EFFECTS OF SELECTIVE LOGGING ON A BIRD COMMUNITY IN THE BRAZILIAN ATLANTIC FOREST[1]

ALEXANDRE ALEIXO[2]

*Pós-graduação em Ecologia, Universidade Estadual de Campinas, CP 6109, CEP 13083-970,
Campinas, SP, Brazil*

Abstract. I evaluated the effects of selective logging upon a bird community in the Brazilian Atlantic forest. Two areas 500 m apart were selected for quantitative (point censuses) avian surveys: a non-fragmented primary forest (PF) and a selectively logged forest (LF). Six of eight quantitative measures of vegetation structure compared between PF and LF were reduced at LF. Indices of avian species richness and diversity were very similar between PF and LF sites; species composition, however, differed strongly. Although the composition of guilds remained largely the same, most guilds differed in membership between PF and LF in at least one species. Understory and terrestrial insectivores were the most sensitive ecological groups (with most species missing in LF), as also observed in the process of forest fragmentation in other parts of the Neotropics. Based on the results of this study, I recommend the following procedures to minimize adverse effects of selective logging on bird communities in the Atlantic forest: (1) logged areas should be close enough to unfragmented, unlogged forests to allow recolonization of some species, (2) the exploitation of the forest should be carried out using as few roads and as little mechanized equipment as possible, and (3) long-term rotation should be used in areas designed for logging to allow time for forest regeneration.

Key words: Atlantic Forest, bird communities, point counts, selective logging, southeastern Brazil.

Resumo. No presente estudo investiguei os efeitos do corte seletivo de espécies arbóreas sobre uma comunidade de aves da Mata Atlântica, nas proximidades de Sete Barras, SP, Brasil. Um levantamento quantitativo de avifauna foi efetuado numa mata inexplorada (PF) e outra explorada por madeireiros e palmiteiros (LF). Apesar da maior parte dos parâmetros estruturais da vegetação sofrer redução na LF, os padrões de riqueza e diversidade das comunidades de aves diferiram pouco entre os dois tipos de mata estudados. A composição da avifauna, por outro lado, foi bastante alterada na LF. A composição dos grupos ecológicos da avifauna alterou-se pouco de um modo geral entre as matas, mas na maioria dos grupos pelo menos uma espécie foi prejudicada pelo corte seletivo. Espécies insetívoras de subosque e de solo compõe o perfil ecológico mais ameaçado da avifauna, repetindo o mesmo padrão de grupos ecológicos mais prejudicados pela fragmentação florestal. São feitas as seguintes recomendações a métodos de retirada seletiva de madeira, no sentido de serem menos danosos a comunidades de aves florestais da Mata Atlântica: (1) manter a maior proximidade possível entre matas exploradas e não exploradas e contínuas, (2) aplicar práticas exploratórias que utilizem o menor número possível de vias de acesso e que reduzam a exploração mecanizada (arraste e transporte das toras) ao estritamente necessário e (3) estabelecer rodízio nas áreas a serem exploradas.

INTRODUCTION

Vegetation structure is thought to be one of the key features influencing avian species richness at the local level (Wiens 1989). Many studies have shown changes in the composition and structure of tropical bird communities once any kind of disturbance (natural or human) occurs in

the vegetation (Terborgh and Weske 1969, Schemske and Brokaw 1981).

The selective extraction of timber is considered an alternative economic activity with low environmental impact (CIFOR 1993). Although damage induced by this type of extraction in tropical forests is lower than that of traditional techniques, it is clear that it can adversely affect vegetation structure and composition (Uhl and Vieira 1989, Frumhoff 1995). Many studies have reported that the organization of tropical bird communities also is modified by selective logging, with a significant reduction in the num-

ber and abundance of some species (Wong 1986, Lambert 1992, Mason 1996).

The Atlantic Forest of southeastern Brazil is considered one of the most threatened ecosystems in the world (Brown and Brown 1992); its avifauna is the most endangered part of the Neotropical bird assemblage (Stotz et al. 1996), with future extinctions predicted for many species (Brooks and Balmford 1996). Except for studies on the impact of forest fragmentation (Willis 1979, Aleixo and Vielliard 1995, Christiansen and Pitter 1997) and cocoa plantations (Alves 1990), no other studies on the impact of human activities on bird communities are available for the Atlantic Forest.

In this paper I compare the composition and structure of a bird community between undisturbed and logged forest plots in the Brazilian Atlantic Forest by addressing three questions: (1) how do bird assemblages differ in species composition and abundance, (2) how are avian species richness and diversity affected by selective logging, and (3) do different ecological groups of the community differ in their sensitivity to selective logging?

METHODS

STUDY AREA

The two forest plots studied (primary and logged forests) are ca. 30 km southwest of the township of Sete Barras, southern São Paulo State, southeastern Brazil (see map in Aleixo and Galetti 1997).

The area of primary forest studied (designated PF) is within the limits of the Parque Estadual Intervales (PEI), at the Saibadela field station (24°14'09"S, 48°04'51"W). The PEI comprises about 490 km² of continuous forest, encompassing an elevational gradient of roughly 1,000 m (from 70 to 1,100 m). At the Saibadela station the average elevation is about 100 m (variation between 70 and 350 m), and the vegetation is predominantly undisturbed ("Mata Atlântica de Encosta," or foothill Atlantic Forest, Joly et al. 1991) with some treefall gaps. Trees in the families Lauraceae, Myrtaceae, Palmae, and Rubiaceae are predominant in the forest (Almeida-Scabbia 1996). The average canopy height is about 25 m with some emergent trees of 38 m tall. For a detailed description of the climate (annual variation in temperature and rainfall) at the Saibadela station see Aleixo and Galetti (1997).

No hunters were reported within the limits of the Saibedela station during the field work due to an efficient guard system.

The logged forest plot (designated LF) is about 500 m from the PF; the plots are separated by a small creek and human-disturbed habitats (pastures and banana plantations). The size of the area covered by LF is difficult to estimate but, judging by comparison with PF, certainly comprises several thousands of hectares. LF was exploited only in 1985, 12 years before this study, by loggers and palm-heart poachers. The following tree species were harvested: *Euterpe edulis* (Palmae), *Cedrella fissilis* (Meliaceae), *Ocotea* spp. (Lauraceae), *Hymenaea altissima* (Caesalpiniaceae), *Copaifera trapezifolia* (Caesalpiniaceae), *Platymiscium floribundum* (Papilionaceae), and *Virola* spp. (Myristicaceae). Most trees of these species and other emergent trees left in the area are not appropriate for timber use because of the shape of their trunks or cavities. Most individuals of the palm *Euterpe edulis* still standing at LF are seedlings.

Two roads roughly 1 km long were opened in a steep terrain at LF to permit access of trucks and tractors to the vicinity of areas where trees were cut with chainsaws. During the study, hunters had free access to LF.

BIRD CENSUSES

Censusing tropical birds is notoriously difficult, because most techniques were originally developed for temperate regions (Karr 1981). Censuses that estimate density (spot/territory mapping) have been used in the Neotropics (Terborgh et al. 1990, Thiollay 1994), but these techniques are not appropriate for lekking species, singing females, nonterritorial birds with large home-ranges, and birds with interspecific territoriality (Robinson and Terborgh 1995). Censuses that estimate relative abundance are usually the most appropriate for tropical birds, especially for comparative studies (Bibby et al. 1993).

In this study, relative abundance was estimated by unlimited distance point-counts (Blondel et al. 1981, Vielliard and Silva 1990). Abundance is expressed by the IPA (index of point abundance), which is the total number of contacts with a given species divided by the total number of points sampled in a given forest plot. Contact is defined as a sight or auditory record of one individual or a bird flock of a given species in the vicinity of the point. The radius of

detection in this method is not taken into account because of the difficulty in estimating how far a bird is calling from the point sampled.

Seventy-three points were placed in PF (area ~160 ha) and 24 in the LF (area ~100 ha). The difference in the number of points and area covered between the forests was due to logistical problems, such as finding appropriate terrain for setting of point counts in LF. Sample sizes of counts in PF (n = 163) and LF (n = 142), however, were quite similar. Although only one site of each forest type was surveyed, the area covered in each site is considered representative for tropical forest bird communities (Terborgh et al. 1990, Thiollay 1994), which is also supported by the large number of rare species surveyed in both plots (see Appendix).

Point-counts were taken between 30 min before and 3 hr after sunrise, which is considered the daily peak of vocal activity of the avifauna in the Neotropics. Each point was sampled for 20 min, thus allowing the sampling of five points each morning. During point-counts, I remained stationary while recording individuals and species seen or heard around the point. The minimum distance between two points sampled in the same morning was 200 m, following standard procedures (Bibby et al. 1993). PF and LF were censused monthly for 25 months (January 1994–January 1996).

ASSIGNMENT OF SPECIES TO GUILDS

Species recorded in the censuses were assigned to 15 distinct ecological groups ("guilds") based on feeding habits, foraging substrate, and preferred foraging strata in the vegetation. This classification was based on that proposed for Atlantic Forest bird communities by Willis (1979) with some rearrangements and additions based on personal observations and literature search.

VEGETATION STRUCTURE

Vegetation structure at PF and LF was measured using the point quarter method (Cottan and Curtis 1956). Data from PF is from Almeida-Scabbia (1996). For each sampling point, four trees at least 5 cm diameter and 1.5 m tall were randomly selected for sampling. For each tree, height, diameter at breast height (dbh), and distance from the sampling point were recorded. Phytosociological parameters were calculated with the FITOPAC statistical package developed by George J. Shepherd (Departamento de Botân-

ica, Universidade Estadual de Campinas, Campinas-SP, Brazil). Forest layers were defined following the classification of Almeida-Scabbia (1996) for PF, for comparison between PF and LF.

STATISTICAL ANALYSIS

Indices of similarity and diversity were calculated for the bird communities in PF and LF. The qualitative index of similarity adopted was Jaccard's:

$$IsJ = C(pf, lf)/[T(pf) + T(lf)]$$

where C(pf, lf) is the number of species shared by PF and LF, and T(pf) and T(lf) are the total number of species in PF and LF, respectively. The quantitative index of similarity used was Morisita's:

$$I = 100 - \Sigma|p(pf) - p(lf)|/2$$

where $|p(pf) - p(lf)|$ is the absolute value of the difference of the proportion which each species is represented in each forest plot. Diversity was estimated based on Shannon-Wiener's index:

$$H' = -\Sigma(p_i)l_n(p_i)$$

where p_i is the proportion of contacts achieved with each species in relation to the total number of contacts gathered in a given forest plot.

The differences between the H' of PF and LF were tested by the Mann-Whitney U-test with correction for normality. The Wilcoxon matched-pair rank test was used to test whether the relative abundance of species varied significantly between PF and LF. The null-hypothesis is that species abundance did not differ significantly between PF and LF. All tests followed Zar (1996) with a 5% significance level.

The G-test with a correction factor was used to test for the differences between the number of contacts (corrected for sampling effort, i.e., IPA × 100) of each species recorded in both forest types. When the expected number of contacts was fewer than five, the exact probabilities were calculated by the binomial test. Because G-tests were performed over 100 statistical comparisons, the P-value chosen was 0.01.

Bird census points at PF and LF were ordinated based on species composition and abundance. The ordination technique used was reciprocal averaging (Hill 1973, Ludwig and Reynolds 1988) performed by the PC-ORD 2.1 statistical package (McCune and Mefford 1995)

TABLE 1. Comparative structural parameters of the vegetation between primary and logged forest plots in an Atlantic Forest site near Sete Barras, São Paulo State, Brazil.

Parameter	Primary[a]	Logged[b]	% of variation[c]
Tree density (No. individuals ha^{-1})	1,545	1,403	−9.2
Dead tree density (No. individuals ha^{-1})	44.2	63.1	+43
Total tree basal area (m^2 ha^{-1})	52.5	40.6	−23
Percentage of understory trees sampled (1.5–5 m)	30.2	19.6	−35
Percentage of midstory trees sampled (5.1–17 m)	58.9	75.9	+29
Percentage canopy trees sampled (17.1–38 m)	11	3.9	−65
Average diameter (cm)	15.4	12.5	−19
Average height (m)	9.1	7.9	−12.5

[a] 804 trees sampled in 0.520 ha.
[b] 400 trees sampled in 0.285 ha.
[c] Calculated by the formula: (LF − PF)/PF × 100. A negative sign before a given value indicates a reduction in the respective parameter in LF, whereas a positive sign before a given value denotes an increase in the respective parameter in LF.

without axis rescaling and downweighting of rare species.

RESULTS

VEGETATION STRUCTURE

The vegetation at LF is very similar to that of PF, except for the greater number of large forest gaps dominated by early successional species, such as many Melastomataceae and *Cecropia* spp. Many places, however, are covered with taller and thicker vegetation typical of later successional stages.

All vegetation parameters had lower values in LF with the exception of dead tree density and percentage of trees sampled in the midstory (Table 1). Based on the tree height distribution, four strata were recognized in the forest plots: ground (0–1.5 m), understory (1.5–5 m), midstory (5.1–17 m), and canopy (17.1–38 m). The ground stratum was not sampled because most trees, herbs, and shrubs in this stratum have a smaller diameter and are shorter than the minimum measurements required by the methodology used. The distribution of trees in the three strata sampled shows that two out of three are reduced in LF (Table 1). Selective logging caused a decrease in the tree density at LF. Cutting of big and abundant tree species (like the palm heart tree, *Euterpe edulis*, the most abundant tree at PF; Almeida-Scabbia 1996) also affected other vegetation structural parameters, such as basal area, average diameter, and average tree height.

BIRD COMMUNITY STRUCTURE

Of the 234 bird species recorded in PF, LF, and neighboring areas, which include marshes, banana plantations, and other disturbed habitats, 191 species (81.6%) are forest-dwelling species

recorded during qualitative surveys in PF and LF (Aleixo and Galetti 1997). See Aleixo and Galetti (1997) for a detailed account on the migration status and habitat preferences of these species. In the point counts, 170 species were recorded. In PF, 141 species were recorded, 13 (9.2%) of which were exclusive to this forest type. Of the 157 species recorded in LF, 29 species (18.5%) were restricted to this forest type. The number of species shared between PF and LF was 128 (75% of the total recorded during censuses in both forest types). The similarity in species composition between PF and LF was comparatively high (75%), and intermediate between the values reported (Table 2) for bird communities studied in plots of logged and unlogged forests in Amazonia (52–59%) and Borneo (96–97%).

The Shannon-Wiener diversity indices (H′) for PF and LF did not differ significantly (Mann-Whitney U-test; $U = 10,932$, $P > 0.9$). Other studies conducted in the Neotropics (Thiollay 1992, Mason 1996) reported lower indices of diversity and evenness for LF when compared to PF (Table 3).

Morisita's index of similarity between the bird communities of PF and LF, based on the abundance estimates for 170 species recorded in the censuses, is I = 53.6%. Of the 128 species shared between PF and LF, 8 (6%) were significantly more abundant in PF, whereas 13 (10%) were significantly more abundant in LF (Table 4). However, most species shared by PF and LF (107 species; 83.6%) had statistically similar abundance estimates between PF and LF (Appendix).

Of the 15 guilds recognized in this study, only 2 differed significantly in the average number of

TABLE 2. Comparative richness of primary and logged forest bird communities in several tropical localities.

Locality	Species richness per forest type		Similarity (%)[a]	Source
	Primary	Logged		
Amazonia, French Guyana	239	163	52	Thiollay 1992
Amazonia, Amazonas, Brazil	153	101	59	Johns 1991
Amazonia, Amazonas, Venezuela	87	95	55	Mason 1996
Western Malaysia	83	73	66	Wong 1985
Ulu Segama, Borneo, Malaysia	207	199	96	Lambert 1992
Tekan, Borneo, Malaysia	193	188	97	Johns 1992
Atlantic Forest, Brazil	141	157	75	This study

[a] Jaccard's qualitative index of similarity (see Methods).

contacts between PF and LF. These two guilds (edge omnivores/insectivores, and bamboo insectivores) showed a significant increase in the average number of contacts in LF (Wilcoxon paired test, $z = 3.88$, $P < 0.001$, and $z = 2.38$; $P < 0.05$, respectively). When the variation in the average number of contacts between PF and LF is compared on a species basis, however, the picture changes. Based on the G and binomial tests, in 11 of 15 guilds, at least one species was exclusive to or significantly more abundant in PF, indicating that the response to selective logging is highly variable within guilds (Table 4, Appendix).

In 12 guilds, most species (50% or more) did not differ significantly in abundance between PF and LF: arboreal frugivores, terrestrial granivores, canopy frugivores/insectivores, understory frugivores/insectivores, edge omnivores/insectivores, diurnal carnivores, understory insectivores, terrestrial insectivores, aerial insectivores, canopy insectivores, nocturnal insectivores, and nectarivores/insectivores. However, among the terrestrial insectivores, understory insectivores, and nocturnal carnivores, 23%, 23.5%, and 100% of the species, respectively, were either exclusive to or significantly more abundant in PF (Table 4, Appendix). For these three guilds, Morisita's index of quantitative similarity was lower than 50%, indicating important changes in species abundance be-

tween PF and LF. Only one guild (bamboo insectivores) had most of its members exclusive or significantly more abundant in LF.

Ordination of 97 point counts based on species composition and abundance of 170 species recorded on the censuses in PF and LF produced three significant axes. The first axis separates points sampled near dawn (starting 30 min before sunrise), with positive values, from the points sampled during the rest of the morning (2 or 3 hr after sunrise), with negative values. This is explained by the recording of crepuscular birds that tend to reduce or stop their vocal activities after dawn (such as Solitary Tinamou *Tinamus solitarius,* Forest-Falcons *Micrastur* spp., Least Pygmy-Owl *Glaucidium minutissimum,* Rufous Motmot *Baryphthengus ruficapillus,* Planalto Woodcreeper *Dendrocolaptes platyrostris,* White-throated Woodcreeper *Xiphocolaptes albicollis,* and Variegated Antpitta *Grallaria varia*). This pattern of daily activity is not affected by the selective logging, because PF and LF points overlap substantially along this axis.

The second axis separates most points sampled in PF (with positive values) from those sampled in LF (with negative values; Fig. 1). On this axis, overlap is low between PF and LF points (around zero), indicating that a distinct bird community is found in LF, with colonization by species rare or

TABLE 3. Comparative indices of diversity (H') and evenness (H'/l$_n$S) recorded for tropical bird communities in primary and logged forests.

Locality	H'		H'/l$_n$S		Source
	Primary	Logged	Primary	Logged	
Amazonia, French Guyana	4.90	4.51	0.89	0.88	Thiollay 1992
Amazonia, Venezuela	3.45	3.40	0.92	0.90	Mason 1996
Atlantic Forest, Brazil	4.16	4.34	0.84	0.86	This study

TABLE 4. Species shared between primary (PF) and logged (LF) forests whose abundance estimates (IPA × 100) differed statistically between these forest types in a site of Atlantic Forest in Sete Barras, São Paulo State, Brazil. Nomenclature follows Sick (1997).

Guild and Species	S[a]	Abundance[b]		G-test[c]
		PF	LF	
Arboreal frugivores				
Columba plumbea	LF	20	41	7.3
Pionus maximiliani	LF	22	44	7.4
Triclaria malachitacea	PF	22	6	9.5
Carpornis melanocephalus	PF	55	17	21.0
Lipaugus lanioides	LF	1	12	11.6
Canopy frugivores/insectivores				
Platycichla flavipes	PF	75	42	9.4
Understory frugivores/insectivores				
Schiffornis virescens	LF	6	23	10.4
Turdus albicollis	PF	162	80	28.3
Edge omnivores/insectivores				
Basileuterus culicivorus	LF	1	20	20.6
Thraupis cyanoptera	LF	6	19	7.0
Pitylus fuliginosus	LF	4	80	83.8
Trunk and twig insectivores				
Picumnus cirratus	LF	4	31	23.3
Sittasomus griseicapillus	PF	17	3	10.5
Terrestrial insectivores				
Formicarius colma	PF	108	37	36.1
Sclerurus scansor	PF	15	2	10.9
Understory insectivores				
Dysithamnus stictothorax	LF	1	31	34.9
Pyriglena leucoptera	LF	13	49	22.0
Bamboo insectivores				
Scytalopus indigoticus	LF	5	30	19.5
Canopy insectivores				
Cichlocolaptes leucophrus	LF	36	65	8.4
Cnemotriccus fuscatus	PF	9	1	7.0
Nectarivores/insectivores				
Coereba flaveola	LF	2	13	8.7

[a] Code: PF = species significantly more abundant in this forest type; LF = species significantly more abundant in this forest type.
[b] Number of contacts corrected for sampling effort (IPA × 100) gathered with a given species in PF and/or LF.
[c] Result of the G-test applied to the number of contacts corrected for sampling effort with species recorded in both PF and LF. All tests significant at $P < 0.01$.

absent in PF (such as White-breasted Tapaculo *Scytalopus indigoticus,* White-collared Foliage-Gleaner *Anabazenops fuscus,* Golden-crowned Warbler *Basileuterus culicivorus,* and Black-throated Grosbeak *Pitylus fuliginosus*).

The third axis tends to separate species according to a small elevational gradient in the study sites. Species such as Buff-fronted Foliage-Gleaner *(Philydor rufus),* Olivaceous Woodcreeper *(Sittasomus griseicapillus),* Oustalet's Tyrannulet *(Phylloscartes oustaleti),* and Olive-green Tanager *(Orthogonys chloricterus)* are more abundant at points at higher elevations, both in PF and LF. Points higher than 180 m have positive values in general, whereas points below 100 m tend to have negative values.

Because fewer points, covering a smaller area, were placed at LF, sampling effort per area was more intensive at LF than PF. The possible effects of differing sampling intensities in PF and LF are threefold: (1) due to an area effect, one would expect to record fewer species in LF than PF, (2) because of a more intense sampling at LF, the cumulative species-curve for LF would
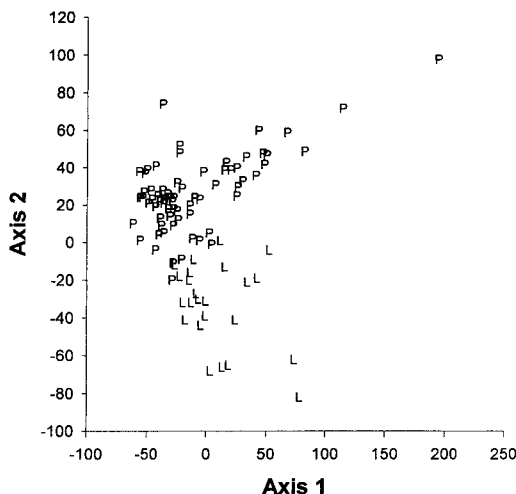
FIGURE 1. Ordination by correspondence analysis of 97 point counts placed in primary (denoted by P) and logged (denoted by L) forest plots in an Atlantic Forest site near Sete Barras, São Paulo State, Brazil. Ordination based on the composition and abundance of 170 species.

reach an asymptote before that for PF, and (3) a more intense sampling effort per area would yield biased high indices of abundance for some species at LF, affecting the axis scores of points in the multivariate space. All these predictions however, were falsified; in fact, LF had a higher species richness than PF (Table 2), and its cumulative species-curve reached an asymptote three weeks before the study was completed, when no new species had been recorded at PF for two months. From the 13 species that were recorded at both forest types and that had significantly higher indices of abundance at LF, 8 were recorded at PF exclusively in treefall gaps and forest edges (White-barred Piculet *Picumnus cirratus,* White-breasted Tapaculo, Spot-breasted Antvireo *Dysithamnus stictothorax,* White-shouldered Fire-Eye *Pyriglena leucoptera,* Cinnamon-vented Piha *Lipaugus lanioides,* Bananaquit *Coereba flaveola,* Golden-crowned Warbler, and Azure-shouldered Tanager *Thraupis cyanoptera*; Aleixo and Galetti 1997), hence suggesting that their higher indices of abundance at LF are a result of expansion of their selected habitat types in this plot, rather than sampling error. Even though the remaining two species were recorded in the interior of PF (Greenish Mourner *Schiffornis virescens,* and Black-throated Grosbeak), independent qualitative surveys

(described in Aleixo and Galetti 1997) showed that these species were indeed scarce at PF.

Differences in sampling effort did not compromise comparisons between bird communities of PF and LF because: (1) the area sampled at LF (100 ha), even though smaller than the area sampled at PF (160 ha), has the minimum size recommended for studies of Neotropical bird communities (Terborgh et al. 1990, Thiollay 1994). Hence, area effects might compromise comparisons when at least one of the plots is much smaller than 100 ha, or when there is a striking difference in size between plots; and (2) sampling of the bird communities at PF and LF can be considered thorough despite differences in sampling intensity, because by the end of the field work species-curves for both sites had reached an asymptote. It is thus assumed that differences detected between PF and LF bird communities represent genuine patterns, indicating that selective logging and elevation have an important role in organizing bird communities in the study sites.

DISCUSSION

SPECIES DIVERSITY, RICHNESS, AND SIMILARITY

Richness, diversity, and qualitative similarity indices were very similar between primary forest (PF) and logged forest (LF) bird communities. This overall similarity in the bird community contrasts with great changes in vegetation structure observed between PF and LF (Table 1). This indicates that although the selective logging altered the vegetation structure in LF, these changes did not reduce the overall richness and diversity of the bird community in this forest type. In fact, the changes in vegetation structure, with the production of large areas of secondary habitats, allowed an increase in richness and diversity in the bird community in LF. This pattern of disturbance allows the coexistence of many forest and forest edge species in the same area, leading to a local increase in richness and diversity (Schemske and Brokaw 1981, Wunderle et al. 1987, Johns 1996). This same pattern of community response to disturbance is found among several groups of organisms (Lugo 1988), including studies of several animal groups found in selectively logged forests, such as beetles, butterflies, tapirs, rodents, and primates (Frumhoff 1995).

Another factor contributing to the similarity

in species richness, diversity, and composition between bird communities of PF and LF is the proximity of these forest plots. This allows a continuous flow of individuals between PF and LF, preventing the local extinction in LF of even some species with low dispersal abilities, such as some terrestrial insectivores, like Variegated Antpitta and leaftossers (*Sclerurus* spp., Stouffer and Bierregaard 1995).

Some studies from other Neotropical selectively logged forests (all conducted in Amazonian forests) have reported significant decreases in bird species richness and diversity in logged forests when compared to unlogged forests, following great changes in vegetation structure (Johns 1991, Thiollay 1992). This differs from results of studies conducted in southeast Asia, where richness, diversity, and composition of bird communities of unlogged and logged forests were similar, although important changes in species abundance occurred (Wong 1986, Johns 1992, Lambert 1992). These latter three studies were carried out in recovering forests, with elapsed time after the last logging operation varying from 8 to 25 years.

Studies conducted in the Neotropical region also censused birds in regenerating covering forests, varying from 1 to 6 years (Mason 1996) and from 10 to 11 years (Johns 1991, Thiollay 1992) after logging. Bird community diversity decreased 1 year after logging (Thiollay 1992, Mason 1996) but returned to similar levels of unlogged forests after 5 years in at least one case (Mason 1996). In French Guyana, however, no recovery in diversity was observed even 10 years after logging (Thiollay 1992).

The difference in response to logging between Amazonian and Atlantic Forest bird communities can be explained by use of more deleterious techniques of selective logging in Amazonia. Johns (1988) showed that different methods of selective logging have different effects on the vegetation structure of tropical forests, and that opening of roads is one of the main causes of extensive damage in forest structure. In my study, only two narrow roads were opened by loggers in LF, because the steep terrain prohibited use of heavy machinery. Thiollay (1992) reported that 0.5 km of roads were opened for each 100 ha of forest explored, with total deforestation of a belt of about 20 m on each side of the road. Mason (1996) reported damage to the vegetation similar to that reported by Thiollay

(1992), whereas Johns (1991), although he did not quantify vegetation damage in his study, mentioned that a network of roads was opened in his survey plots.

Damage caused to vegetation structure by logging cannot explain why Amazonian bird communities are more sensitive to logging than southeast Asian ones, because the damage in Dipterocarpaceae forests is one order of magnitude higher than in Amazonia (Mason 1996). The heavier effect of logging on Amazonian, when compared to Atlantic Forest and southeast Asian bird communities, can also be due to historical differences in the evolution of their avifaunas. A smaller proportion of Amazonian species use secondary habitats than in other areas of the Neotropics, such as the Atlantic Forest and Central America (Stotz et al. 1996). Similarly, a very high proportion of Amazonian species are intolerant to disturbance (Stouffer and Bierregaard 1995, Robinson and Terborgh 1997), which contrasts markedly with what is observed in southeast Asian bird communities (Wong 1986, Lambert 1992). So far, long-term studies have shown that richness and diversity of bird communities in tropical logged forests are similar to those of unlogged forests, except in Amazonia, where an unrivaled area of tropical forest allowed the evolution of a forest bird community with more strict habitat requirements.

SPECIES COMPOSITION AND ABUNDANCE

When the *G* and binomial tests are applied to the corrected number of contacts of each species, 63% (107) of the 170 species do not differ significantly in abundance between PF and LF (Appendix). Conversely, about 37% of the species were either exclusive or significantly more abundant in one of the forest types. Even when the analysis is restricted to the species shared between PF and LF, 16.4% of these 128 species exhibit preference for one of the forest types (Table 4). These differences in species composition and abundance can account for the reduced overlap among the point counts of PF and LF along the second axis of the ordination graph (Fig. 1).

The reduction in six of the eight vegetation parameters in LF had important effects on some segments of the bird community, changing abundance patterns of some species. Karr and Brawn (1990) and Mason (1996) suggested that reduction in tree density causes microclimatic changes in the understory due to increasing insolation,

which in turn affects the composition and abundance of arthropods available to birds. Changes in vegetation structure also can affect nest site availability, which leads to local extinction or decrease in abundance of species with precise nest site requirements (Martin 1988). The reduction in the understory and canopy of LF was 35% and 65%, respectively, which might have contributed to changes in the abundance of some species, explaining differences detected between the bird communities of PF and LF by the ordination analysis.

CONSERVATION IMPLICATIONS

In this study, selective logging did not reduce richness and diversity of a bird community in the Atlantic Forest. Similarities in species richness and diversity do not translate directly into conservation priorities, mostly because additional species observed only in LF are associated with disturbance, second growth or semi-open habitats, and consequently, are more widespread and of lower conservation value than species restricted to PF (see Stotz et al. 1996).

Twenty-one species (12.3% of 170 species recorded in both plots) were either exclusive or significantly more abundant in PF and were presumably adversely affected by selective logging (Table 4, Appendix). These species can be regarded as threatened if selective logging becomes a widespread activity in the remaining patches of undisturbed Atlantic Forest. Among these species, five Atlantic Forest endemic taxa, Blue-bellied Parrot (*Triclaria malachitacea*), Black-headed Berryeater, Red-ruffed Fruitcrow (*Pyroderus scutatus scutatus*), Russet-winged Spadebill (*Platyrinchus leucoryphus*), and Eye-ringed Tody-Tyrant (*Hemitriccus orbitatus*) are currently listed in the Red-Data Book and regarded as threatened or near-threatened (Collar et al. 1992). Their sensitivity to logging provides further evidence that their status should be monitored more carefully during the next few years (Aleixo and Galetti 1997).

Two factors were probably critical in causing the relatively low impact of selective logging on the bird community studied: (1) low disturbance of the vegetation structure, due mostly to the lack of an intensive mechanized exploitation at LF, and (2) the large area covered by unlogged forest surrounding LF. So far, there are no data available for any other site in the Atlantic Forest that could be contrasted with the present study,

allowing a direct comparison of the effects of distinct logging intensities on bird communities. However, studies for other regions show a positive correlation between level of disturbance and species loss in tropical forest bird communities (Johns 1992, Lambert 1992, Mason 1996), and the same response should be expected for Atlantic Forest bird communities.

As discussed previously, an extensive protected area close to LF, with almost 500 km², provides a steady influx of individuals searching for territories or nest sites at LF. This, added to the fact the local species pool is as complete as it can get for an area of Atlantic Forest, may prevent many local extinctions (Aleixo and Galetti 1997). The deleterious impact of logging on the bird community studied would probably increase with distance from the continuous unlogged forest, because of the addition of fragmentation and isolation effects. Some species-rich ecological groups such as understory and terrestrial insectivores are as heavily affected by forest fragmentation (Stouffer and Bierregaard 1995) as by selective logging (Thiollay 1992, Mason 1996) and should be regarded as disturbance-indicator species. Isolated tracts of Atlantic Forest with predominantly secondary vegetation are reported to lose species at a high rate (Aleixo and Vielliard 1995).

Based on these findings, the following procedures are proposed to minimize adverse effects of selective logging on bird communities in the Atlantic Forest: (1) logged areas should be close enough to unfragmented, unlogged forests to allow recolonization of some species, (2) the exploitation of the forest should be carried out using as few roads as possible, minimizing the use of mechanized equipment to fell and transport trees, and (3) long-term rotation should be used in areas designed for logging to allow time for forest regeneration.

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APPENDIX. Species exclusive to one forest type or whose abundance estimates did not differ statistically between primary (PF) and logged (LF) forests in a site of Atlantic Forest in Sete Barras, São Paulo State, Brazil. Nomenclature follows Sick (1997).

Guild and Species

ARBOREAL FRUGIVORES

Penelope obscura (n)[a], *Pipile jacutinga* (n), *Pyrrhura frontalis* (n), *Forpus xanthopterygius* (n), *Brotogeris tirica* (n; 92, 77), *Touit melanonota* ?[b] (LF; 0, 1), *Pionopsitta pileata* (n), *Selenidera maculirostris* (n), *Baillonius bailloni* (LF; 0, 6), *Ramphastos vitellinus* (n; 24, 12), *Ramphastos dicolorus* (n), *Carpornis cucullatus* (n), *Pyroderus scutatus* (PF; 2, 0), *Procnias nudicollis* (n).

TERRESTRIAL GRANIVORES

Tinamus solitarius (n; 67, 44), *Crypturellus obsoletus* (n), *Crypturellus noctivagus* (n; 76, 51), *Crypturellus tataupa* (LF; 0, 1), *Odontophorus capueira* (n), *Leptotila verreauxi* (n), *Leptotila rufaxilla* (LF; 0, 2), *Geotrygon montana* (n).

CANOPY FRUGIVORES/INSECTIVORES

Trogon viridis (n), *Trogon rufus* (n; 7, 19); *Myiodynastes maculatus* (n), *Pachyramphus marginatus* (n), *Tityra cayana* (LF; 0, 1), *Tityra inquisitor* (n), *Oxyruncus cristatus* (n), *Cyanocorax caeruleus* (n), *Cyclarhis gujanensis* (n), *Orchesticus abeillei* (LF; 0, 1), *Hemithraupis ruficapilla* (n), *Orthogonys chloricterus* (n), *Euphonia violacea* (n), *Euphonia pectoralis* (n), *Tangara seledon* (n), *Tangara cyanocephala* (n), *Cacicus haemorrhous* (n).

UNDERSTORY FRUGIVORES/INSECTIVORES

Baryphthengus ruficapillus (n), *Mionectes rufiventris* (PF; 8, 0), *Chiroxiphia caudata* (n), *Ilicura militaris* (n), *Trichothraupis melanops* (n), *Habia rubica* (n).

EDGE OMNIVORES/INSECTIVORES

Myiopagis caniceps (n), *Myiornis auricularis* (n), *Todirostrum poliocephalum* (n), *Colonia colonus* (n), *Attila rufus* (n; 12, 23), *Sirystes sibilator* (n), *Pitangus sulphuratus* (n; 4, 14), *Megarynchus pitangua* (LF; 0, 5), *Myiozetetes similis* (n), *Conopias trivirgata* (n), *Legatus leucophaius* (LF; 0, 1), *Tyrannus melancholicus* (n), *Pachyramphus castaneus* (LF; 0, 1), *Pachyramphus validus* (n), *Manacus manacus* (LF; 0, 1), *Turdus rufiventris* (LF; 0, 2), *Turdus amaurochalinus* (LF; 0, 1), *Vireo olivaceus* (PF; 1, 0), *Tachyphonus cristatus* (PF; 1, 0), *Tachyphonus coronatus* (n), *Thraupis palmarum* (LF; 0, 2), *Tersina viridis* (n), *Saltator similis* (LF; 0, 10).

DIURNAL CARNIVORES

Accipiter superciliosus ? (LF; 0, 1), *Rupornis magnirostris* (n), *Leucopternis polionota* (n), *Spizaetus tyrannus* (LF; 0, 1), *Herpetotheres cachinnans* (n), *Micrastur semitorquatus* (n), *Micrastur ruficollis* (n).

APPENDIX. Continued.

Guild and Species

NOCTURNAL CARNIVORES

Pulsatrix koeniswaldiana (PF; 1, 0), *Strix hylophila* (PF; 1, 0).

TRUNK AND TWIG INSECTIVORES

Colaptes melanochloros (LF; 0, 1), *Piculus flavigula* (n), *Celeus flavescens* (n; 80, 106), *Dryocopus lineatus* (LF; 0, 3), *Melanerpes flavifrons* (PF; 1, 0), *Veniliornis spilogaster* (n), *Campephilus robustus* (LF; 0, 2), *Philydor lichtensteini* (n), *Xenops minutus* (n), *Xiphocolaptes albicollis* (n), *Lepidocolaptes fuscus* (n).

TERRESTRIAL INSECTIVORES

Amaurolimnas concolor (PF; 1, 0), *Aramides saracura* (n), *Merulaxis ater* (n), *Myrmeciza squamosa* (n), *Chamaeza meruloides* (LF; 0, 2), *Chamaeza campanisona* (n), *Grallaria varia* (n), *Conopophaga melanops* (n), *Sclerurus mexicanus* (LF; 0, 2), *Lochmias nematura* (n), *Basileuterus rivularis* (n).

UNDERSTORY INSECTIVORES

Malacoptila striata (PF; 1, 0), *Dysithamnus mentalis* (n), *Myrmotherula gularis* (n), *Myrmotherula minor* (LF; 0, 1), *Myrmotherula unicolor* (n), *Philydor atricapillus* (n), *Automolus leucophthalmus* (n), *Dendrocincla turdina* (n), *Dendrocolaptes platyrostris* (n), *Leptopogon amaurocephalus* (n), *Hemitriccus orbitatus* (PF; 7, 0), *Platyrinchus mystaceus* (n), *Platyrinchus leucoryphus* (PF; 10, 0), *Myiobius barbatus* (PF; 4, 0), *Lathrotriccus euleri* (n).

BAMBOO INSECTIVORES

Psilorhamphus guttatus (LF; 0, 1), *Batara cinerea* (LF; 0, 3), *Drymophila squamata* (n), *Synallaxis ruficapilla* (LF; 0, 1), *Cranioleuca pallida* (LF; 0, 1), *Anabazenops fuscus* (LF; 0, 10).

AERIAL INSECTIVORES

Streptoprocne zonaris (n; 5, 16), *Chaetura cinereiventris* (n), *Chaetura andrei* (n), *Progne chalybea* (n), *Stelgidopteryx ruficollis* (n).

CANOPY INSECTIVORES

Piaya cayana (n), *Notharchus macrorhynchus* (n), *Hypoedaleus guttatus* (n), *Herpsilochmus rufimarginatus* (n), *Terenura maculata* (n), *Philydor rufus* (n), *Phylloscartes sylviolus* (n), *Phylloscartes oustaleti* (n), *Phylloscartes paulistus* (n), *Tolmomyias sulphurescens* (n), *Attila phoenicurus* (PF; 4, 0).

NOCTURNAL INSECTIVORES

Otus choliba (n), *Otus atricapillus* (n), *Glaucidium minutissimum* (n), *Nyctibius griseus* (n), *Lurocalis semitorquatus* (n).

NECTARIVORES/INSECTIVORES

Ramphodon naevius (n), *Phaethornis squalidus* (n), *Melanotrochilus fuscus* (n), *Thalurania glaucopis* (n), *Amazilia versicolor* (n), *Aphantochroa cirrhochloris* (LF; 0, 1), *Dacnis cayana* (LF; 0, 1), *Chlorophanes spiza* (n).

[a] Code: n = species without statistically significant variation in abundance between PF and LF; PF = species occurring exclusively in PF; LF = species occurring exclusively in LF. Numbers denote number of contacts with a given species in PF and LF, respectively. Number of contacts are reported only for exclusive species or for species whose difference in number of contacts between PF and LF equals or is larger than 10.
[b] Specific identity of the species in question is uncertain, although the presence of a species in this genus or species group is granted.