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Research Article

Recuperation of the *Terra Firme* Forest Understory Bird Fauna Eight Years after a Wildfire in Eastern Acre, Brazil

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The present study evaluated the characteristics of the understory bird fauna of four fragments of *terra firme* forest in eastern Acre, Brazil, that were impacted by wildfires in 2005. The study investigated the species richness and the composition of trophic guilds using mist-netting on eight transects (four in burned plots and four in control plots in the same forest fragments). Eight plots (0.12 ha) were also established parallel to each transect to record the number of live trees (DBH $\geq$ 10 cm), palms, and dead trees. Bamboo stems were quantified in 0.024 ha subplots. No significant difference was found between burned and control plots in the species richness or abundance of birds, nor was any significant pattern found in the NMDS ordination of the composition of the communities or guilds. The Principal Components Analysis (PCA) found that the burned plots were physiognomically distinct, due principally to the number of bamboo stems and dead trees. Multiple regressions based on the PCA scores and bird species richness and abundance found no significant trends. The findings of the present study indicate that the understory bird assemblage of the areas affected by a single wildfire in 2005 had almost totally recuperated eight years after this event.

1. Introduction

Amazonia encompasses the world's largest [1] and most diverse [2] tropical forest. The Amazon forest plays an active role in the hydrological cycle [3] and is characterized by its low flammability [4]. However, since the middle of the last century, it has suffered an ongoing and widespread process of anthropogenic habitat fragmentation [5]. This process appears to be altering the natural resistance of the Amazon forest to the effects of fire [6, 7].

Agricultural burn-off is one of the principal anthropogenic impacts on natural forests, and, thus, one of the primary causes of the loss of biodiversity from these environments [8–10]. Widely used in the Amazon region [8], burn-off may affect the local climate [4, 11], as well as causing a range of ecological impacts [4, 12–14]. These impacts may accumulate where the burn-off is recurrent [15]. The periodic droughts caused by El Niño events have been making the forest drier and more flammable [14, 16], with devastating effects for the local fauna, in particular understory birds [14, 17, 18], large vertebrates [19], and arthropods [20].

The response of the bird fauna to disturbances caused by forest fires is being monitored in tropical forests of Southeast Asia [21, 22], in central Brazilian Amazonia [15, 17, 23–25], in the southern and western Amazon basin [26], and in forests that have been selectively logged [18]. Few studies have analyzed the long-term effects of fire on Amazonian bird assemblages, however [14, 27]. In this biome, the principal studies have involved time scales of one year [14, 18], 15 months [24], three years [26], and 10 years [27] following the burn-off event. However, the work in temperate regions has helped in the process of understanding the recovery of wealth and composition of birds after long period of regeneration [28].

Understory birds are among the vertebrates most vulnerable to changes in the frequency and intensity of habitat disturbances [15, 29–31]. Insectivorous species are the most sensitive to the different forms of disturbance [17, 18, 24,

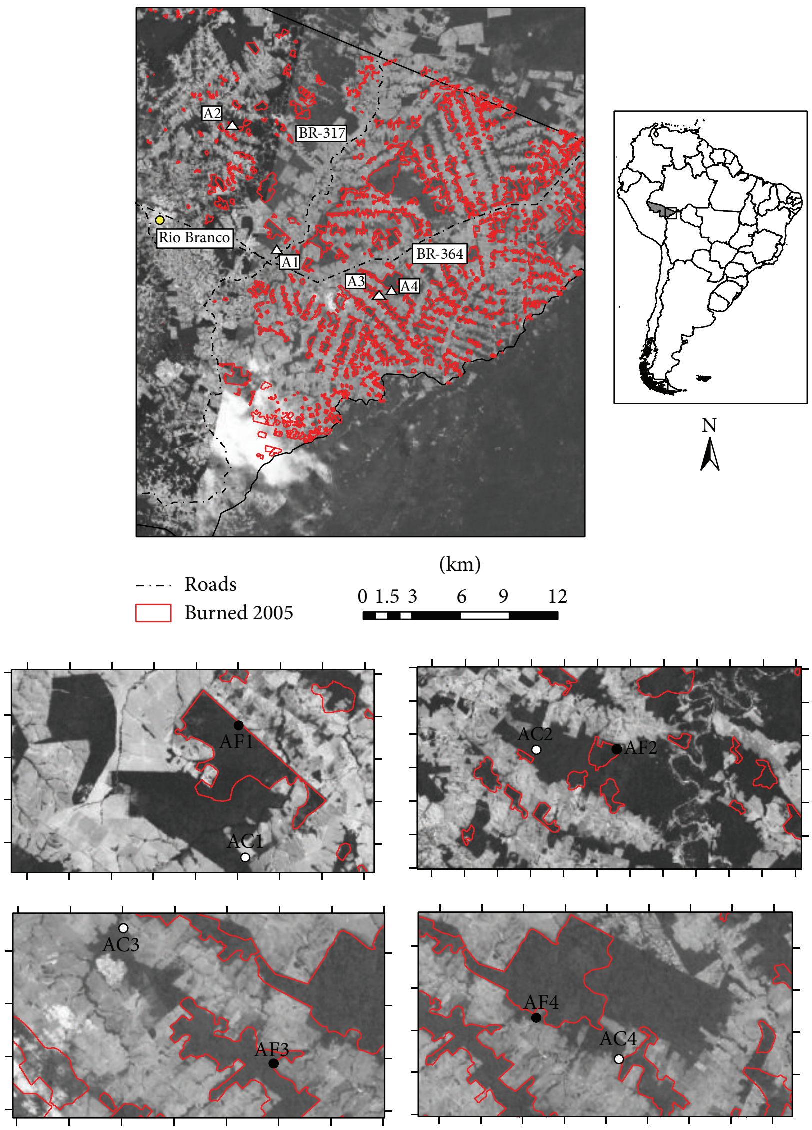

Figure 1: Eastern Acre, Brazil (F1). The sites outlined in red were burned in 2005. The triangles indicate the location of the four study sites (A1, A2, A3, and A4) within the study area (Table 1), and in the more detailed maps (F2–F5), the circles (○) represent the control sites (AC1–AC4), and the squares (□) represent the sites burned in 2005. The dark areas in the map represent the existing vegetation and the clear areas represent the anthropogenic environments.

26, 32–34], and the different guilds are affected directly by the impacts of fires. While insectivorous antbirds [17], insectivore-folivores, and terrestrial and arboreal insectivores may all be impacted negatively [24], nectarivores and arboreal granivores may actually increase in abundance [4].

In 2005, the Brazilian state of Acre suffered its most severe drought of the preceding 40 years [35]. This drought provoked one of the greatest environmental disasters ever observed in the region and contributed to an increase in accidental fires and large-scale wildfires [36, 37]. Eastern Acre, which is the state's most densely populated region, was also the most affected region by uncontrolled wildfires. Few data are available on the regeneration of the forest habitats of eastern Acre or the recuperation of their bird communities since the events of 2005. In this context, the present study investigated the effects of the forest fires that occurred in the region in 2005 on the species composition and richness, relative abundance, and trophic guilds of the understory birds found in fragments of *terra firme* forest in eastern Acre, which is located in the southwestern Brazilian Amazon basin.

2. Study Area and Methods

2.1. Study Areas. The present study focused on four forest fragments in eastern Acre, Brazil (Figure 1). The region's climate is classified as Am [38], that is, humid equatorial, with a mean temperature of 26°C, and annual precipitation between 1750 mm and 2000 mm. The driest month is June, with rainfall of 32 mm, while the wettest is February, at 299 mm [39]. The forests in Acre are mostly dominated by

Table 1: Characteristics of the study areas in eastern Acre, Brazil.

Site	Plot	Size (ha)	Coordinates
A1	AC1 (control)	1100	10°02′20″ S, 67°33′49″ W
A1	AF1 (burned)	1049.85	09°59′14″ S, 67°33′59″ W
A2	AC2 (control)	1700	09°45′40″ S, 67°39′53″ W
A2	AF2 (burned)	172.71	09°45′26″ S, 67°37′25″ W
A3	AC3 (control)	140	10°05′34″ S, 67°22′59″ W
A3	AF3 (burned)	200	10°08′07″ S, 67°20′06″ W
A4	AC4 (control)	200	10°08′40″ S, 67°16′42″ W
A4	AF4 (burned)	80	10°07′42″ S, 67°18′41″ W

bamboos of the genus *Guadua* [40], pioneer species that form dense stands [41]. The study fragments are composed of open rainforest with a predominance of bamboo set in a matrix of cattle pasture. The fragments varied in size from less than one hundred hectares to over one thousand (Table 1).

At each site, eight transects were established, four in each plot (control or burned in 2005). At all four sites, the two plots were located within the same forest fragment (Figure 1, F2 to F5). This was important to minimize the possible effects of differences in the structure of the forest between plots.

The study sites were identified initially by consulting Landsat TM images from 2005 (orbit points 001/67 and 002/67), using a spectral mixture analysis. This approach permits the estimation of the proportion of each component (soil, shadow, and vegetation) within each pixel, indicating which is predominant [42]. Where fire scars were detected, the sites were compared with data from the Technological Foundation of the State of Acre (FUNTAC) for confirmation of the area burned. The history of fires was verified using the Enhanced Vegetation Index (EVI) run in the MOD13 package. The values recorded for this index were compared with Landsat TM images between 2004 and 2011 (the last year for which images were available) associated with the data on heat spots obtained from the National Institute for Space Research (INPE) site [43]. Interviews and visits to the study sites were used to confirm that none of the areas selected for the study had suffered fire damage in the years since 2005.

2.2. Surveys of the Bird Fauna. The bird fauna was surveyed in the dry season, between April and November 2013, using 20 mist nets (12 m × 2.5 m; 36 mm mesh), set along trails of 120 m in length. Four transects were established within each burned site and four at each control site. The transects were 500 m apart and were located at least 50 m from the forest margin, in order to avoid possible edge effects. The nets were set between 06:30 h and 13:30 h on two consecutive days and checked every 40 minutes and were deactivated during periods of intense rainfall or cold spells. A standard sampling effort of 560 net hours was implemented at each site. The birds captured were identified to species and marked with metallic bands provided by ICMBIO/CEMAVE (Brazilian National Center for Research and Conservation of Wild Birds).

Guilds were identified based on the proposal of Root [44] and were defined based on a combination of feeding preferences and foraging strategies. In the Amazon biome, these guilds include antbirds, bamboo forest insectivores, solitary arboreal birds, bird associated with clearings, and birds that form mixed species flocks [33, 45–47]. Feeding guilds include frugivores, omnivores, piscivores, granivores, insectivores, and nectarivores [48]. The birds were also classified in relation to their degree of sensitivity to anthropogenic disturbance, as (A) high, (B) medium (some degree of resistance), and (C) low sensitivity. This indicator is used to classify the species of birds that may become rare or disappear, in habitats that are altered, overhunted, or fragmented [47]. The taxonomic classification of the species was based on that of the Brazilian Committee for Ornithological Records [49].

2.3. Habitat Sampling. Eight sample plots of 120 m × 10 m (0.12 ha) were established at each site, four within the control plots and four in the burned plots. The following components of forest structure were quantified in each plot: (i) the number of live trees with a diameter at breast height (DBH at 1.3 m from the ground) of at least 10 cm [50] and (ii) the number of dead trees. The dead trees were assessed with regard to the degree of the decomposition of the wood, being classified as (i) stage 1 (ST1), recently fallen or imperceptible level of decomposition (no signs of insect or fungal attack), (ii) stage 2 (ST2), initial decomposition (some evidence of insect and fungal attack), and (iii) stage 3 (ST3), advanced decomposition with clear signs of rotting (loss of at least 30% of mass), verified by the manual examination of the substrate, which fragments easily [51]. Subplots (120 m × 2 m) were demarcated within the main plots to record the number of palms and bamboo stems with a height of at least 2 m.

2.4. Statistical Analyses. Species richness was compared between treatments (control versus burned plots) using species rarefaction curves produced in the R program [52]. The individuals captured were counted as samples and the curves were calculated using the Mao Tau estimator.

Species composition and the guilds of the bird assemblages of the two treatments were using a nonmetric multidimensional scaling (NMDS) approach, based on Bray-Curtis indices of the absolute abundance of the different species collected in each treatment [53, 54]. A PERMANOVA of the similarity matrix with 999 permutations was used to test the significance ($\alpha = 0.05$) of differences between the bird assemblages of the burned and control plots, considering the plots as repetitions. The R program 2.14.0 [55] was used to construct the similarity matrix and run the analyses (NMDS and PERMANOVA), using the vegan package.

Given the small number of samples, the abundance of the species was compared between treatments using a two-sample permutation test. Student's t-test ($\alpha = 0.05$) was used to compare the mean number of individuals collected between treatments according to their degree of environmental sensitivity [47].

A Principal Components Analysis (PCA) was used to verify differences in the structure of the forest between burned and control plots. This analysis uses an orthogonal

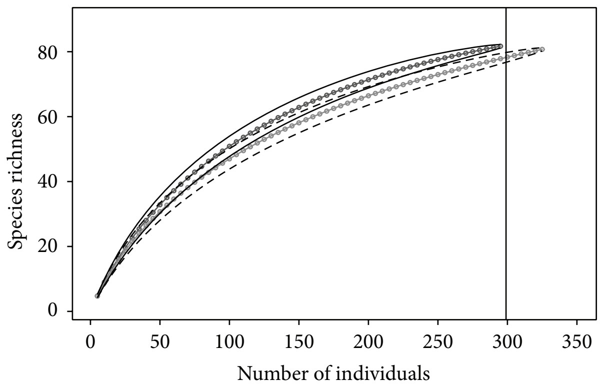

Figure 2: Species rarefaction curves for the control and burned plots surveyed in the present study in eastern Acre, Brazil. The lines represent the 95% confidence limits.

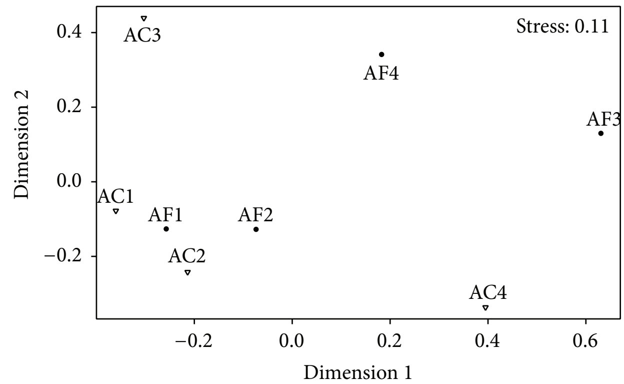

Figure 3: Results of the NMDS analysis of the species composition of the burned (AF1, AF2, AF3, and AF4) and control (AC1, AC2, AC3, and AC4) plots surveyed during the present study in eastern Acre, Brazil, based on the Bray-Curtis index.

transformation of a dataset for variables that may be correlated to a set of noncorrelated linear variables known as principal components [53]. The variables analyzed here were the standard deviation of the DBH, the mean number of bamboo stems, the mean number of dead trees, and the mean number of palms in the plots of the two treatments (control versus burned). The values recorded for axes 1 and 2 of the PCA (the components that best explained the variation in forest structure [56]) were used to calculate multiple regressions, one based on species richness of each assemblage and the other on the abundance of birds, which were considered to be the predictor variables, while the PCA scores were the independent variables. The abundance matrices produced for the NMDS and PCA analyses were $\log_{10}$-transformed to remove the effects of outlier values and to standardize the measurements to fit on a single graph [57].

3. Results

3.1. The Effects of Burning on Bird Species Richness, Composition, and Abundance. A total of 627 individuals were captured during 4480 net hours of sampling. These specimens represented 106 species belonging to 30 families (Table 2). In the control plots, 299 individuals representing 81 species were captured, with 328 individuals and 83 species being recorded in the burned plots. The rarefaction curves calculated for the two treatments, with data from the *mist nets*, were highly similar (Figure 2), indicating virtually the same levels of species richness.

The NMDS analysis of species composition grouped the control and burned plots separately (Figure 3). Areas A1 and A2 have similar species composition, although the burned plot in A2 is further from the control plot of this area. At sites 3 and 4, the distances between the plots were greater, reflecting the differences in the species composition recorded in the plots, according to the first axis of the NMDS (Figure 3). The low stress value (0.11) indicates that the interpretation of the results can be considered reliable. However, the PERMANOVA found no significant difference in the species composition of the burned and control plots (Pseudo-F = 0.85; $p > 0.05$). The smaller the distance between the points on the graph (AC1-AF1 and AF2-AC2 and AC3-AF3 and AC4-AF4), the greater the similarity in the abundance of individuals collected at each site. Similarly, the greater the distance between the points on the graph (AC1-AF1 and AF2-AC2 and AC3-AF3 and AC4-AF4), the lower the similarity in the abundance of individuals collected at each site.

The most abundant species at the burned sites were *Sciaphylax hemimelaena* (32 individuals), *Phaethornis hispidus* (27 individuals), and *Pipra fasciicauda* (19 individuals). At the control sites, the most abundant species were *Sciaphylax hemimelaena* (31 individuals), *Pipra fasciicauda* (16 individuals), and *Myrmotherula axillaris* (15 individuals). Six species (*Campylorhamphus trochilirostris*, *Chloroceryle aenea*, *Dendrocincla merula*, *Piprites chloris*, *Sclateria naevia*, and *Sclerurus caudacutus*) were captured only at control sites, while three (*Bucco macrodactylus*, *Ramphocelus carbo*, and *Thamnophilus doliatus*) were caught only at the burned ones. However, there was no significant variation ($p > 0.05$) between the burned and control groups (Figure 4).

3.2. The Effects of Fire on the Guilds. The guilds represented by the largest numbers of individuals in the burned plots (Table 2) were the insectivores (77 individuals), nectarivores (45 individuals), birds associated with clearings (45 individuals), frugivores (33 individuals), and omnivores (29 individuals). In the control plots, the most abundant guild was also that of the insectivores (59 individuals), followed by the birds associated with mixed flocks (49 individuals), birds associated with clearings (41 individuals), and the frugivores (31 individuals). The NMDS analysis of the guilds found some similarities between control and burned plots at the same site (Figure 5), but marked differences in other cases. For example, the control sites C1, C2 and the burned site F1 have similar abundance of species. When compared with their burned sites (F1, F2) and control (C1) the abundance of the species is different. Despite this, the PERMANOVA found no significant difference in the clustering of the assemblages

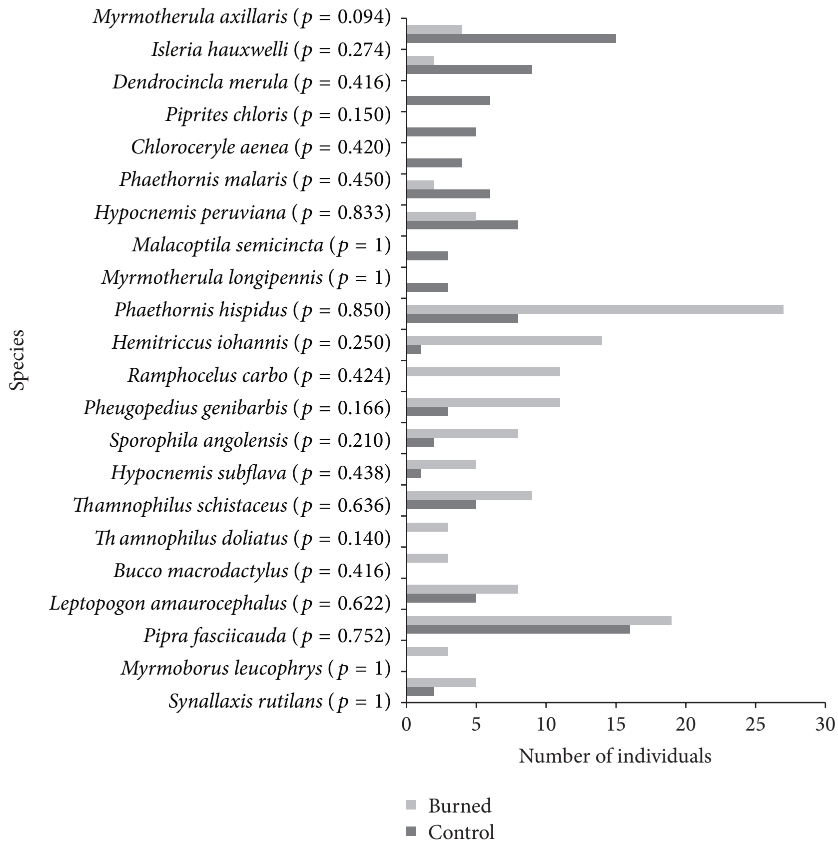

Figure 4: Relative abundance of the most common bird species captured in the burned and control plots in the present study in eastern Acre, Brazil. The probability (p) values presented for each species refer to the results of the two-sample permutation tests for the comparison of the samples from control and burned plots.

of the control and burned sites in terms of their guild composition (Pseudo-F = 1.29; $p > 0.05$).

3.3. The Effects of Burning on Habitat Sensitivity Levels. In relation to the sensitivity of the species to habitat disturbance [47], 39% (105 individuals) of the species captured at the control sites were classified as having high sensitivity, 46% (166 individuals) as having medium sensitivity, and 15% (26 individuals) as having low sensitivity (Table 2). In the burned plots, by contrast, 31% (74 individuals) of the species were classified as having high sensitivity, 49% (194 individuals) as having medium sensitivity, and 20% (59 individuals) as having low sensitivity (Figure 6). These differences were not significant, however ($p > 0.05$).

3.4. The Effects of Fire on Biotic Variability. A total of 668 trees with a DBH of at least 10 cm were identified and marked in the study plots. While sites of the burned plots at sites 1 and 2 had more bamboo stems than their respective control plots, the opposite was true at the other two sites. The number of palms in plot AC2 was higher than that recorded in the respective burned plot, whereas, at all the other sites, the number of palms was higher in the burned plots in comparison with the controls. The number of dead trees in the areas 01, 02, and 03 was higher in fire sites compared to control sites, while in the area 04 the result was reversed, and the number of dead trees in the control site was greater than fire site (Table 3).

The PCA of the biotic variables (Table 3) indicated a degree of segregation between burned and control plots. The first axis explained 68% of the recorded variation and the second axis 29% (Figure 7). The variable that most contributed to the first PCA axis was the number of bamboos stems (0.94). The variable that most contributed to the variation in the data on the second PCA axis (−0.83) was the mean number of dead trees. The PCA divided the samples into three groups (Figure 7). One was formed by three of the burned plots (AF1, AF3, and AF4), the second by the remaining burned plot (AF2) together with control sites 1 and 2 (AC1, AC2), and the third by the two remaining control sites (AC3, AC4). Despite a degree of overlap, there was a relatively clear division between the burned and control sites.

In the multiple regression analysis (Table 4), the biotic variables reviewed in the PCA were not significantly related to either species richness ($R^2 = 0.35$; $F_{(5,26)} = 1.36$; $p = 0.33$) or the abundance of individuals ($R^2 = 0.08$; $F_{(5,26)} = 0.23$; $p = 0.8$). The variables analyzed here were the standard deviation of the DBH, the average of bamboo stems, the average of dead trees, and the average of palms in the plots of the two treatments (control versus burned).

Table 2: Bird species captured during the present study in eastern Acre (Brazil), in burned (AF1–4) and control (AC1–4) plots. S: sensitivity to habitat disturbance (H: high, M: medium, and L: low). TG: trophic guild (IB: insectivore associated with bamboo forest; MF: insectivore associated with mixed flocks; C: carnivore; F: frugivore; G: granivore; I: insectivore; N: nectarivore; O: omnivore; P: piscivore; AB: antbird; SA: solitary arboreal species; CA: species associated with clearings).

Family	Species	S	GT	Number of species captured in plot							
				CA1	CA2	CA3	CA4	FA1	FA2	FA3	FA4
Accipitridae	*Geranospiza caerulescens*	M	C								1
Columbidae	*Columbina talpacoti*	B	G								1
	Leptotila verreauxi	B	G								1
	Leptotila rufaxilla	B	F			1					
	Geotrygon montana	M	F				2				4
Cuculidae	*Coccycua minuta*	B	I			1					1
Strigidae	*Glaucidium hardyi*	—	I						1		
Trochilidae	*Glaucis hirsutus*	B	N			6	3		4	5	2
	Threnetes leucurus	M	N		1						
	Phaethornis ruber	M	N		1	1	1		1	1	
	Phaethornis hispidus	M	N	3	3	2		3	15	5	4
	Phaethornis malaris	A	N		3		3		2		
	Thalurania furcata	M	N		2	1		1	1		
	Amazilia lactea	B	N							1	
Alcedinidae	*Chloroceryle aenea*	M	P			1	3				
	Chloroceryle inda	M	P						1		
Momotidae	*Electron platyrhynchum*	M	O	2	1						1
	Momotus momota	M	O	2				1	1		2
Galbulidae	*Galbula cyanescens*	B	I								2
Bucconidae	*Bucco macrodactylus*	M	I							1	2
	Malacoptila semicincta	A	I	3							
	Monasa nigrifrons	M	I		1	1	1				2
	Monasa morphoeus	A	I		1						
Ramphastidae	*Pteroglossus mariae*	A	F				2				3
	Pteroglossus castanotis	A	O						1		
	Pteroglossus beauharnaesii	A	O							1	
Picidae	*Veniliornis affinis*	M	I		1						
	Veniliornis passerinus	B	I		1	1		1			3
Falconidae	*Micrastur ruficollis*	A	C		1						
Thamnophilidae	*Microrhopias quixensis*	M	AB		1				1		
	Epinecrophylla haematonota	A	I				1			1	
	Epinecrophylla ornata	A	AB		1	1	1	1			
	Myrmotherula axillaris	M	BM	2	5	4	4	2			2
	Myrmotherula longipennis	A	BM				3				
	Formicivora iheringi	A	AB			1					
	Isleria hauxwelli	A	BM	4	2	3			2		
	Thamnomanes schistogynus	A	BM	2	3	1		2	2		
	Thamnophilus doliatus	B	I						1	1	1
	Thamnophilus schistaceus	A	I		1		4		2	6	1
	Thamnophilus aethiops	A	I		3	1	4	2	1	2	1
	Taraba major	B	I			1					1
	Sclateria naevia	M	I	1	1						
	Myrmoborus myotherinus	A	I		3				2		
	Myrmoborus leucophrys	M	I					3			
	Akletos goeldii	A	AB			2					
	Sciaphylax hemimelaena	M	I	15	9	1	6	10	10	7	5
	Cercomacra serva	M	I						2		
	Hypocnemis subflava	M	AB		1			2	3		
	Hypocnemis peruviana	M	AS	1	1		6	3	1	1	
	Willisornis poecilinotus	M	I		2				1		
	Phlegopsis nigromaculata	M	SF	2	4	3		1	5		2
	Gymnopithys salvini	A	SF		5			1	2		

Table 2: Continued.

Family	Species	S	GT	Number of species captured in plot							
				CA1	CA2	CA3	CA4	FA1	FA2	FA3	FA4
Formicariidae	*Formicarius colma*	A	I		1	1			1	2	
Scleruridae	*Sclerurus macconnelli*	A	I	1		1		1			
	Sclerurus caudacutus	A	I	1	1						
Dendrocolaptidae	*Dendrocincla fuliginosa*	A	AS	2	2	2	4	3	1		8
	Dendrocincla merula	A	SF		5	1					
	Sittasomus griseicapillus	M	I	1		1				1	1
	Glyphorynchus spirurus	M	BM	1		1	2	2	1		
	Xiphorhynchus elegans	A	BM	1			1	3	1		
	Xiphorhynchus guttatus	B	BM	1			1	3	1		
	Campylorhamphus trochilirostris	A	AB	1	1						
	Dendrocolaptes certhia	A	I	2		1					1
	Dendrocolaptes picumnus	A	I			1				1	2
Xenopidae	*Xenops minutus*	B	BM	2	2						2
Grallariidae	*Myrmothera campanisona*	H	—		1						
Furnariidae	*Furnarius leucopus*	B	I			1					
	Automolus rufipileatus	M	BM		2	1			1		
	Automolus melanopezus	A	AB					2			
	Automolus ochrolaemus	M	AS	1	3		1	1	3		1
	Anabacerthia ruficaudata	A	I		1						
	Syndactyla ucayalae	M	I			1					
	Synallaxis rutilans	A	AB	1		1		5			
Pipridae	*Pipra fasciicauda*	M	F	3	11		2	3	12	1	3
	Ceratopipra rubrocapilla	A	F		2						
	Lepidothrix coronata	M	F	4	2		2	3	4		
	Machaeropterus pyrocephalus	M	AB		2		1		1		
Onychorhynchidae	*Onychorhynchus coronatus*	A	I	1		2		3			
	Terenotriccus erythrurus	M	I	2					2		
Pipritidae	*Piprites chloris*	A	I	3	1	1					
Rhynchocyclidae	*Mionectes oleagineus*	M	O	1	1				1		2
	Leptopogon amaurocephalus	M	I	2	1	1	1	1	3		4
	Rhynchocyclus olivaceus	A	I					1			
	Tolmomyias poliocephalus	M	I								1
	Hemitriccus flammulatus	M	AB	1	2	2		2	1	2	
	Hemitriccus iohannis	M	I				1		1	9	4
	Lophotriccus eulophotes	M	AB	1	1				3		
Tyrannidae	*Attila spadiceus*	M	I	1							
	Ramphotrigon megacephalum	M	AB						1		
	Ramphotrigon fuscicauda	M	AB	2				2	2		
	Pitangus sulphuratus	B	O	1							
	Cnemotriccus fuscatus	B	I			1		1			
Troglodytidae	*Microcerculus marginatus*	A	I								1
	Pheugopedius genibarbis	B	I	3				4	1	2	4
Turdidae	*Catharus swainsoni*	—	O				1				
	Turdus hauxwelli	A	O								2
	Turdus amaurochalinus	B	O							1	
Passerellidae	*Arremon taciturnus*	M	O				1	2		1	
Parulidae	*Myiothlypis fulvicauda*	—	I		1						
Thraupidae	*Saltator maximus*	B	G				1				
	Ramphocelus carbo	B	O						1	10	
	Lanio luctuosus	M	O				1			1	
	Volatinia jacarina	B	G						1		
	Sporophila angolensis	B	G			1	1		4	2	2
Cardinalidae	*Habia rubica*	A	O	1	1			1		0	
	Cyanoloxia rothschildii	M	G							1	

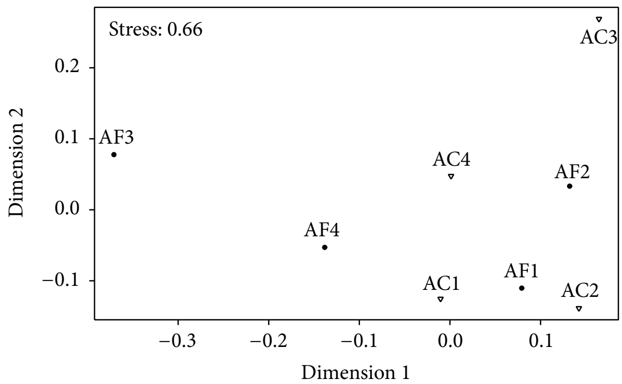

Figure 5: Results of the NMDS analysis of the number of individuals per guild recorded in each control (AC1, AC2, AC3, and AC4) and burned plot (AF1, AF2, AF3, and AF4) in the study area in eastern Acre, Brazil, based on the Bray-Curtis index.

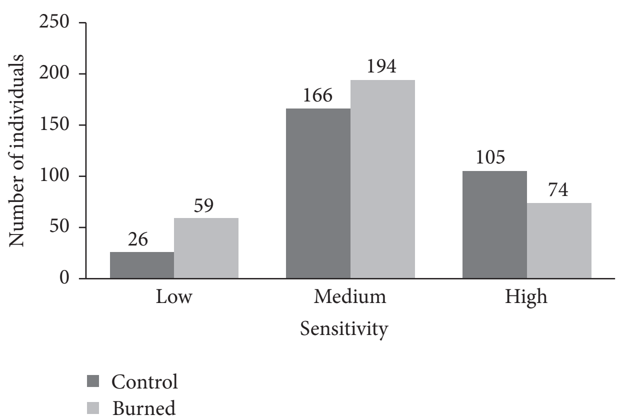

Figure 6: Distribution of the bird fauna of the control and burned plots in eastern Acre, Brazil, according to the sensitivity of the different species to habitat disturbance.

Table 3: Vegetation structure: number of bamboo stems, palms, and dead trees in the study plots in eastern Acre, Brazil. The dead trees were classified according to their degree of decomposition (ST1, ST2, and ST3).

Plot	Bamboo stems	Palm trees	Dead trees			
			ST1	ST2	ST3	Total
AC1	272	18	15	33	10	58
AF1	383	83	25	40	25	90
AC2	187	86	4	10	5	19
AF2	212	56	9	24	8	41
AC3	229	30	3	12	4	19
AF3	6	41	5	35	30	70
AC4	13	28	3	19	15	37
AF4	0	40	5	11	2	18

Table 4: Results of the multiple regression of the biotic variables on the species richness of birds in the study area.

	Estimator	Standard deviation	t	P value
Richness				
Intercept			14.68	0
Score 1	28.47	19.31	1.47	0.20
Score 2	21.78	29.59	0.73	0.49
Abundance				
Intercept			10.91	0
Score 1	19.10	39.64	0.48	0.65
Score 2	28.71	60.74	0.47	0.65

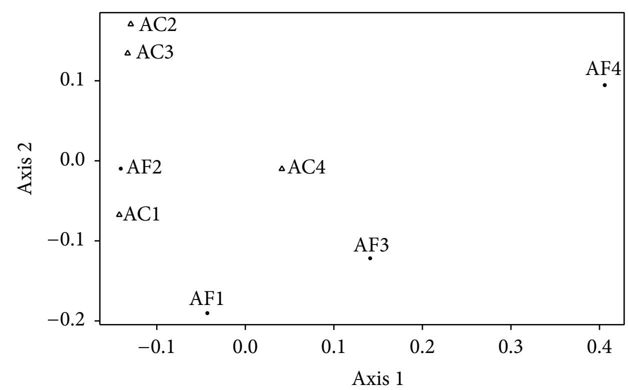

Figure 7: The results of the PCA of the biotic variables recorded in the burned (AF1–4) and control plots (AC1–4).

4. Discussion

Overall, the species richness of understory birds was virtually identical between the burned and control sites. This is because the sample size is small and because of this the results were not reliable enough to be extrapolated universally. Eight years had passed between the 2005 drought and the study period, in 2013, which may have been sufficient for the regeneration of the forest to the point where it was capable of attracting species specialized for the exploitation of secondary forest habitats [58]. In general, disturbed forests tend to have higher bird species richness and abundance in comparison with primary forests [31]. The fires resulted in a mosaic of disturbance, characterized by a mixture of the original vegetation and successional habitats that permitted the colonization of the area by birds adapted to inhabit clearings in the forest or areas undergoing regeneration [14]. Another important point is that the burned sites analyzed in the present study were connected to other tracts of forest in different successional stages, in some cases, with traits of the primary forest, which may have facilitated the recolonization of the disturbed habitat by the birds.

The vegetation of Acre is distinct from that found in most other regions of the Amazon basin [59]. A number of recent studies in permanent plots have indicated that this region is relatively dynamic, with high levels of productivity, but smaller-sized tree species [60]. The defining presence of large tracts of bamboo in the region may indicate a recent history of wildfires [40]. This may be why, eight years after the fires, the assemblages of understory birds did not vary significantly between burned and control sites. A study of the bird fauna in bamboo forests showed that they were less affected by wildfires than those found in the forests of the central Amazon basin, three years after a wildfire [26]. Other studies in Acre [29] and Pará [14, 29] have shown a high degree of correlation between the fauna and the openness of the canopy and basal area, indicating that the characteristics of the bird community found in burned forests three years after the wildfire are directly related to features of habitat structure, such as canopy integrity and the restoration of the understory [24], being reflected in distinct processes of regeneration in the different regions of the Amazon basin [19, 29].

During the initial stages of regeneration following the wildfire, smoke may be fatal for many animals [9], and drastic modifications of the structure and composition of the forest [24] may be among the principal causes of the loss of the loss of bird species during the first few years following a fire [27]. However, as succession progresses, there is a gradual increase in both species richness and the abundance of individuals [15, 22, 61, 62], to the extent that, after eight years, no significant difference was found in comparison with the control sites. The increase in species richness may nevertheless have been at least partially due to a sampling effect, given that mist nets are known to capture larger numbers of birds in secondary forests, where more species fly at lower levels in comparison with primary forest [18, 27]. Recent evidence also indicates that species richness in pairs of taxa may vary considerably depending on the group and the geographic region, demanding further studies using a more ample methodological approach [63]. Both community structure and the abundance of species must be considered for any systematic comparison between disturbed and undisturbed forests [27, 63, 64].

The two-dimensional ordination of the samples in the MDS analysis indicated that the presence of certain differences in the species composition between burned and control sites was not significant. A number of studies in forests of the central Amazon basin [27] have shown that, even after 10 years, the bird assemblage may not be fully recuperated. In tropical forests of Southeast Asia, however, the bird community became totally restructured in less than five years following a wildfire [22]. The findings of the present study are consistent with those from the Chico Mendes Extractive Reserve, also in eastern Acre [27], which showed no significant differences in the composition of the bird communities in burned and unburned sites, only three years after a fire [27]. The period necessary for the regeneration of the forest is still unclear, however, and it is not yet possible to predict the time period necessary for the full recuperation of the bird fauna [27, 56].

The analysis of guilds is an effective approach for the evaluation of bird communities and the impacts of environmental disturbances [65]. This approach is based on the assumption that generalist species will be more tolerant of anthropogenic impacts than those classified as specialists. The NMDS analysis found some differences among feeding guilds between burned and control sites, although they were not significant. The majority of the antbirds and insectivores associated with mixed flocks were more abundant in the control plots. These two guilds are especially sensitive to habitat disturbance [66] and the occurrence of some of these species depends on environments with a closed canopy, with a lack of clearings [67]. Data from the central Amazon basin [15, 17, 24, 27] also indicate that species of these two guilds are highly sensitive to habitat disturbance, apparently due to a reduction in the abundance of arthropods in areas affected by fires. In the present study, all the insectivore guilds were affected negatively by fire, except in the case of the clearing specialists. Other studies have shown that insectivorous birds are sensitive to forest fragmentation and the construction of highways [33, 68].

Mixed flocks tend to disband following habitat disturbance [32, 69], although the species that make up these flocks may respond differently to the process. This may be related to availability of feeding resources and the microclimatic conditions found in the regenerating forest [70] and may account for the fact that some of these species may still be found in burned habitats.

In the present study, insectivorous birds associated with clearings were favored by fire-related disturbance. Other guilds—nectarivores, omnivores, and granivores—were also benefitted. Some members of these guilds are well-adapted for the exploitation of regenerating habitats [34, 58, 71, 72]. These species are considered to be generalists, given their ability to occupy more than one type of habitat [47]. A number of studies in the Amazon basin have shown that clearing insectivores, nectarivores, omnivores, and granivores were all favored by fire-related habitat disturbance [15, 19, 24, 27, 73] and fragmentation [70]. In Southeast Asia, the arboreal frugivore guild was favored in burned habitats [22], which reflected the successional stage presented by the forest.

In the case of the species most sensitive to environmental disturbances [47], the results of the present study indicate no significant difference between the burned plots and the controls. These findings contrast with those from a study in the central Amazon basin [27], which showed that, even after 10 years of recuperation, low and medium sensitivity species were still being benefited by the fire event. While the categories used to characterize the sensitivity of the species to habitat disturbance are only poor indicators of their capacity to occupy habitats and the dynamics of colonization [47, 74], this approach has proven useful in studies of different types of habitat disturbance in the Amazon [18, 64] and Brazilian Atlantic forests [75], providing a useful parameter for the evaluation of large-scale variation in bird communities. The results of the PCA indicated that the structure of the habitat of the burned and control plots was significantly different. This was due primarily to the greater abundance of relatively fine trees (low DBH) in the burned plots. In the primary (control) forest, by contrast, larger trees, considered to represent the climax condition, were more abundant. These results are similar to those of a study in the central Amazon basin [17], in which 74% of the trees in plots had a DBH of less than 20 cm, three years after a fire. This indicates that areas of forest that have suffered fires will initially be characterized by a relatively small number of large trees but that this situation will be reverted over time.

The number of dead trees also differed, with more dead trees being found in the burned plots. This is a characteristic of areas of forest impacted by wildfires [17]. The burned plots also had more dead trees in advanced stages of decomposition. The data indicate that trees continue to die off up to three years after the fire [13, 16, 76].

The variation in the primary axis of the PCA was determined by the number of bamboo stems. These plants take advantage of clearings in the forest produced by tree-fall or deforestation [77] and may colonize large areas of forest in a short time [77, 78], and they may also mask edge effects and tree mortality [79]. Bamboos and palms are also important pioneer plants in the succession of forests impacted by fire [24, 26]. By growing rapidly, the y create favorable conditions for the bird community over a short-time scale and may account for the reestablishment of the understory bird fauna in the present study after only eight years. In a study in the Chico Mendes Extractive Reserve in eastern Acre, the species richness and abundance of birds had recuperated much better three years after a fire than at sites in eastern Amazonia, indicating that the high densities of bamboo in the former region may play an important role in this recuperation [26]. In the present study, the PCA found no evidence of the effect of biotic variables on the species richness and structure of the bird communities.

The regeneration time of the forest may account for differences in the species richness, composition, and abundance of bird assemblages [69]. Data from the central Amazon basin indicate that the characteristics of bird assemblages are closely related to anthropogenic disturbances and the severity of fires. The richness of habitat sensitivity bird species is lower in habitats with lower densities of live trees [15, 17]. In the present study, the data collected on the burned plots indicated that the forest is still in succession.

4.1. Implications for the Conservation of Understory Birds. The results of the present study indicate that, eight years after the fires, the bird assemblages in the impacted habitats had a similar structure to those found in the control areas, which were not burned. This is because the sample size is small and because of this the results were not reliable enough to be extrapolated universally. However, burned habitats are more susceptible to new fires [80], and their bird communities may be more seriously affected [15]. In addition, fires appear to have the most negative impact on bird communities [18] in comparison with other anthropogenic processes, such as habitat fragmentation [33, 69] and selective logging [34]. In this case, there is a clear need for active government policies to prevent and control wildfires in the region. Government agencies must provide incentives for the prevention of wildfires, supported by educational campaigns that aim to understand the motives for the use of burn-off as an agricultural practice and encourage the implementation of preventive practices and low-cost alternatives for the preparation of the soil. In the current scenario, the use of techniques such as firebreaks, for the prevention and control of wildfires, is essential [8]. A reduction in the fragmentation of the forest and the creation of edge habitats, which are known to increase the flammability of the forest, would also be recommended. While deforestation is a common practice for the rearing of cattle, the increasing risk of fires is a major threat to the biodiversity of the remaining forested habitats [8, 80].

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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