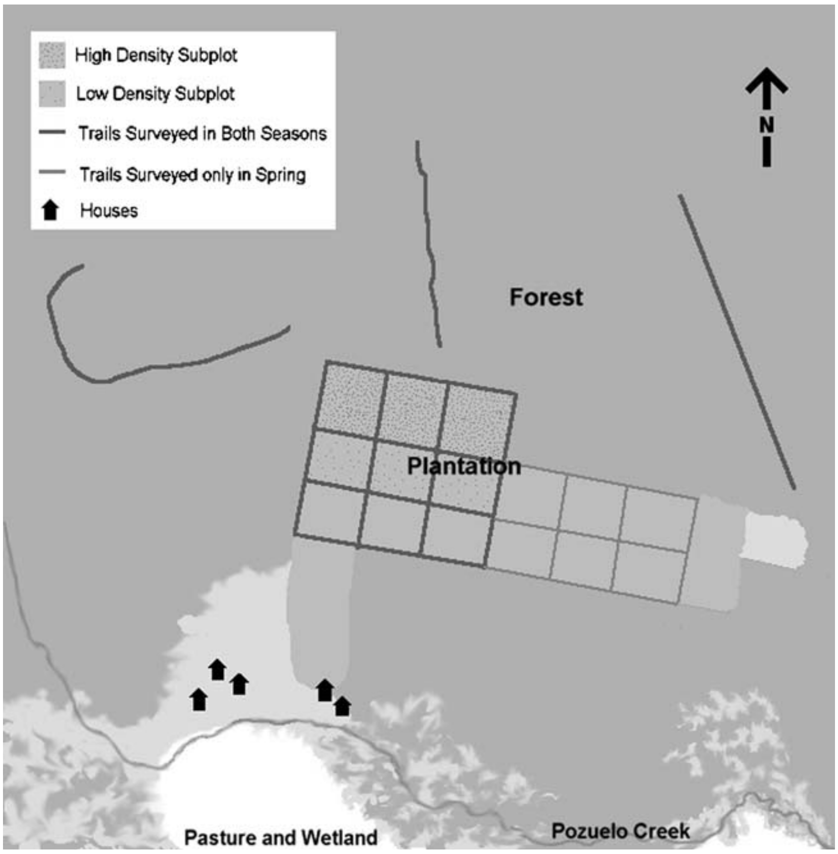

Figure 1. A map of the study site showing the forest, the plantation, the trails surveyed in spring and autumn, and features of the surrounding landscape. Pale gray is degraded forest and capuera (cleared areas that are now regenerating).

Overall, the forest and plantation were similar in terms of elevation, slope, tree species, density of standing-dead trees, and abundance of epiphytes (Cockle 2003). Both had been subject to light logging 25 years before our study. The plantation was created by removing the forest understory and some trees, then planting yerba mate below the tree canopy. Thus, the forest had more lianas and vines, and greater canopy cover than the plantation (80% canopy cover in the forest compared to 60% in the plantation; see Cockle 2003 for more details on the study site).

Within the plantation, we also compared a 12 ha subplot with high tree density and canopy cover (343 stems/ha; 80% cover), to a 12 ha subplot with low tree density and canopy cover (137 stems/ha; 50% cover; Figure 1).

In the forest, we surveyed birds along three trails (525, 1260, and 1000 m, for a total length of 2785 m) that were separated by at least 300 m at all points, and began 75 m from the plantation. In the plantation, we surveyed birds along trails that formed a grid of 200 m $\times$ 200 m cells. We surveyed 15 cells in the spring sampling period and nine in the autumn. Routes in both habitats were marked every 25 m with numbered tags that served as reference points for recording bird locations.

Sampling techniques

Where possible, we used spot-mapping to census birds (International Bird Census Committee 1969; Bibby et al. 2000). We surveyed the forest and plantation on alternate days, choosing our routes in advance and using different starting points and directions to balance for time-of-day within and between sites. In total, we surveyed the entire study site six times in each of spring and autumn. Birds were never surveyed during rain.

Beginning 30 min before first light and for the next 3–4.5 h, we spot-mapped birds along 1–3 km of trail per day, noting every individual or group of birds heard or seen. We identified each bird to species based on songs, calls, and/or visual observation, then estimated its distance and measured its compass direction from our location. We periodically checked distance estimates by visually confirming the location of a bird that had been detected aurally. We could reliably estimate distance and direction for all but two species (*Chamaeza campanisona* and *Grallaria varia*), which we did not attempt to spot-map.

Where possible, we recorded sex, age (adult, immature, or dependent fledgling), behavior (singing, feeding, carrying food, carrying nesting material, begging, fighting, etc.), and whether two records of the same species were simultaneous. Mixed species flocks were treated as a single record, but the number and species of birds in the flock were recorded. For single-species groups registered aurally, we noted simply ‘group’ and later substituted the average group size for that species based on visual observations. We later omitted birds flying in a straight line over the study site and all birds recorded outside the plot that we were surveying (e.g. birds calling in the forest while we were surveying the plantation).

Nocturnal species were spot-mapped in the pre-dawn period of the morning surveys, and in surveys on five clear moonlit nights (between dusk and 02:00). On a further 16 nights we played back recordings of 13 nocturnal species (for details see Cockle 2003); however, we failed to detect any new species using playback, so the results of these surveys are omitted here. Playback was most useful in establishing the year-round presence and territoriality *of Strix huhula* and *Strix virgata* at our study site (for details see Cockle 2003).

Analysis

A preliminary analysis showed that, with the exception of a few migratory species, there was little variation between seasons in the presence and abundance of birds, so we pooled data over the two seasons. Based on published literature (e.g. Sick 1993; Stotz et al. 1996) and AB's field experience, we placed each species into one of the following three categories (see Appendix 1): (1) forest species, (2) edge species (includes species associated with anthropogenic habitats), and (3) aerial species (those that spend most of their active time in the air). Forest species were then divided into five groups based on the strata in which they are most often found: (1) canopy species, (2) midstory species, (3) understory species, (4) forest floor species, and (5) tree trunk species, and five groups based on the predominant food items in their diet: (1) fruit-or-grain-eaters, (2) fruit-and-insect-eaters, (3) insectivores, (4) nectarivores, (5) carnivores and carrion-eaters.

Qualitative measures

Species were considered to be occasional or accidental, and therefore excluded from the qualitative analysis, if they were encountered on fewer than five occasions and either (a) used the site only as a stop-over during migration (e.g. *Elaenia albiceps*), (b) were found only within 20 m of the edge of the habitat (e.g. *Thamnophilus caerulescens* in the plantation), or (c) were visiting from outside the study site (e.g. *Syndactila rufosuperciliata* visiting from nearby gallery forest).

We tested the completeness of species lists by plotting species accumulation curves for the forest and the plantation. Since species richness is affected by plot size (James and Rathbun 1981), we calculated species richness using only the part of the plantation that was surveyed in both seasons (43.8 ha) and an equivalent sized, randomly selected portion of the forest (also 43.8 ha), hereafter referred to as the 'main plots'. We assumed that most species at our study site could be detected up to 100 m away. In order to reduce differences in detectability between habitats, and to be certain that all our records fell within the habitat we were surveying, we excluded birds detected beyond 100 m from our location. We plotted the accumulated number of species against the total number of individuals accumulated in each of the two main plots. Since both curves reached a plateau, species richness is compared based on the total number of species accumulated in each of the main plots.

We calculated the Sørensen coefficient (Brower and Zar 1977) to examine qualitative community similarity between the forest and the plantation, based on the species found in the main plots:

$$CC_s = 2c/(s_1 + s_2)$$

where s_1 is the number of species in community 1 (forest), s_2 is the number of species in community 2 (plantation) and c is the number of species shared by both communities.

For each habitat-, strata- and diet group, we calculated the number of species found only in the forest (forest-restricted), as a proportion of all species in the group. For example, a high proportion of forest-restricted species in a given diet group suggests that birds dependent on the given food source avoided the plantation. We tested whether different habitat-, strata-, and diet groups had different proportions of forest-restricted species, using a χ^2 analysis of contingency tables with $\chi^2 = 0.05$ (Zar 1999).

Quantitative measures

Since we spent about equal time in each habitat (104 and 103 morning hours in the forest and plantation, respectively), we compared the total number of encounters (records) of each species between habitats, for each of the 123 species that was recorded more than 10 times, to get an index of abundance. Because we covered the same routes every week, our records presumably included repeat observations of the same individuals, thus violating the independence assumptions of most statistical tests. Rather than test for statistical differences between the forest and plantation, we considered a species to be more abundant in the forest than in the plantation if there were at least twice as many records of that species in the forest as in the plantation. To find out whether habitat-, strata-, and diet groups differed in the proportion of species that were more abundant in the forest than in the plantation, we used a χ^2 analysis of contingency tables with $\chi^2 = 0.05$ (Zar 1999).

For 31 territorial species, we also estimated breeding density using standard territory mapping (International Bird Census Committee 1969) with some modifications to adapt the method to the tropics (after Terborgh et al. 1990; Thiollay 1994; see Cockle 2003, for details). To calculate breeding density, we divided the number of territories by the area surveyed, and multiplied by 100 for a density expressed as N° territories/100 ha. Since trails were at least 200 m apart, we did not assume to have surveyed all points between trails. Rather, we plotted a detection function (number of encounters versus distance from trail) for each species, and used the shoulder of this curve to determine the area that was effectively mapped (see Cockle 2003, for details). We considered species to differ in density between the two habitats if their density was twice as high in one habitat as in the other (following Marsden et al. 2001).

Comparisons within the plantation

To determine whether variation in tree density affected the use of the plantation by birds, we compared two 12 ha subplots within the plantation. For comparison, we selected a subset of the total visits to the subplots, balancing for time of day, time of year, and location within the subplot (i.e. corner, edge, or middle). Night birds were excluded. This exercise reduced our sample size, so that we did not have enough observations to detect all species in each of the two subplots, or to compare the number of encounters by species. Instead, we compared the two subplots based on the total number of encounters of birds in each habitat-, strata-, and diet group (adding up all the records of all species in each group).

Results

In 207 h of morning spot-mapping and 29 h of night-surveys and playback, we registered 13,752 contacts with 201 species of birds in the study site.

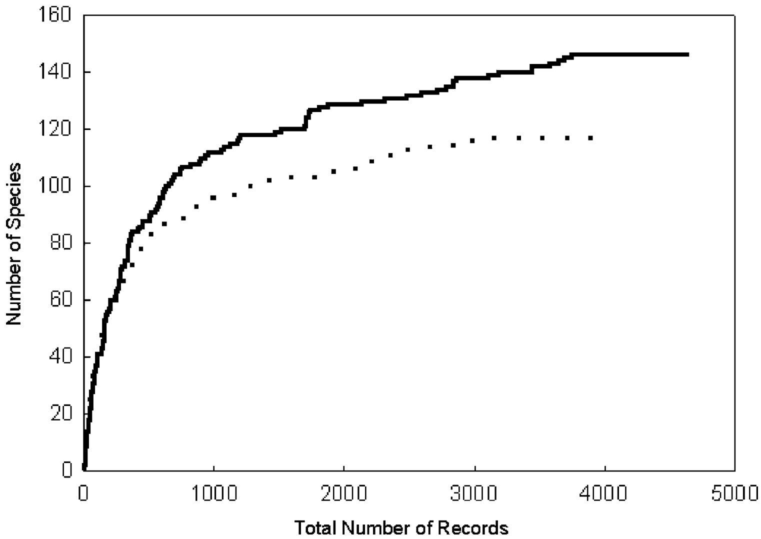

Figure 2. Total number of species recorded in the main plots in the forest (solid line) and in the plantation (broken line) in relation to the total number of records of any species in the same plot.

Table 1. Percent (%) of species in each habitat-, strata-, and diet group, that 1) were restricted to the forest, and 2) were more abundant in the forest than in the plantation (twice as many records in the forest as in the plantation).

	Restricted to the forest	More abundant in the forest
Total	30	40
Edge species	3	0
Aerial species	0	0
Forest species	38	52
Canopy species	14	24
Midstory species	44	81
Understory species	88	100
Forest floor species	70	80
Tree trunk species	9	12
Fruit-or-grain eaters	20	17
Fruit-and-insect eaters	30	46
Insectivores	44	60
Nectarivores	0	100
Carnivores	67	–

Species richness

In the main plots, we registered 4627 contacts in the forest and 4024 contacts in the plantation. We detected 165 species of birds (occasional species omitted): 145 in the forest and 116 in the plantation (Figure 2).

Qualitative community similarity

In total, 49 of the 165 species recorded in the main plots were found only in the forest, 96 were found in both habitats, and 20 were restricted to the plantation. Thus, 66% of the birds present in the forest were also present in the plantation, and Sørensen' coefficient of community similarity was 0.74.

The proportion of species restricted to the forest differed significantly among habitat groups ($\chi^2 = 16.7$, df $= 2$, $p < 0.001$) and strata groups ($\chi^2 = 48.3$, df $= 4$, $p < 0.001$), but not diet groups ($\chi^2 = 9.34$, df $= 4$, $p > 0.05$; Table 1). Forest birds, especially understory-, forest floor-, and midstory species, were those most often restricted to the forest (Table 1).

Total number of encounters for each species

Overall, 40% of species were encountered at least twice as many times in the forest as in the plantation, and were considered to be more abundant in the forest. We found significant differences among habitat groups ($\chi^2 = 25.1$, df $= 2$, $p < 0.001$), strata groups ($\chi^2 = 39.2$, df $= 4$, $p < 0.001$), and diet groups ($\chi^2 = 10.6$, df = 3, $p < 0.025$) in the proportion of species that showed higher abundance in the forest than the plantation (Table 1).

Estimated density

Of the 31 territorial species for which we estimated density, only two were present in similar densities in both habitats (no more than twice as many territories in one habitat as in the other; Figure 3). Of the remaining 29 species, 20 were more than twice as common in the forest, and 9 were more than twice as common in the plantation.

Threatened species

During this study we recorded one Endangered species (*Amazona vinacea*; lUCN, 2002), one Vulnerable species (*Tinamus solitarius*; IUCN, 2002) and five near-threatened species (*Dryocopus galeatus*, *Piculus aurulentus*, *Phylloscartes eximius*, *Phylloscartes sylviolus*, and *Polioptila lactea*; IUCN, 2002). All seven species were encountered in the forest, and five were also encountered in the plantation. *Amazona vinacea*, *Phylloscartes sylviolus*, and *Polioptila lactea* were recorded at least twice as often in the plantation as in the forest.

Comparisons within the plantation

In the selected spot-mapping visits to the high- and low tree density subplots, we recorded 3202 contacts with 106 species of birds. Both forest- and edge birds were more common in the low tree density subplot (Figure 4). Among forest birds, canopy species and fruit-or-grain-eaters were markedly more common in the low tree density subplot, while understory species were more common in the high tree density subplot (Figure 4).

Discussion

The composition of the bird community differed between the shade-grown yerba plantation and the forest, but 66% of the species using the forest also used the plantation. Forest birds were both more abundant and more diverse in the forest, while edge species were more abundant and more diverse in the plantation. Never-the-less, five IUCN-listed forest species were encountered in the plantation (of seven recorded in the forest). Midstory, forest floor, and understory species, in particular, were less diverse and less abundant in the plantation. In contrast, canopy- and tree trunk birds showed high community similarity and similar numbers of encounters in both habitats, suggesting that most species in these groups are able to use the plantation habitat. We found stronger differences between strata groups than between diet groups, but, among forest birds, fruit-or-grain-eaters were found more often in the plantation compared to the other diet groups.

Within the plantation, both forest- and edge species were most abundant where tree density was low. Among forest species, canopy birds made up the majority of the records and were most common where tree density was low, while the few understory and midstory birds were more abundant where tree density was high. Among forest canopy species, fruit-and-grain-eaters were the only diet group with a large difference in abundance between the two tree densities, with a higher abundance where tree density was low.

There are four main sources of bias that could affect our results. (1) The layout of survey routes differed between the plantation (grid) and the forest (long trails), so that rare species were more likely to be absent from the plantation by chance. We minimized this bias by using large plots (see Terborgh et al. 1990). (2) We spent considerable time surveying along the

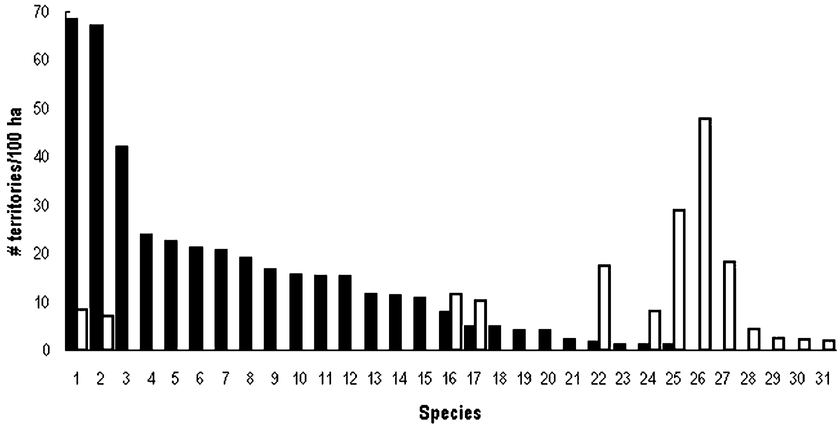

Figure 3. Number of territories per 100 ha, for 31 species, in the forest (black) and plantation (white). 1 = *Basileuterus culicivorus*, 2 = *Myiornis auricularis*, 3 = *Conopophaga lineata*, 4 = *Synallaxis ruficapilla*, 5 = *Crypturellus obsoletus*, 6 = *Basileuterus leucoblepharus*, 7 = *Platyrinchus mystaceus*, 8 = *Dysithamnus mentalis*, 9 = *Thamnophilus caerulescens*, 10 = *Hemitriccus diops*, 11 = *Trichothraupis melanops*, 12 = *Capsiempis flaveola*, 13 = *Otus atricapillus*, 14 = *Synallaxis cinerascens*, 15 = *Lathrotriccus euleri*, 16 = *Glaucidium brasilianum*, 17 = *Otus choliba*, 18 = *Leptopogon amaurocephalus*, 19 = *Corythopis delalandi*, 20 = *Habia rubica*, 21 = *Automolus leucophthalmus*, 22 = *Myiodynastes maculatus*, 23 = *Mionectes rufiventris*, 24 = *Contopus cinereus*, 25 = *Pitangus sulphuratus*, 26 = *Troglodytes aedon*, 21 = *Megarynchus pitangua*, 28 = *Colonia colonus*, 29 = *Camptostoma obsoletum*, 30 = *Myiozetetes similis*, 31 = *Falco sparverius*.

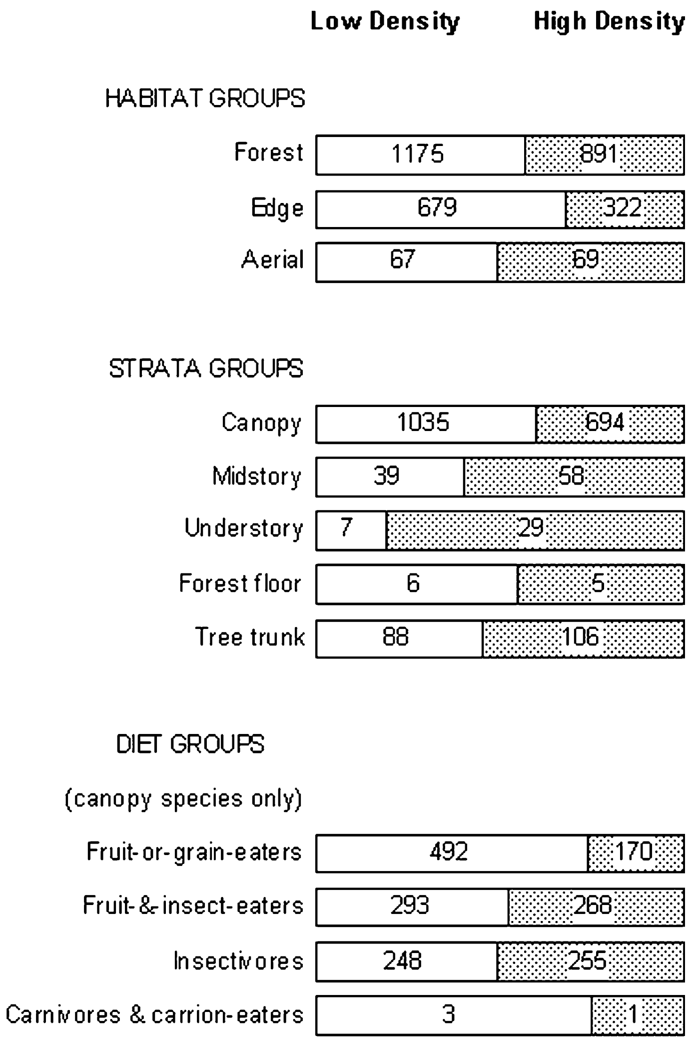

Figure 4. Number of bird records in low- (white) and high- (stippled) tree density subplots within the plantation, for each of the habitat-, strata-, and diet groups. Nectarivores are excluded because there were no canopy nectarivores at our study site.

edge of the plantation, but almost no time at the edge of the forest. This biased our results toward a lower number of encounters in the plantation compared to the forest, because we ignored birds detected outside of the habitat we were surveying. (3) Visibility (and hence detectability) was higher in the plantation than in the forest. (4) Our study considered only one plantation and only one forest site, so our results cannot be generalized.

Shade-grown crops as habitat for forest birds

With some exceptions, our species-level study was consistent with the results of Alves' (1990) study that examined families of Atlantic forest birds in a shade-grown crop. Consistent with our results, Alves (1990) found that, compared to nearby Atlantic forest, plantations of shade-grown cacao supported lower abundance of antbirds (Formicariidae and Thamnophilidae), tinamous (Tinamidae), and manakins (Pipridae), most of which are forest floor and understory species. However, our study at the species-level revealed some interesting differences that would not have been detected in the family level study. For example, although both studies found that tyrant-flycatchers (Tyrannidae) as a family were at least as abundant in the shade-grown crops as in the forest (see Appendix 1), our study found that only tyrant-flycatchers of the forest canopy and forest edge were more abundant in the plantation than the forest, while flycatchers of the forest floor and understory were absent from the plantation. Despite differences between species for several families, our results support the general conclusions of Alves' (1990) study that, although some forest species are absent, birds are abundant in shade-grown crops with native trees, adjacent to native Atlantic forest.

Compared to most other studies of birds in shade-grown crops (Greenberg et al. 1997a,b; Calvo and Blake 1998), our study revealed a higher proportion of forest birds in the plantation. In large part, this may be explained by the proximity of native forest to our plantation. Surveys in plantations within deforested landscapes rarely find birds associated with interior forest (Greenberg et al. 1997a,b; Calvo and Blake 1998). In contrast, near large tracts of natural forest, other studies have found between 25 and 62% of forest bird species in shade-grown crops (Terborgh and Weske 1969; Thiollay 1995; Canaday 1997).

While proximity to native forest is important, several other factors also play a role in determining the bird diversity of plantations. High canopy cover and tree density, for instance, may allow more forest birds to use a shade-grown crop (Greenberg et al. 1997b; Calvo and Blake 1998). Contrary to this observation, we found that forest birds (other than a few midstory and understory birds) were more common in the plantation subplot with lower tree density, suggesting that, at the tree densities we studied, high canopy cover and tree density were less important than other factors in allowing Atlantic forest birds to use the shade-grown yerba plantation.

Other authors have predicted that forest birds will be most abundant in plantations with structural and floristic diversity and abundant edible fruit (Moguel and Toledo 1999; Rice and Greenberg 2000), We find support for these hypotheses when we consider the combined results of several field studies, including ours. Plantations with structural and floristic diversity and abundant edible fruit (including plantations, like ours, where the canopy consisted of remnant forest trees; Alves 1990; Greenberg et al. 1997b; Calvo and Blake 1998) tend to support a greater diversity of birds, particularly canopy frugivores, compared to less diverse plantations without fruit (Thiollay 1995; Calvo and Blake 1998).

Management considerations

Although the shade-grown yerba plantation did not support forest understory or midstory birds, it contained nearly all of the canopy- and tree trunk species from the nearby forest, including five globally threatened and near-threatened species. These results suggest that shade-grown yerba mate may be an appropriate land-use for buffer zones around reserves in the Atlantic forest. Our study considered only one plantation, and, therefore, we do not know whether our results can be generalized. That said, the Atlantic forest requires urgent conservation action, so we suggest an 'adaptive management' approach to shade-grown yerba mate.

Shade-grown yerba mate could be especially beneficial, and less damaging to existing forest, if used to rehabilitate some of the land that has already been deforested, including plantations of yerba mate currently grown in the open. Planting a wide diversity of native forest trees might return some of the structural complexity and floristic diversity of natural forest to previously cleared land, allowing forest birds to re-colonize areas from which they are currently excluded. Agronomically this appears to be feasible. Eibl et al. (2000) found promising yields for yerba mate grown alongside native tree seedlings on abandoned agricultural land, and another study is underway to explore the costs of reforestation with yerba mate and other native trees, on land adjacent to Iguazú National Park in Argentina (S. Holz, in litt.).

In our plantation, a high tree density subplot (343 stems/ha; 80% canopy cover) did not support more forest birds than a low tree density subplot (137 stems/ha; 50% canopy cover), suggesting that increasing canopy cover beyond certain levels may not lead to increased abundance or diversity of forest birds. Further studies in the Atlantic forest should aim to confirm or refute these results, and to examine other ways to increase the bird conservation value of shade-grown crops.

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Appendix 1. List of species detected in the plantation and forest, with habitat groups, strata groups, diet groups, special conservation status, presence/absence in the plantation and forest, estimated density in each habitat, and total number of encounters in each habitat.

Species[A]	Habitat[D]	Strata[E]	Diet[F]	IUCN Status[G] (endemic spp.)[H]	Presence and density[I] N° territories/100 ha (N° territories total)		Total N° birds within 100 m of observer	
					Forest	Plant'n	Forest	Plant'n
Tinamidae								
Tinamus solitarius[C]	f	f	fi	LR/nt(e)	Occasional	–	0	0
Crypturellus obsoletus	f	f	fi		23(22)	–	78	0
Crypturellus parvirostris	e				–	Occasional	0	0
Crypturellus tataupa	f	f	fi		+	+	43	2
Cathartide								
Coragyps atratus[B,C]	e				+	+	1	8
Cathartes aura[B,C]	e				+	Occasional	4	1
Sarcoramphus papa[B,C]	f	c	c		+	–	4	0
Accipitridae								
Leptodon cayanensis[B,C]	f	c	c		+	+	1	1
Elanoides forficatus[B]	a				+	*	23	138
Harpagus diodon[B,C]	f	c	i		+	+	2	2
Ictinia plumbea[B]	a				+	*	39	88
Geranospiza caerulescens[B,C]	f	c	c		Occasional	–	1	0
Buteo magnirostris	e				–	(1)	1	20
Falconidae								
Micrastur ruficollis	f	m	c		(4)	–	4	0
Micrastur semitorquatus	f	c	c		(3)	(1)	2	3
Falco sparverius[B,C]	e				–	2(2)*	0	20
Cracidae								
Penelope superciliaris[B,C]	f	m	fi		+	–	1	0
Odontophoridae								
Odontophorus capueira	f	f	fi	(e)	Occasional	–	0	0

Rallidae								
Aramides saracura	f	f	i	(e)	Occasional	–	0	0
Columbidae								
Columba speciosa	f	c	fg		(1)	–	11	0
Columba picazuro	f	c	fg		+	+	22	153
Columba cayennensis	f	c	fg		+	+	24	38
Zenaida auriculata	e				–	Occasional	0	2
Claravis pretiosa[C]	f	f	fg		+	+	3	3
Leptotila verreauxi	f	f	fg		+	+	7	21
Leptotila rufaxilla	f	f	fg		+	–	3	0
Geotrygon montana[B,C]	f	f	fg		+	–	3	0
Psittacidae								
Aratinga leucophthalmus	f	c	fg		+	*	104	76
Pyrrhura frontalis	f	c	fg		+	*	212	411
Forpus xanthopterygius	e				–	+	0	16
Brotogeris chiriri	e				Occasional	+	2	69
Pionopsitta pileata	f	c	fg	(e)	+	+	12	10
Pionus maximiliani	f	c	fg		+	*	66	275
Amazona vinacea	f	c	fg	EN(e)	+	+	13	175
Cuculidae								
Coccyzus euleri	f	c	i		Occasional	Occasional	0	0
Coccyzus melacoryphus[B]	e				–	Occasional	0	1
Piaya cayana	f	c	i		+	+	54	22
Crotophaga major	f	m	i		Occasional	–	4	0
Crotophaga ani	e				–	(1 group)	0	23
Guira guira	e				–	(2 grps)	0	26
Dromococcyx phasianellus[C]	f	u	i		+	–	1	0
Dromococcyx pavoninus[C]	f	u	i		+	–	2	0
Tytonidae								
Tyto alba	e				+	+	0	1
Strigidae								
Otus choliba	f	m	i		5(2)	10(5)*	16	43
Otus atricapillus[B]	f	m	i		12(4)	+	17	1

Appendix 1. Continued.

Species[A]	Habitat[D]	Strata[E]	Diet[F]	IUCN Status[G] (endemic spp.)[H]	Presence and density[I] N° territories/100 ha (N° territories total)		Total N° birds within 100 m of observer	
					Forest	Plant'n	Forest	Plant'n
Strix hylophila	f	c	c		Occasional	–	0	0
Strix virgata	f	c	c		(2)	–	1	0
Strix huhula	f	c	c		(1)	–	2	0
Glaucidium brasilianum	f	m	i		8(10)	12(7)	43	36
Nyctibiidae								
Nyctibius aethereus[C]	f	c	i		(1)	–	0	0
Nyctibius griseus	f	c	i		+	+	8	6
Caprimulgidae								
Lurocalis semitorquatus	a				+	+	45	71
Nyctidromus albicollis	e				–	+	0	4
Caprimulgus sericocaudatus	f	c	i		Occasional	–	0	0
Apodidae								
Cypseloides fumigatus	a				–	Occasional	0	1
Streptoprocne zonaris	a				–	Occasional	0	1
Chaetura cinereiventris	a				+	+	29	140
Chaetura meridionalis	a				–	+	0	33
Trochilidae								
Phaethornis eurynome[B]	f	m	n		+	+	66	30
Anthracothorax nigricollis[B]	e				–	Occasional	0	1
Stephanoxis lalandi[B]	f	m	n	(e)	+	+	26	6
Chlorostilbon aureoventris[B]	e				–	+	0	2
Thalurania furcata[B]	f	m	n		–	+	2	2
Thalurania glaucopis[B]	f	m	n	(e)	+	+	14	4
Hylocharis chrysura[B]	e				+	+	3	19
Agyrtria versicolor[B]	f	m	n		+	+	2	1
Trogonidae								
Trogon rufus	f	m	fi		(6)	+	48	3
Trogon surrucura	f	c	fi		+	*	114	124

Momotidae								
Baryphthengus ruficapillus	f	m	i	(e)	+	Occasional	52	6
Momotus momota	f	m	i		(1)	–	6	0
Bucconidae								
Notharchus swainsoni[B]	f	c	i	(e)	+	*	7	15
Nystalus chacuru	e				–	Occasional	0	4
Nonnula rubecula[B]	f	m	i		+	Occasional	15	1
Ramphastidae								
Pteroglossus castanotis	f	c	fg		(3 grps)	(2 grps)*	78	96
Selenidera maculirostris	f	c	fg	(e)	(2)	(1)	35	14
Ramphastos dicolorus	f	c	fg		(4 grps)	(2 grps)*	19	27
Picidae								
Picumnus temminckii[B]	f	u	i	(e)	+	+	24	5
Melanerpes candidus	e				–	Occasional	0	0
Melanerpes flavifrons	f	c	fi		+	+	23	176
Veniliornis spilogaster	f	m	i	(e)	+	+	18	67
Piculus aurulentus	f	c	i	LR/nt (e)	+	+	8	2
Colaptes melanochloros	f	t	i		+	+	3	25
Celeus flavescens[C]	f	t	i		+	*	5	11
Dryocopus galeatus[C]	f	t	i	VU (e)	+	+	1	1
Dryocopus lineatus[C]	f	t	i		+	*	2	12
Campephilus robustus[C]	f	t	i	(e)	+	+	5	18
Furnariidae								
Synallaxis ruficapilla[B]	f	u	i	(e)	24(7)	–	117	0
Synallaxis cinerascens	f	u	i		11(7)	–	69	0
Cranioleuca obsoleta	f	c	i	(e)	Occasional	Occasional	1	2
Syndactila rufosuperciliata	f	u	i		Occasional	Occasional	4	4
Philydor lichtensteini	f	m	i	(e)	+	+	228	75
Philydor rufus	f	c	i		+	+	19	7
Philydor atricapillus	f	m	i	(e)	+	–	3	0
Automolus leucophthalmus	f	u	i	(e)	2(2)	–	32	0
Sclerurus scansor	f	f	i	(e)	(1)	–	5	0
Heliobletus contaminatus	f	c	i	(e)	+	Occasional	3	1

Appendix 1. Continued.

Species[A]	Habitat[D]	Strata[E]	Diet[F]	IUCN Status[G] (endemic spp.)[H]	Presence and density[I] N° territories/100 ha (N° territories total)		Total N° birds within 100 m of observer	
					Forest	Plant'n	Forest	Plant'n
Xenops minutus	f	m	i		+	–	14	2
Xenops rutilans	f	c	i		+	+	20	12
Dendrocolaptidae								
Dendrocincla turdina	f	t	i	(e)	+	–	9	0
Sittasomus griseicapillus	f	t	i		+	+	237	175
Xiphocolaptes albicollis	f	t	i		+	*	57	36
Dendrocolaptes platyrostris	f	t	i		+	*	90	79
Lepidocolaptes fuscus	f	t	i		+	+	50	7
Lepidocolaptes falcinellus	f	t	i		–	+	0	1
Thamnophilidae								
Mackenziaena severa	f	u	i	(e)	+	–	37	0
Thamnophilus caerulescens	f	u	i		17(9)	Occasional	159	2
Dysithamnus mentalis	f	u	i		19(12)	–	196	0
Herpsilochmus rufimarginatus	f	c	i		+	+	221	6
Terenura maculata	f	c	i	(e)	+	+	71	4
Pyriglena leucoptera	f	u	i	(e)	+	–	70	0
Formicariidae								
Chamaeza campanisona	f	f	i		+	–	41	0
Grallaria varia	f	f	i		+	–	3	0
Conopophagidae								
Conopophaga lineata	f	u	i	(e)	42(15)	–	190	0
Tyrannidae								
Mionectes rufiventris	f	u	fi	(e)	1(1)	–	5	0
Leptopogon amaurocephalus	f	u	i		5(3)	–	33	0
Hemitriccus diops[B]	f	u	i	(e)	16(5)	–	85	0
Corythopis delalandi	f	f	i		4(2)	–	30	0
Phyllomyias virescens[B]	f	c	i	(e)	+	+	3	6

Camptostoma obsoletum	f	c	fi		+	3(1)*	4	36
Capsiempis flaveola[B]	f	u	i		15(3)	–	34	0
Myiopagis caniceps	f	c	i		+	+	125	94
Myiopagis viridicata	f	c	i		+	+	8	2
Elaenia flavogaster	e				–	Occasional	0	1
Elaenia albiceps[B,C]	e				–	Occasional	0	1
Phylloscartes eximius	f	m	i	LR/nt(e)	+	–	2	0
Phylloscartes ventralis[B,C]	f	c	i		+	–	2	0
Phylloscartes sylviolus[B,C]	f	c	i	LR/nt(e)	+	(1)*	3	25
Myiornis auricularis[B]	f	u	i	(e)	67(16)	7(2)	236	10
Tolmomyias sulphurescens	f	m	i		+	+	9	4
Platyrinchus mystaceus	f	u	i		21(7)	–	141	0
Cnemotriccus fuscatus[B,C]	f	u	i		+	–	6	0
Lathrotriccus euleri	f	u	i		11(9)	Occasional	109	2
Contopus cinereus	f	c	i		1(1)	8(4)*	10	80
Colonia colonus	e				+	4(2)*	2	22
Sirystes sibilator	f	c	i		+	+	47	91
Myiarchus swainsoni	e				+	+	2	29
Myiarchus ferox	e				–	Occasional	0	1
Ramphotrigon megacephala	f	m	i		(1)	–	6	0
Tyrannus melancholicus	e				–	Occasional	0	3
Empidonomus varius[C]	e				–	+	0	8
Megarynchus pitangua	e				+	18(12)*	12	168
Conopias trivirgata	f	c	i		+	+	25	45
Myiodynastes maculatus	e				2(1)	18(8)*	12	139
Myiozetetes similis	e				–	2(1)	0	7
Legatus leucophaius[C]	e				–	*	0	5
Pitangus sulphuratus	e				1(1)	29(14)*	16	342
Schiffornis assemblage								
Schiffornis virescens	f	m	fi	(e)	(4)	–	48	0
Piprites chloris	f	m	fi		+	+	54	4
Pachyramphus viridis	e				+	+	13	52
Pachyramphus castaneus	e				+	*	3	74

Appendix 1. Continued.

Species[A]	Habitat[D]	Strata[E]	Diet[F]	IUCN Status[G] (endemic spp.)[H]	Presence and density[I] N° territories/100 ha (N° territories total)		Total N° birds within 100 m of observer	
					Forest	Plant'n	Forest	Plant'n
Pachyramphus polychopterus	e				–	Occasional	0	1
Pachyramphus validus	e				–	+	0	11
Tityra cayana	f	c	fi		+	+	58	124
Tityra semifasciata	f	c	fi		–	+	0	3
Tityra inquisitor	f	c	fi		+	*	48	136
Cotingidae								
Pyroderus scutatus[C]	f	c	fi	(e)	–	Occasional	0	0
Oxyruncidae								
Oxyruncus cristatus	f	c	fi		+	+	37	14
Pipridae								
Pipra fasciicauda[B,C]	f	u	fi		(4)	–	36	3
Chiroxiphia caudata	f	m	fi	(e)	(2)	–	14	0
Vireonidae								
Cyclarhis gujanensis	f	c	i		(3)	+	39	3
Vireo olivaceus	f	c	i		+	–	3	0
Corvidae								
Cyanocorax cyanomelas	e				–	Occasional	0	0
Cyanocorax chrysops	f	c	fi		+	+	170	293
Hirundinidae								
Progne chalybea	a				–	–	5	5
Progne tapera	a				–	–	3	3
Petrochelidon pyrrhonota	a				–	–	0	4
Troglodytidae								
Troglodytes aedon	e				–	48(20)	0	412
Polioptilidae								
Polioptila lactea[B]	f	c	i	LR/nt(e)	+	+	8	16

Turdidae								
Turdus subalaris[C]	f	c	fi	(e)	+	–	1	0
Turdus rufiventris	e				+	+	8	25
Turdus leucomelas	e				+	*	50	442
Turdus amaurochalinus	e				+	+	8	7
Turdus albicollis	f	m	fi		+	+	4	1
Parulidae								
Parula pitiayumi	f	c	i		+	+	91	70
Basileuterus culicivorus	f	u	i		69(33)	9(3)	501	66
Basileuterus leucoblepharus	f	u	i		21(12)	–	217	0
Thraupidae								
Conirostrum speciosum	f	c	i		+	+	185	194
Cissopis leveriana	f	c	fi		+	+	40	15
Hemithraupis guira	f	c	i		+	+	333	238
Tachyphonus coronatus[C]	f	u	fi		Occasional	–	3	0
Habia rubica	f	u	fi		4(3)	–	45	1
Trichothraupis melanops	f	u	fi		15(8)	–	133	1
Thraupis sayaca	e				Occasional	+	2	70
Pipraeidea melanonota[B,C]	f	c	fi		+	+	2	1
Euphonia chlorotica	f	c	fi		+	+	16	81
Euphonia violacea	f	c	fi		+	+	34	56
Euphonia pectoralis	f	c	fi	(e)	+	+	52	41
Chlorophonia cyanea[B,C]	f	c	fi		+	+	14	26
Tangara seledon[B,C]	f	c	fi	(e)	+	+	10	60
Dacnis cayana[B,C]	f	c	fi		+	+	25	46
Tersina viridis	e				+	+	23	139
Emberizidae								
Coryphospingus cucullatus[C]	e				–	–	1	0
Sporophila caerulescens	e				–	–	0	1
Arremon flavirostris	f	f	fg		–	–	2	0
Zonotrichia capensis	e				–	–	0	3

Appendix 1. Continued.

Species[A]	Habitat[D]	Strata[E]	Diet[F]	IUCN Status[G] (endemic spp.)[H]	Presence and density[I] N° territories/100 ha (N° territories total)		Total N° birds within 100 m of observer	
					Forest	Plant'n	Forest	Plant'n
Icteridae								
Cacicus haemorrhous	f	c	fi		+	*	56	127
Icterus cayanensis	e				+	+	16	87
Gnorimopsar chopi	e				Occasional	+	2	27
Molothrus bonariensis	e				–	Occasional	0	1
Molothrus oryzivorus	e				–	Occasional	0	1
Molothrus rufoaxillaris	e				–	+	0	9

[A]Taxonomy follows Mazar Barnett and Pearman (2001).
[B]Species whose vocalization cannot be heard consistently 100 m away.
[C]Species that vocalize infrequently during the time of year covered by our study seasons.
[D]Habitat groups are: f = forest; e = edge, a = aerial.
[E]Strata groups (for forest birds only) are: c = canopy, m = midstory, u = understory, f = forest floor, t = tree trunk.
[F]Diet groups (for forest birds only) are: fg = fruit-or-grain-eater, fi = fruit-and-insect-eater, i = insectivore, n = nectarivore, c = carnivore or carrion-eater.
[G]IUCN conservation status follows IUCN (2002). EN = endangered, VU = Vulnerable, LR/nt = lower risk / near-threatened.
[H]Species endemic to the Atlantic forest are marked (e). We follow Guyra Paraguay (2004).
[I]Presence (in the main plots) is indicated by +, the estimated density, the total number of territories, or* (see below). Species considered absent are marked – if they were never recorded in the habitat, or 'occasional' if they were occasional visitors to the habitat. We report the total number of territories and estimated density only for species for which these numbers could be determined in both habitats.
* Species confirmed breeding in the habitat (active nests, adults repeatedly carrying nest material or food to the same tree, or newly fledged young within a known territory)

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