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Bird Community Traits in Recently Burned and Unburned Parts of the Northeastern Pantanal, Brazil: A Preliminary Approach

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Abstract: Although fire is a natural phenomenon in the dynamics of some biomes around the world, it can threaten the biodiversity of certain ecosystems. Climate change and the expansion of anthropogenic activities have drastically increased the occurrence of large-scale burnings worldwide. The 2020 fire events in the Pantanal marked a historically unprecedented record, burning an area of approximately 40,000 km^2. However, how fires affect the local wildlife has yet to be evaluated. The aim of this study was to investigate the recovery of the avifauna in the Pantanal of Mato Grosso by comparing data selected from a previous study conducted between 2014 and 2016 with data collected in burned areas nine to twelve months after the fire. We compared diversity and community composition, investigated the influence of species trait foraging guild, foraging strata, and body mass on their response to fire, and complemented it with species' individual responses. Bird richness and Shannon diversity were lower in burned areas, and the composition significantly varied between burned and unburned areas. The species' response toward burned and unburned areas was significantly mediated by their traits, with smaller, piscivorous, omnivorous, ground and water, and midstory to canopy species being the most sensitive toward the environmental changes caused by the fire. Thirty-three species showed a negative response toward burned areas, but 46 species showed the opposite response, and 24 species were similarly abundant in unburned and burned areas. The present study is the first evaluation of the response of birds to the extreme fire events in the Pantanal and provides valuable insight into the recovery and resilience of local avifauna.

Keywords: bird community; diversity; fire effects; species traits

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1. Introduction

Fire is a natural phenomenon in a variety of biomes worldwide, especially in savanna ecosystems [1–4]. Several studies have reached the consensus that fires are a necessary disturbance for the maintenance of diversity and biological processes in these ecosystems [2–5] and even have a determining role in ecosystem evolution [6,7]. This influence can be evidenced by many plant species that have developed diverse adaptations to address a regime of periodic fires [5,7–10].

However, fire has become a serious threat to biodiversity, even for adapted ecosystems, since climate change, in conjunction with expanding anthropogenic activities (e.g., agricultural impacts), has dramatically increased the occurrence of large-scale burnings [4,11]. These types of fires are triggered at the height of the dry seasons and reach high intensities, devastating vast areas of vegetation. In contrast, natural fires, which are caused by electrical discharges, generally occur at the beginning of the rainy season [12].

The resilience and recovery of avian communities after fire incidents are driven by many factors. Previous studies suggest that low–severe or patchy fire can, at least temporarily, boost bird diversity by creating a distinct mosaic of successional stages [13–15], and after a fire, there are often changes in the bird assemblage and increased bird richness or abundances can be observed [16–19]. However, a severe fire can also reduce diversity, cause a shift toward open areas or generalist bird species, and impoverish the bird community, especially in fire-sensitive habitats such as rainforests, where fire reduces the understory and canopy or even transforms forests into savanna habitats [13,20–23].

Fire severity and time since a fire have been shown to condition the post-fire succession of birds [13,18,19,22,24–27], and factors such as habitat preferences, preferred stratum, feeding guild, body mass, mobility, sensitivity toward disturbance, or degree of specialization can favor or disadvantage the adaptation of a species to the changed environment (e.g., [22,23,25,28–33]). Nearby unburned refuges can enhance the rapid recovery of bird assemblages after a fire [34], but while some species can cope with the changes or might even thrive under the new conditions, others will only return after the burned areas have sufficiently recovered.

Assessing the response of bird communities to burned areas thus provides crucial information about the adaptation capacity and tolerance of bird species, but it can also reveal important information about the dynamics and resilience of the environment [35]. Given their high potential for physical dispersal and easy detection, birds are considered ideal for verifying environmental health and processes such as habitat fragmentation and ecological restoration [36,37]. Some functional groups of birds contribute considerably to ecological processes related to habitat succession, pollination, and seed dispersal [36,37] and thus are essential to maintaining ecosystems and can play an important role in the recovery of ecosystems after fires.

The Pantanal, the largest floodplain in the world, is considered a fire-prone and fire-dependent ecosystem [3,38,39] since it contains widespread grasslands and savanna-like ecosystems [40]. However, the region, similar to all other fire-dependent ecosystems in Brazil, also contains fire-sensitive vegetation types such as semideciduous forests [4]. The wetland system is considered stable and resilient as long as natural patterns and periodicities of flooding and wildfire are maintained [41], but the region suffers from long droughts and a lack of significant flooding during rainy periods, a situation that has contributed to the generation of catastrophic fires such as those started by arson in 2020 [42,43].

The 2020 fire events burned approximately 40,000 km^2 (30%) of the Pantanal, destroying vast areas of vegetation, 43% of which had not been burned in the last two decades [43–45]. Recent research suggests that over 3120 km^2 have been severely degraded by fires but that there is good potential for natural regeneration [46]. Locally, the fires have substantially reduced vegetation health and water quality. These effects have been shown to be only short-term, suggesting great resilience of the ecosystem; however, the observed vegetation recovery is currently mainly related to regrowing shrubs and grasses, and it might take a long time until the Pantanal returns to its pre-fire state [47].

Despite the fact that the Pantanal, compared to other Brazilian biomes, had the highest hotspot average between 2002 and 2019, very few studies related to fire effects have been conducted for this biome. Research has been carried out mainly in the *Cerrado*, the Brazilian savanna, but even there has rarely addressed the effects of fire on fauna, particularly on the avifauna [48–50]. Studies on the impact of fire on the Brazilian avifauna have also been conducted in the Amazon region (e.g., [24,25,28,51,52]) and in the Brazilian Highland Grasslands (e.g., [26,53]); however, from the Pantanal, very little is known about how birds respond to fire disturbance [29], and the impact of recent, severe fire events on the diverse local avifauna has yet to be evaluated.

Approximately 617 bird species are known to occur in the Pantanal, representing 32% of all avifauna known in Brazil and highlighting the region's importance in maintaining a rich avifauna [54]. A first investigation on the number of vertebrates immediately killed by the 2020 fire events assumed that birds were among the most impacted [55], demonstrating that even the most mobile organisms may have had a limited chance of escaping intense and aggressive flames. Survivors of fire events must face changes in vegetation structure and its cascading effects of changed food source availability, nesting opportunities, or exposure to predation (e.g., [56–61]), particularly when fire destroys such a vast amount of area. It is speculated that more than half of the bird species occurring in the Pantanal may have had their population affected by fires to some extent [54], and a recent study suggests that the fires substantially reduced suitable habitats for Hyacinth Macaws (*Anodorhynchus hyacinthinus*) [62]. The impact of fires on the local avifauna might be particularly pronounced, as habitat heterogeneity, in addition to seasonal flood pulses, is considered a driving factor for the richness, abundance, and structure of bird communities and trophic guilds in the region [63–66].

The aim of this study was to provide a first insight into the response of the avifauna toward burned areas after the severe 2020 fire events in the Pantanal of Mato Grosso by comparing bird community data obtained during a short-term study in burned areas nine to twelve months after the fire with data selected from a previous long-term bird study conducted in the same area between 2014 and 2016 [67]. We compared avian diversity and community composition between the burned and unburned areas and investigated whether the species response was moderated by feeding guild, preferred foraging strata, or body mass to identify general trends across species and complemented the analysis with individual species responses.

2. Materials and Methods

2.1. Study Area

This study was carried out in the northeastern Pantanal in the Parque SESC Baía das Pedras (16°29′55″ S, 56°24′47″ W, 119–131 m altitude), a privately protected unit of the SESC Private Natural Heritage Reserve (RPPN) in the municipality of Poconé in Mato Grosso, Brazil (Figure 1). Our study area comprises an area of approximately 4200 hectares and is located in the floodplain of the Cuiabá River, one of the main tributaries of the Paraguai River in the Pantanal. The climate of the region is tropical, with dry winters and rainy summers, and the mean annual precipitation is 1400 mm [68]. The area is subjected to the Pantanal annual hydrological cycle, which is divided into four seasonal periods: (1) dry, from July to September, when there is a strong hydric deficit; (2) rising water, from October to December, when the precipitation period begins; (3) high water, from January to March, when flooding is at the highest level; and (4) receding water, from April to June, when the water level begins to decline [69,70].

The municipality of Poconé was the most impacted by fire events in Mato Grosso [71]. Approximately 869,170 hectares were burned in the region, of which 97.3% were natural areas, namely forest formations (37%), wetlands (29.7%), grassland formations (23.4%), vegetation in dried-up rivers and lakes (4.4%), and savanna (2.8%) [72]. In our particular study area, the fire was contained before it could widely spread, and only a small portion of approximately 3% was severely burned. However, the fire consumed large parts of the surrounding areas, including 93% of the SESC Private Natural Heritage Reserve (RPPN), which is situated beside the Parque SESC Baía das Pedras [73]. Before the 2020 fire events, the Parque SESC Baía das Pedras was not affected by fires for at least 20 years.

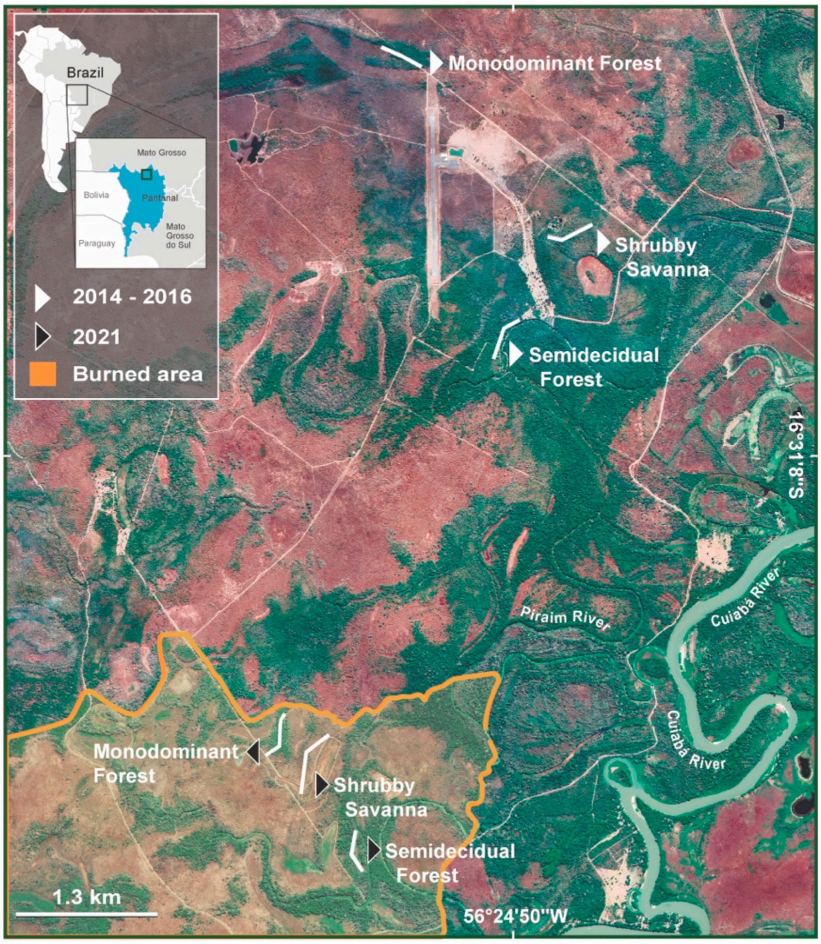

Figure 1. Locations of the three sampled unburned areas in 2014–2016 (markings, white arrow) and three sampled burned areas in 2021 (markings, black arrow) in our study area in the Pantanal of Poconé, MT, Brazil.

2.2. Bird Survey

To evaluate potential differences in bird species diversity and composition between burned and unburned areas, three different phytophysiognomies within the burned part of the study area were selected: two forest ecosystems, semidecidual forest and monodominant forest (‘*Cambarazal*’), and one savanna ecosystem, shrub savanna. The selected areas were repeatedly sampled during two consecutive seasonal periods: the receding water period (May and June of 2021) and the dry period (between July and September of 2021).

Three methods, described below, were used to sample each area equally in both seasonal periods: mist nets, point counts, and autonomous acoustic recordings, resulting in a total of 18 samples in three burned areas. To compare the data collected in the areas hit by fire, we selected bird community data from a multiannual survey conducted in the study area between 2014 and 2016 [67]. As the study area part affected by the fire was not evaluated during this previous study, we selected 18 samples from three areas located in another part but with the same type of vegetation physiognomies and proximity to the river arm for comparison (Figure 1). To ensure a similar sampling with all three methods in both seasonal periods at the comparable sites, we further had to select samples obtained during a larger time period than the samples from the burned areas. The samples used for the comparison were collected during the dry period in 2014, the subsequent receding period in 2015 (two sites), and the receding period in 2016 (one site).

Avian nomenclature follows the South American Classification Committee [74].

2.3. Mist Nets

Within each sampling area, five mist nets were installed [75,76]. These mist nets were 9 m long, 2.7 m high, 20 mm × 20 mm mesh, and were laid out in a straight transect line in the field, totaling 45 m in length. The nets were open from 6:00 to 11:00 h and from 15:00 to 17:00 h [77] for four days per area per seasonal period. During field campaigns, mist nets remained installed in each sampling area for two consecutive days and moved thereafter to another sampling site. Birds caught in mist nets were weighed to collect data on body mass.

2.4. Point Counts

In each area, four-point counts, separated from each other by at least 200 m [75], were established. At each point, birds were recorded four times per seasonal period for 10 min, resulting in 160 min of sampling per area per seasonal period. At each point, the birds were observed, and their vocalizations were recorded using the Zoom H4N portable recorder or TASCAM. The data obtained were transferred to external drivers and later sent to the INAU Pantanal BioData Center—IPBC, hosted at the Federal University of Mato Grosso, Brazil, for further analysis and identification of the sampled bird species.

2.5. Autonomous Acoustic Recordings

One automatic recorder model SM2 + of Wildlife Acoustics, Inc., (Maynard, MA, USA) Firmware Version 3.10, configured for hardware amplification of 48 dB and software amplification of 6 dB, was installed in each of the sampling areas. Two omnidirectional microphones with a sampling rate of 48 kHz and a resolution of 16 bits were installed in each recorder. The recorders stayed for at least two days in each sampling area, recording the sounds 24 h per day. All sound data collected were archived at IPBC for further analysis.

From the total recorded hours, we selected four stretches of the audio from 6:00 to 7:00 h and four stretches from 16:00 to 17:00 h from four different days per seasonal period per area, resulting in eight hours per area per seasonal period to listen and identify the bird vocalizations.

2.6. Bird Functional Traits

For each detected species, we classified the dominant feeding guild following Stotz et al. [78] and Wilman et al. [79], which included carnivorous (CAR), frugivorous (FRU), granivorous (GRA), insectivorous (INS), nectarivorous (NEC), omnivorous (OMN), and piscivorous (PIS). Based on Stotz et al. [78], Wilman et al. [79] and personal observations of the birds in the Pantanal, we further classified the main foraging strata of each species as ground (G), understory (U), midstory (M), canopy (C), water (W), and combinations of those for species with multiple preferences, including ground to understory (GU), ground to midstory (GUM), ground to canopy (GUMC), ground and water (GW), midstory to canopy (MC), understory to midstory (UM), and understory to canopy (UMC).

The third trait of interest was body mass. For species not caught in mist nets during the study, body mass (in grams) was based on Dunning Jr. [80] and Wilman et al. [79].

2.7. Statistical Analysis

All statistical analyses were conducted in R (Version 4.2.1) [81].

First, we compared taxonomic diversity between burned and unburned areas following an approach proposed by Chao et al. [82]. The approach is based on the framework of Hill numbers or 'effective number of species' [83] and consists of four steps conducted in the *iNEXT.4steps* package (Version 1.0.1), an updated and expanded version of the *iNEXT* package [84,85]. The analysis includes the assessment and graphical visualization of (1) the sample completeness profile to investigate the extent of undetected diversity, (2) size-based rarefaction and extrapolation analysis to investigate if we can infer true diversity and the asymptotic diversity profile to statistically evaluate differences in diversity, (3) non-asymptotic coverage-based rarefaction and extrapolation analysis, which allows fair diversity comparisons for a standardized fraction of the assemblage's individuals when data do not contain sufficient information to infer true diversity, and (4) an evenness profile, where evenness is assessed and compared for the standardized assemblage fraction. The three most widely used species diversity measures, species richness, Shannon diversity, and Simpson diversity, as special cases of orders $q = 0$, 1, and 2, are used, where q determines the measure's sensitivity to species abundances; $q = 0$ (species richness) counts the species equally without regard to their relative abundances, $q = 1$ (Shannon diversity) counts all individuals equally and can be interpreted as the effective number of abundant species, and $q = 2$ (Simpson diversity) discounts all but the highly abundant species and can be interpreted as the effective number of highly abundant species in the assemblage.

We used species abundance data to estimate the taxonomic diversity of all three diversity orders via the *iNEXT4steps* function. Extrapolation curves were extrapolated to the maximum recommended size (two times the reference sample size). A total of 999 bootstrap replications were conducted to construct the 95% confidence intervals. Non-overlapping confidence intervals indicate significant differences at the 5% level, whereas overlapping confidence intervals need to be interpreted with caution, as they do not guarantee non-significance [82,86].

Second, we evaluated differences in bird species composition between burned and unburned areas, species' individual response, and the role of species traits in their response using a model-based fourth-corner approach [87]. We used the *traitglm* function in the *mvabund* package (Version 4.2.1) [88–90], which fits a fourth-corner model to predict abundance across several taxa (L) as a function of environmental variables (R) and traits (Q). The environmental–trait interaction is understood as the fourth corner and gives a set of standardized coefficients that describe how environmental response across taxa varies as traits vary and can be interpreted as a measure of importance. When no trait matrix is provided, the function fits a multivariate species distribution model assuming a different environmental response for each species and uses species identities as Q. We build three matrices of sample–species count data, sample–environment data, and species trait data and fit two multivariate generalized linear fourth-corner models using the '*manyglm*' method to predict abundance as a function of (1) fire impact (burned/unburned) only and (2) fire impact and species traits. We assumed a negative binomial distribution for count data. Due to potential sensitivities with rare species, we only included species with $n \geq 4$ in this analysis [91]. Additionally, for the model including species traits, the 12 defined strata were reduced to 6 broader strata (GU (G+U+GU), GUMC (GUM+GUMC), UM, UMC, MC (M+C+MC), GW (GW+W)), as several strata were only represented by very few species (e.g., C = 2 species, M = 1 species, see Table A1 for details).

As the three methods used during this study have previously been shown to vary in their success in detecting bird species [92], some variation in abundance across samples might be explained by the different sampling mechanisms used during this study. To account for variation in total abundance across samples, a term for row total abundance was added in both fourth-corner models, such that all other terms model relative abundance rather than absolute abundance ('compositional term') [91]. To adjust for different levels of abundance of different response variables, a column effect was included.

To test the significance of the two models, score-test statistics and p-values were calculated using 999 resampling iterations via PIT–trap block resampling using the *anova.traitglm* function in *mvabund* [88]. As we repeatedly sampled the same areas and observations might be correlated, resampling was restricted to within areas by using area ID as a blocking variable.

For visual interpretation, we added a LASSO penalty using the '*glm1path*' method in both models, which sets any terms in the model that do not explain any variation in species response to zero. For nonzero coefficients, the nature and strength of the environment–trait interactions are indicated by the sign and magnitude of the interaction coefficients [87]. We then generated heatmaps of the standardized fourth-corner coefficients using the *levelplot* function of the *lattice* package (Version 0.20-45) [93].

As the independence of sites is a key assumption of this approach [89], we investigated whether closer sample areas had a more similar species composition prior to the analysis using the Mantel test in the *vegan* package (Version 2.6-4) [94]. We built two dissimilarity matrices of the area–species count data and area coordinates using the Bray–Curtis index and Euclidean distance via the *vegdist* function and assessed correlation via the *Mantel* function with the Pearson correlation method and 999 permutations.

3. Results

Throughout the study, we obtained 2209 detections of 183 bird species from 46 families. In burned areas, we identified 1088 detections of 129 bird species; in unburned areas, we identified 1121 detections of 145 bird species. The number of detections per species varied between 1 and 90 records (Ø = 12 detections). The most representative guild in terms of the number of detections was INS (1098 detections of 70 species), followed by OMN (643 detections of 56 species), FRU (201 detections of 21 species), GRA (107 detections of 8 species), NEC (81 detections of 6 species), CAR (57 detections of 17 species), and PIS (22 detections of 5 species). The most representative strata were GU (794 detections of 46 species), followed by MC (462 detections of 54 species), UMC (455 detections of 28 species), UM (265 detections of 21 species), GUMC (170 detections of 15 species), and GW (63 detections of 19 species). The body mass of the species ranged between 3.1 and 4400 g (Ø = 225.1 g) (Table A1).

The result of the Mantel test showed no significant correlation (r = 0.4194, $p = 0.1$), suggesting that there is no distance decay of similarity.

The result of the diversity analysis suggests an undetected diversity in unburned and burned areas, as the two estimated sample completeness profiles increased with diversity order. Sample completeness for $q < 1$ was higher in burned than in unburned areas, although confidence intervals widely overlap. As q increases, the two curves become indistinguishable, suggesting similar sampling completeness in unburned and burned areas. The estimated sample completeness for orders of $q = 0$, 1, and 2 for unburned and burned areas data indicate that the data cover at most 76.6% and 85.1% of the total species, the detected species cover approximately 96.3% and 97% of the assemblage's individuals, and approximately 99.8% of the individuals of highly abundant species (Table 1, Figure 2a).

Table 1. The numeric values for the three special cases of $q = 0$, 1, and 2 corresponding to Figure 2a–e. Values in brackets indicate the difference to the associated 95% lower and upper confidence limit.

Sample Completeness Profiles (Figure 2a)			
Completeness	**$q = 0$**	**$q = 1$**	**$q = 2$**
Unburned areas	76.6% (+/−0.12)	96.3% (+/−0.01)	99.8% (+/−0.001)
Burned areas	85.1% (+/−0.11)	97.0% (+/−0.01)	99.8% (+/−0.001)
Asymptotic analysis (Figure 2b,c)			
Diversity	**$q = 0$**	**$q = 1$**	**$q = 2$**
Unburned areas			
Asymptotic	189.2 (+/−33.8)	87.9 (+/−5.5)	59.5 (+/−4.7)
Empirical	145.0 (+/−8.9)	80.2 (+/−4.7)	56.6 (+/−4.2)
Undetected	44.2	7.7	2.9
Burned areas			
Asymptotic	151.7 (+/−24.2)	77.2 (+/−4.4)	55.6 (+/−3.8)
Empirical	129.0 (+/−7.7)	71.5 (+/−4.1)	52.9 (+/−3.7)
Undetected	22.7	5.7	2.7

Table 1. *Cont.*

Non-asymptotic coverage-based rarefaction and extrapolation (Figure 2d)			
Maximum standardized coverage Cmax = 98.6%			
Diversity	**$q = 0$**	**$q = 1$**	**$q = 2$**
Unburned areas Burned areas	171.7 (+25.0/−24.0) 140.9 (+/−18.0)	84.8 (+5.4/−5.5) 73.7 (+/−4.3)	58.0 (+4.4/−4.5) 53.8 (+/−3.6)
Evenness among species abundances (Figure 2e)			
Diversity	**Pielou J′**	**$q = 1$**	**$q = 2$**
Unburned areas Burned areas	0.86 0.87	0.49 (+/−0.05) 0.52 (+/−0.06)	0.33 (+/−0.04) 0.38 (+/−0.05)

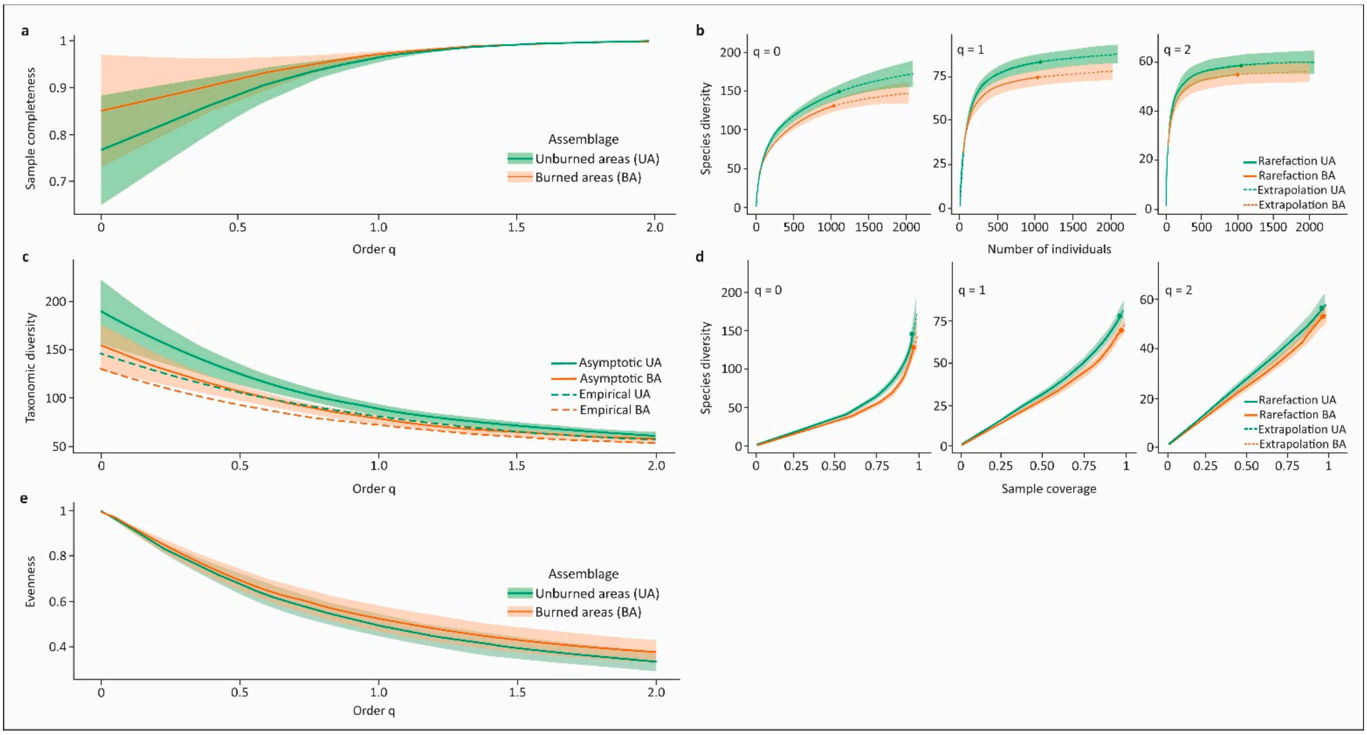

Figure 2. (**a**) Estimated sample completeness curves as a function of order q between 0 and 2 for bird species data collected in unburned areas (UA, green) (S_{obs} = 145, n = 1121) and burned areas (BA, orange) (S_{obs} = 129, n = 1088); (**b**) sample-sized-based rarefaction (solid lines) and extrapolation curves (dashed lines) for diversity of orders $q = 0$ (species richness), $q = 1$ (Shannon diversity), and $q = 2$ (Simpson diversity). Extrapolation up to double the reference sample size (n = 2242 for UA, n = 2176 for BA); (**c**) asymptotic estimates of diversity profiles (solid lines) and empirical diversity profiles (dashed lines); (**d**) coverage-based rarefaction (solid lines) and extrapolation (dashed lines) curves up to the corresponding coverage value or a doubling of each reference sample size; (**e**) evenness profile as a function of order q, for $0 < q \leq 2$, based on the normalized slope of Hill numbers. Solid dots denote observed data points. All shaded areas denote 95% confidence intervals obtained from a bootstrap method with 999 replications. Numerical values corresponding to the gaps are shown in Table 1.

The size-based rarefaction and extrapolation sampling curves for diversity order $q = 0$ suggest that the current data do not contain sufficient information to estimate true species richness. The asymptotic estimates thus represent lower bounds, and the difference between the unburned and burned area assemblages cannot be accurately assessed. The same is true for order $q = 1$, although the curves almost stabilize. The curves for order

$q = 2$ level off, implying that the asymptotic diversity estimates are reliable for Simpson diversity (Table 1, Figure 2b).

The undetected Simpson diversity in unburned and burned areas was 2.9 and 2.7, respectively, indicating that approximately three highly abundant species were not detected in the assemblages. The difference in species is 3.9, suggesting a similar diversity in unburned and burned areas. The undetected species richness was at least 44.2 and 22.7, and the undetected Shannon diversity was at least 7.7 and 5.7 in unburned and burned areas, respectively (Table 1, Figure 2c).

For species richness and Shannon diversity, inference and significance testing can be performed up to a standardized coverage value of $C_{\max} = 98.6\%$. At this value, the difference in species richness is 30.8 species, and the difference in Shannon diversity is 11.1 species, suggesting a higher species richness and diversity of abundant species in unburned areas than in burned. However, only for Shannon diversity can we truly infer statistically significant differences at the maximum coverage value, as confidence intervals do not overlap. The confidence intervals also do not overlap for lower sample coverage values between approximately 63% and unity. At lower coverage values, we can observe a significant difference in species richness as well (Table 1, Figure 2d).

Under the coverage value of 98.6%, Pielou's evenness measure shows that the evenness among species abundances is similar in unburned and burned areas and the evenness profile suggests that the evenness values for the unburned and burned areas assemblages are very close for all orders of q (Table 1, Figure 2e).

For the fourth-corner approach, 80 rare species ($n < 4$) were excluded, resulting in a total of 103 species and 2081 detections used for this analysis, which are presented in the heatmaps. The results of the species distribution model suggest an overall significant interaction between fire impact and species (df = 102, score = 384.7, $p = 0.048$), indicating that species composition varied between unburned and burned areas. Fourth-corner interaction coefficients for the individual species ranged between −0.204 and 0.157. Thirty-three species were less abundant in burned areas, with *Pheugopedius genibarbis*, *Cranioleuca vulpina*, *Hypocnemoides maculicauda*, and *Campylorhamphus turnidus* showing the strongest negative response. Forty-six species were more abundant in burned areas, with *Synallaxis hypospodia*, *Myiophobus fasciatus*, and *Amblyramphus holocericeus* showing the strongest positive response. Twenty-four species showed no variation in abundance (Figure 3a).

The results of the fourth-corner analysis further revealed a significant interaction between bird species traits and fire impact (df =12, score = 75.06, $p = 0.024$). Fourth-corner coefficients ranged between −0.146 and 0.106, with the strongest negative association between species belonging to the PIS guild and burned areas. Species belonging to the OMN guild and strata GW and MC also showed a negative correlation with burned areas. In contrast, the strongest positive association was found for the UMC strata. The second highest positive coefficient was found for body mass, indicating that in burned areas, species tended to have a higher body mass. Guild NEC, GRA, and FRU were also positively linked to burned areas. Guild CAR showed a very low positive coefficient close to zero, and guild INS and strata GU were set to zero when the LASSO penalty was applied, suggesting that these traits had little interaction with fire impact in predicting the abundance of bird species (Figure 3b).

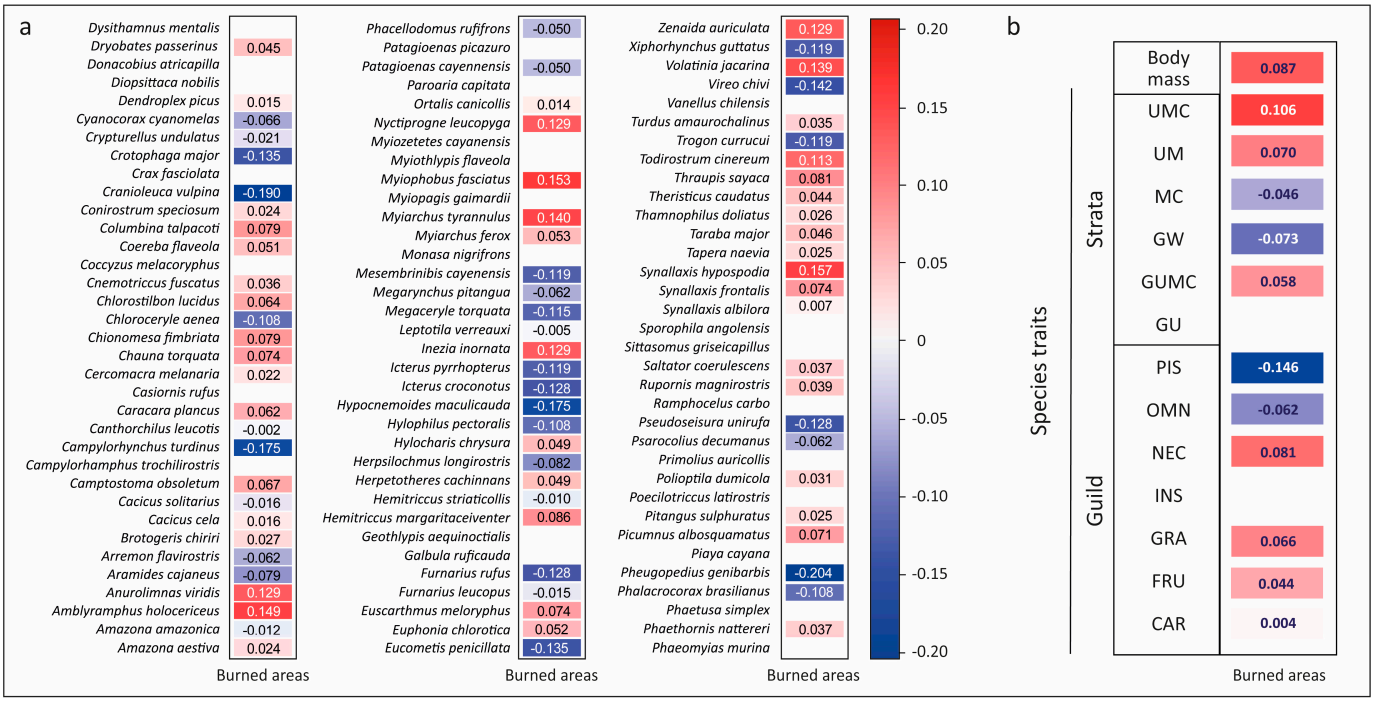

Figure 3. Standardized interaction coefficients between (**a**) bird species abundance and fire impact (burned/unburned) and (**b**) bird species traits body mass (g), main foraging strata, dominant feeding guild, and fire impact from the fourth-corner models after variable selection using the LASSO penalty. Color shadings represent the strength of interactions and their direction (blue = negative, red = positive). The identified main foraging strata include ground to understory (GU), ground to canopy (GUMC), ground and water (GW), midstory to canopy (MC), understory to midstory (UM), and understory to canopy (UMC); dominant feeding guilds include piscivorous (PIS), omnivorous (OMN), nectarivorous (NEC), insectivorous (INS), granivorous (GRA), frugivorous (FRU), and carnivorous (CAR). A total of 103 ($n \geq 4$) of the 183 bird species found during the study were considered for the analysis (see Table A1 for details).

4. Discussion

Bird species richness and Shannon diversity were lower in burned areas one year after the fire, suggesting that these areas did not recover sufficiently to maintain a similar diversity as unburned areas before the fire. However, Simpson diversity was stable, indicating that abrupt environmental changes mainly led to a decrease in rarer and commonly detected species but favored highly abundant species. The species rarely detected during our study might be particularly affected by the fire, as rare species usually occur in lower population sizes and often have more narrow habitat tolerances than widely distributed species. Evenness in the burned areas bird assemblage apparently recovered to a similar level as in unburned areas within one year, suggesting no fundamental changes in the dominance structure after a severe fire.

Contrary to our observations, Kinnaird and O'Brien [95] reported similar overall species richness before and one year after a fire in a Sumatran rainforest. Similarly, Barlow et al. [28] reported that burned and unburned forest plots generally exhibited similar bird species richness 10 to 15 months after understory fires in an Amazonian forest. However, comparisons with previous studies addressing the changes in the avifauna after a fire impact should be performed with caution, as the recovery of avifauna and vegetation after a fire can strongly vary depending on the fire severity, time since the fire, and habitat type considered. Nonetheless, when compared to these previous studies, the recovery of the diversity in burned areas in our study area seems to be rather slow and might be an indicator of the drastic changes caused by the 2020 fire events in the burned areas.

However, although species richness and Shannon diversity decreased in the burned areas in our study area, this might not necessarily be true for each burned habitat type investigated during this study. A previous study from the Pantanal suggested that six to seven years after a fire, the forest dominated by *Attalea phalerata* showed a lower number of species, but the forest dominated by *Guadua* sp. or *Vochysia divergens* ('*Cambarazal*') did not show a similar pattern. Moreover, the *Cambarazal* forest did not show variation in bird richness one to two years after the fire [29], suggesting a rather fast recovery of the avifauna in this particular habitat type. Thus, it is possible that the observed differences in diversity during our study are mainly related to particular habitat types, and further studies, including a larger number of sites in different habitats, are needed to address this potential variation.

Our results further suggest that the bird communities in burned and unburned areas in our study area had distinct community compositions and that these differences were mediated by the species foraging niche, diet, and body mass. According to the trait analysis, species with a fish-based diet responded negatively toward burned areas one year after the fire, and we observed a negative trend for species using ground and water as their main foraging strata, albeit the effect was much less pronounced. This might have resulted from the reduction in suitable habitats close to water bodies but is likely also associated with a temporal decrease in water quality after the fire, as observed in other areas of the Pantanal [47]. The fires might have, at least temporarily, affected the fish population, as charcoal and ash can contaminate rivers and promote harmful bacteria that kill fish, and eroded soils are flushed downstream [96]. In addition to the consequences of fires, the studied region faced long periods of drought and low levels of rainfall during 2019–2020, similar to all other Pantanal regions [43]. This reduced the water availability in water bodies, contributing to the drastic reduction in suitable environments and forage sources for water-dependent species. It is, however, important to mention that the piscivorous guild and species using ground and water for foraging were represented by comparably few species in our analysis; thus, our results should be interpreted with caution. Nonetheless, water-related or piscivorous species were largely missing in the burned areas, suggesting that species with these particular preferences are sensitive to fire disturbance.

An omnivorous diet also appears to pose a disadvantage in burned areas one year after the fire in our study area. Previous studies suggest that omnivores can be attracted to recently or frequently burned sites due to increased accessibility of forage sources in clearings [16,97], but studies conducted up to 15 months after a fire suggest similar results as ours for omnivores [22,25,28,33,95], indicating that one year after a fire, burned areas do not support a similar number of omnivores as unburned areas before the fire.

In addition to ground and water, the use of midstory and canopy for foraging was the only other strata negatively linked to the species' response to burned areas, although the effect was less pronounced. Fire can cause a strong reduction in foliage in the middle and upper forest canopy and increase herbaceous and shrub cover [28,98,99]. Even three years after a fire, changes in the bird assemblage have been shown to be strongly associated with these changes in canopy cover and understory regeneration [24,25], suggesting a rather long recovery time for the midstory and canopy strata after a fire and insufficient recovery in our study area. One year after the fire, species with this particular preference are more likely to be dispersed to nearby, unharmed areas.

In contrast, a wider niche breadth, including the understory in addition to the midstory and canopy, appears to be a strong advantage in burned areas. In fact, our results suggest the overall trend that the use of the understory is positively linked to the species' response toward burned areas, although the positive effect of the understory to midstory or ground to canopy strata was less pronounced. The vertical shift of productivity from the canopy toward the understory after the fire might have benefitted the faster reoccupation of species feeding additionally in the understory. This, however, does not seem to extend to the sole use of the ground to understory strata for foraging. Ground and understory species might not have profited to the same extent due to the increased competition in the understory stratum.

Body mass also appears to play an important role in species response toward burned areas one year after the fire, with larger birds more likely to be found in burned areas than smaller ones. A similar shift in body mass distribution was observed by Lee et al. [32] within four months after a fire. This shift might also be related to the different recovery times of the understory and canopy after a fire, as smaller birds have been shown to be mainly associated with dense canopies and larger birds with dense understories [23].

We also observed the overall trend that nectarivores, granivores, and frugivores responded positively toward burned areas, although the strength of the effect varied for each guild and was most pronounced for nectarivores. Similar results as ours for nectarivores and granivores were found by Barlow et al. [28], suggesting that one year after a fire, burned areas might be valuable habitats for these guilds. In our study area, the richness and abundance of nectarivores such as hummingbirds have been shown to be related to habitat type and seasonal availability of forage sources [100]. Fire can affect the temporal pattern and enhance the availability of nectar, pollen, and fruits [101]. This post-fire flowering and the lower vegetation after a fire attract nectarivores to burned areas [26,101,102]. However, the beneficial effects have been shown to be only temporary, as studies conducted up to four years after a fire suggest a similar or even lower abundance of nectarivores in burned areas [21,103].

The positive interaction of granivores and burned areas found in our study area might also be related to the increased accessibility to forage sources after the fire. According to Woinarski [16], the exposed resource of fallen seeds after the reduction of extremely dense and tall grasses by a fire can attract species for several months after the fire. These findings also seem to extend to arboreal granivores primarily feeding on seeds in trees, which have been shown to strongly increase one and three years after a fire [25].

For frugivores, the time since the fire, and consequently the sufficient recovery of burned habitats, appears to play an important role. One year after the fire, this guild has shown to still appear in lower abundance in burned areas, whereas three years after the fire, the opposite can be observed [21,23,95]. Contrary to these findings, our results suggest a low positive trend for this guild in burned areas one year after the fire, which might indicate a good recovery of fruit-bearing trees and canopy structure. However, our results also suggest that the midstory and canopy strata have not recovered sufficiently yet; thus, the slightly higher abundance of frugivores in burned areas is likely mainly related to the proximity of unharmed areas, which provide additional resources.

According to the trait analysis results, carnivores and insectivores were not decisive factors for the species' responses to fire impact. Previous studies suggest varying results for both guilds. The number of carnivores in forests can be reduced after a fire [23], but carnivores can also be related to recently burned sites and the associated lower vegetation [16,26], which facilitates the detection of prey in burned areas. We did not observe similar trends during our study; however, carnivores were one of the least common guilds detected during our study and were represented by only three species; thus, our results should be interpreted with caution.

In contrast, insectivores were the most common guild found during our study. Insectivores have been shown to strongly decline one year after forest fires in previous studies [23,25]; however, there is also evidence that the guild can profit from burned areas and occur in higher numbers one and three years after fire [21,95]. Fire-impacted areas in the Cerrado and Pantanal have shown a rapid recovery of arthropods [104–109], which is induced by a high capacity for vegetation regrowth [104,105,108]. Additionally, some insect groups might be attracted to burned areas. Gall-inducing dipterans can be attracted by the younger and tenderer leaves of resprouting plants [110]; weevils and fruit flies by the flowering response of some plant species to fire [104]; and ants by the availability of other resprouting plant components such as extrafloral nectaries [111]. In our study area, this potentially fast recovery apparently did not lead to a general increase in insectivores in burned areas.

The species distribution model, however, indicates a more complex relationship between individual species and fire impact, which might reflect the impact of the unique combination of traits as well as the individual habitat and forage preferences of the species. For example, despite the overall trends, the small ground and understory insectivores S. hypospodia and M. fasciatus and the small midstory to canopy forager Inezia inornata were apparently able to benefit from burned areas and the potential increase in arthropods. The same seems to apply for the insectivores Myiarchus tyrannulus, Nyctiprogne leucopyga, and Todirostrum cinereum and for some omnivorous species, such as the ground and understory foragers A. holocericeus and Anurolimnas viridis. These species' habitat preferences include grass and low shrub areas, brushy savanna, pastures, successional vegetation, forest borders, or marshes with herbaceous vegetation [112–116], and they might thus have profited from the regrowth and increased availability of forage sources in burned areas.

Similar differences between overall trends and individual species responses that might be related to the species' individual habitat use can be observed among the negatively responding species. For example, the ground and understory insectivores P. genibarbis and H. maculicauda, the understory to canopy forager Xiphorhynchus guttatus, and the ground to canopy forager Pseudoseisura unirufa are known to occupy and forage in the forest edge of riverine forests and dense thickets of bamboo, understory of lowland evergreen forests and vegetation that overhangs water, gallery forests and seasonally flooded savannas, older second growth, and mature forest [117–120]. Burned areas, particularly burned forests, were thus not necessarily suitable habitats for these species.

Indeed, when considering each species' documented range-wide habitat use [121], we observed a general trend toward more open-area-related species in burned areas. Almost all species that responded positively toward burned areas during our study are reportedly related to savanna, shrubland, or grassland habitats, but a large portion use forest in addition. In contrast, species that responded negatively toward burned areas were mainly related to forest habitats, and for the majority, forest ecosystems were identified as habitats of major importance at some point in their lifecycle. The opening of the understories and the formation of clearings resulting from the death of trees caused by the passage of the fire created attractive conditions for habitat generalist species and birds of open formations, which are common in the surrounding savanna areas. Species with preferences for forest habitats might more likely have dispersed to unharmed areas.

5. Conclusions

Our results suggest that burned areas one year after the 2020 fire events had lower avian diversity and different species composition than unburned areas prior to the fires and highlight that, depending on species traits and preferences, some groups and species are more susceptible to the changes in the environment than others are. However, the changes in bird composition and diversity in burned areas are ongoing processes subject to changing environmental conditions and the recovery of each vegetation type. The present study thus provides insight into only the avifaunal response during a particular time since the fire and during a particular successional state, and further studies are needed to evaluate the long-term recovery of the Pantanal avifauna.

It is also important to mention that as we sampled different sites after and before the fire incident, sampled during different years, and considered repeated samples from a larger time period for the unburned areas than for the burned areas, some differences in diversity or composition between the burned and unburned areas might have existed even before the fire events or could be related to underlying natural dynamics over time. Additionally, given the comparably short duration and small number of areas sampled, the sample sizes for some species were rather low. Further studies considering more different sites and additional potentially influencing factors or species traits are urgently needed to identify bird species and groups that are generally vulnerable to fire impact and to draw conclusions that are valid beyond our study area and the particular sites sampled.

Nonetheless, the present study provides a valuable first insight into the effect of the fires during a particular time since the fire and might serve as a starting point for further comprehensive studies. Given the lack of knowledge from the Pantanal region and the increased risk of severe periods of drought due to climate change and intensification of agriculture, information regarding the resource availability and capacity of bird species to disperse in search of food, refuge, and places for reproduction is important for understanding the life dynamics of these animals in response to fire. In addition, birds play important roles in seed dispersal, pollination, decomposition, prey regulation, nutrient deposition, and ecosystem engineering, and in the long term, a decrease in avian diversity and functional groups could severely disrupt ecological processes and initiate tropic cascades [122,123]. However, as the Pantanal has little importance for endemic species and all species occur in adjacent regions as well [124], the recent fire events might not have permanently disrupted the local avifauna. Functional guilds that are already present in burned areas, such as nectarivores, granivores, or frugivores, potentially increase seed dispersal and pollination when most needed and thereby pave the way for species that were still largely missing one year after the fire.

Nonetheless, unnatural fire events such as those that occurred in 2020 must be avoided to prevent the permanent loss of biodiversity and ecosystem resilience [125]. Even though the Pantanal is considered a fire-prone ecosystem, forest formations within it are not fire-prone and can face significant changes when fires occur. Given the high mortality of tree species in forest environments and the long time needed for vegetation to recover, a more open and degraded environment can develop if fires occur more frequently [4].

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Appendix A

Table A1. List of bird species with their corresponding traits detected in unburned areas and in burned areas nine to twelve months after the fire in the northeastern Pantanal, SESC Park Baía das Pedras, Poconé municipality, Mato Grosso state, Brazil. Nomenclature follows the South American Classification Committee (SACC) [74], https://www.museum.lsu.edu/~Remsen/SACCBaseline.htm (accessed on 31 May 2023). Classification of the dominant guild and main foraging strata are based on Stolz et al. [78] and Wilman et al. [79]; body mass on Dunning Jr. [80], Wilman et al. [79], and on measurements taken during the study. Abbreviations: CAR (carnivorous), FRU (frugivorous), GRA (granivorous), INS (insectivorous), NEC (nectarivorous), OMN (omnivorous), PIS (piscivorous), C (canopy), G (ground), GU (ground to understory), GUM (ground to midstory), GUMC (ground to canopy), GW (ground and water), M (midstory), MC (midstory to canopy), U (understory), UM (understory to midstory), UMC (understory to canopy), W (water). Strata in brackets indicate the original strata classification for species included in broader classes for the statistical analysis.

Order/Family/Species	Name	Guild	Strata	Body Mass (g)	Unburned Areas	Burned Areas	Total
Tinamiformes							
Tinamidae							
Crypturellus undulatus (Temminck, 1815)	Undulated Tinamou	OMN	GU (G)	564.4	38	19	57
Anseriformes							
Anhimidae							
Chauna torquata (Oken, 1816)	Southern Screamer	OMN	GW	4400.0	3	11	14
Anatidae							
Dendrocygna viduata (Linnaeus, 1766)	White-faced Whistling Duck	OMN	GW	690.0	1	0	1
Dendrocygna autumnalis (Linnaeus, 1758)	Black-bellied Whistling Duck	OMN	GW	755.3	0	2	2
Galliformes							
Cracidae							
Penelope ochrogaster (Pelzeln, 1870)	Chestnut-bellied Guan	OMN	MC	1179.7	1	0	1
Pipile cujubi (Pelzeln, 1858)	Red-throated Piping-Guan	FRU	MC	1195.8	0	1	1
Ortalis canicollis (Wagler, 1830)	Chaco Chachalaca	OMN	UMC	539.0	36	38	74
Crax fasciolata (Spix, 1825)	Bare-faced Curassow	OMN	GU (G)	2600.0	4	2	6
Columbiformes							
Columbidae							
Patagioenas picazuro (Temminck, 1813)	Picazuro Pigeon	FRU	GUMC	279.0	5	3	8
Patagioenas cayennensis (Bonnaterre, 1792)	Pale-vented Pigeon	FRU	MC	229.0	7	2	9
Leptotila verreauxi (Bonaparte, 1855)	White-tipped Dove	GRA	GU	146.9	36	25	61
Zenaida auriculata (Des Murs, 1847)	Eared Dove	GRA	GUMC (GUM)	110.2	0	4	4
Claravis pretiosa (Ferrari-Perez, 1886)	Blue Ground Dove	FRU	GUMC (GUM)	68.2	1	2	3
Columbina talpacoti (Temminck, 1811)	Ruddy Ground Dove	GRA	GU (G)	46.0	4	16	20
Columbina picui (Temminck, 1813)	Picui Ground Dove	GRA	GU (G)	47.0	0	1	1
Cuculiformes							
Cuculidae							
Guira guira (Gmelin, 1788)	Guira Cuckoo	OMN	GU	141.0	1	0	1
Crotophaga major (Gmelin, 1788)	Greater Ani	OMN	GUMC (GUM)	148.3	7	0	7
Crotophaga ani (Linnaeus, 1758)	Smooth-billed Ani	OMN	GUMC (GUM)	110.1	2	1	3

Table A1. *Cont.*

Order/Family/Species	Name	Guild	Strata	Body Mass (g)	Unburned Areas	Burned Areas	Total
Cuculiformes							
Cuculidae							
Tapera naevia (Linnaeus, 1766)	Striped Cuckoo	INS	GUMC (GUM)	48.4	12	16	28
Dromococcyx pavoninus (Pelzeln, 1870)	Pavonine Cuckoo	INS	GU	46.4	1	0	1
Piaya cayana (Linnaeus, 1766)	Squirrel Cuckoo	OMN	MC	102.0	4	2	6
Coccyzus melacoryphus (Vieillot, 1817)	Dark-billed Cuckoo	INS	MC	49.7	3	1	4
Caprimulgiformes							
Caprimulgidae							
Nyctiprogne leucopyga (Spix, 1825)	Band-tailed Nighthawk	INS	GUMC (GUM)	27.3	0	4	4
Apodiformes							
Trochilidae							
Phaethornis nattereri (Berlepsch, 1887)	Cinnamon-throated Hermit	NEC	GU (U)	3.1	7	12	19
Phaethornis pretrei (Lesson and Delattre, 1839)	Planalto Hermit	NEC	GU (U)	5.6	0	1	1
Heliomaster furcifer (Shaw, 1812)	Blue-tufted Starthroat	NEC	MC	5.4	1	2	3
Chlorostilbon lucidus (Shaw, 1812)	Glittering-bellied Emerald	NEC	UMC	3.5	4	12	16
Chionomesa fimbriata (Gmelin, 1788)	Glittering-throated Emerald	NEC	UMC	4.9	7	28	35
Hylocharis chrysura (Shaw, 1812)	Gilded Hummingbird	NEC	UMC	4.5	2	5	7
Gruiformes							
Aramidae							
Aramus guarauna (Linnaeus, 1766)	Limpkin	CAR	GW	1080.0	2	0	2
Rallidae							
Anurolimnas viridis (Statius Muller, 1776)	Russet-crowned Crake	OMN	GU (G)	64.3	0	4	4
Aramides cajaneus (Statius Muller, 1776)	Gray-cowled Wood-Rail	OMN	GU (G)	397.0	13	2	15
Charadriiformes							
Charadriidae							
Vanellus chilensis (Molina, 1782)	Southern Lapwing	INS	GU (G)	327.0	2	2	4
Rynchopidae							
Rynchops niger (Linnaeus, 1758)	Black Skimmer	PIS	GW (W)	297.7	1	0	1
Laridae							
Phaetusa simplex (Gmelin, 1789)	Large-billed Tern	PIS	GW (W)	235.0	3	1	4
Eurypygiformes							
Eurypygidae							
Eurypyga helias (Pallas, 1781)	Sunbittern	CAR	GU (U)	210.0	1	0	1
Suliformes							
Phalacrocoracidae							
Phalacrocorax brasilianus (Gmelin, 1789)	Neotropic Cormorant	CAR	GW (W)	1239.3	4	0	4

Table A1. *Cont.*

Order/Family/Species	Name	Guild	Strata	Body Mass (g)	Unburned Areas	Burned Areas	Total
Pelecaniformes Ardeidae							
Tigrisoma lineatum (Boddaert, 1783)	Rufescent Tiger-Heron	CAR	GW	813.0	2	0	2
Butorides striata (Linnaeus, 1758)	Striated Heron	CAR	GW	201.5	3	0	3
Ardea alba (Linnaeus, 1758)	Great Egret	CAR	GW	871.3	0	1	1
Pilherodius pileatus (Boddaert, 1783)	Capped Heron	CAR	GW	568.6	1	0	1
Egretta thula (Molina, 1782)	Snowy Egret	CAR	GW	371.0	0	1	1
Threskiornithidae							
Mesembrinibis cayennensis (Gmelin, 1789)	Green Ibis	OMN	GW	756.0	5	0	5
Theristicus caerulescens (Vieillot, 1817)	Plumbeous Ibis	OMN	GW	1500.0	1	2	3
Theristicus caudatus (Boddaert, 1783)	Buff-necked Ibis	OMN	GU (G)	1726.0	4	8	12
Cathartiformes Cathartidae							
Coragyps atratus (Bechstein, 1793)	Black Vulture	CAR	GU (G)	1881.7	1	0	1
Cathartes burrovianus (Cassin, 1845)	Lesser Yellow-headed Vulture	CAR	GU (G)	935.0	0	1	1
Accipitriformes Accipitridae							
Busarellus nigricollis (Latham, 1790)	Black-collared Hawk	CAR	GW	766.1	1	0	1
Rostrhamus sociabilis (Vieillot, 1817)	Snail Kite	CAR	GW	366.9	1	0	1
Buteogallus urubitinga (Gmelin, 1788)	Great Black Hawk	CAR	GUMC	1152.9	0	2	2
Rupornis magnirostris (Gmelin, 1788)	Roadside Hawk	CAR	GUMC (GUM)	269.0	9	16	25
Strigiformes Strigidae							
Glaucidium brasilianum (Gmelin, 1788)	Ferruginous Pygmy- Owl	CAR	MC	75.1	0	3	3
Trogoniformes Trogonidae							
Trogon curucui (Linnaeus, 1766)	Blue-crowned Trogon	OMN	MC	54.0	5	0	5
Coraciiformes Momotidae							
Momotus momota (Linnaeus, 1766)	Amazonian Motmot	OMN	UM	115.0	1	0	1
Alcedinidae							
Megaceryle torquata (Linnaeus, 1766)	Ringed Kingfisher	PIS	GW (W)	317.0	12	0	12
Chloroceryle amazona (Latham, 1790)	Amazon Kingfisher	PIS	GW (W)	126.4	1	0	1
Chloroceryle aenea (Pallas, 1764)	American Pygmy Kingfisher	PIS	GW (W)	13.8	4	0	4
Galbuliformes Galbulidae							
Galbula ruficauda (Cuvier, 1816)	Rufous-tailed Jacamar	INS	UM	26.5	19	15	34
Bucconidae							
Monasa nigrifrons (Spix, 1824)	Black-fronted Nunbird	INS	GUMC (GUM)	80.7	10	7	17

Table A1. *Cont.*

Order/Family/Species	Name	Guild	Strata	Body Mass (g)	Unburned Areas	Burned Areas	Total
Piciformes Ramphastidae							
Ramphastos toco (Statius Muller, 1776)	Toco Toucan	OMN	MC	618.0	1	1	2
Picidae							
Picumnus albosquamatus (d'Orbigny, 1840)	White-wedged Piculet	INS	UMC	11.9	5	17	22
Dryobates passerinus (Linnaeus, 1766)	Little Woodpecker	INS	MC	32.1	6	12	18
Campephilus melanoleucos (Gmelin, 1788)	Crimson-crested Woodpecker	OMN	MC	256.0	0	2	2
Dryocopus lineatus (Linnaeus, 1766)	Lineated Woodpecker	OMN	MC	183.2	1	1	2
Celeus lugubris (Malherbe, 1851)	Pale-crested Woodpecker	INS	MC	137.0	2	1	3
Piculus chrysochloros (Vieillot, 1818)	Golden-green Woodpecker	INS	MC	88.0	1	0	1
Falconiformes Falconidae							
Herpetotheres cachinnans (Linnaeus, 1758)	Laughing Falcon	CAR	UMC	623.6	2	5	7
Micrastur semitorquatus (Vieillot, 1817)	Collared Forest-Falcon	CAR	UMC	621.7	1	0	1
Caracara plancus (Miller, 1777)	Crested Caracara	OMN	GU (G)	1078.6	1	5	6
Psittaciformes Psittacidae							
Myiopsitta monachus (Boddaert, 1783)	Monk Parakeet	FRU	MC	120.0	1	0	1
Brotogeris chiriri (Vieillot, 1818)	Yellow-chevroned Parakeet	FRU	UMC	61.6	21	29	50
Amazona aestiva (Linnaeus, 1758)	Turquoise-fronted Parrot	FRU	MC	451.0	6	8	14
Amazona amazonica (Linnaeus, 1766)	Orange-winged Parrot	FRU	MC	370.0	20	12	32
Anodorhynchus hyacinthinus (Latham, 1790)	Hyacinth Macaw	FRU	MC	1331.0	0	2	2
Eupsittula aurea (Gmelin, 1788)	Peach-fronted Parakeet	FRU	UM	84.6	2	0	2
Primolius auricollis (Cassin, 1853)	Yellow-collared Macaw	FRU	UMC	245.0	4	1	5
Ara ararauna (Linnaeus, 1758)	Blue-and-yellow Macaw	FRU	MC	1125.0	0	1	1
Diopsittaca nobilis (Linnaeus, 1758)	Red-shouldered Macaw	FRU	MC	150.9	5	3	8
Psittacara leucophthalmus (Statius Muller, 1776)	White-eyed Parakeet	FRU	MC	158.0	1	2	3
Passeriformes Thamnophilidae							
Taraba major (Vieillot, 1816)	Great Antshrike	INS	GU	59.2	14	28	42
Thamnophilus doliatus (Linnaeus, 1764)	Barred Antshrike	INS	UM	27.0	18	24	42
Thamnophilus pelzelni (Hellmayr, 1924)	Planalto Slaty-Antshrike	INS	UM	20.9	0	1	1
Thamnophilus amazonicus (Sclater, 1858)	Amazonian Antshrike	INS	GU (U)	18.7	1	0	1
Dysithamnus mentalis (Temminck, 1823)	Plain Antvireo	INS	UM	14.9	2	2	4
Herpsilochmus longirostris (Pelzeln, 1868)	Large-billed Antwren	INS	MC	12.8	9	1	10
Formicivora rufa (Wied, 1831)	Rusty-backed Antwren	INS	GU (U)	10.8	0	3	3

Table A1. *Cont.*

Order/Family/Species	Name	Guild	Strata	Body Mass (g)	Unburned Areas	Burned Areas	Total
Passeriformes							
Thamnophilidae							
Cercomacra melanaria (Ménétries, 1835)	Mato Grosso Antbird	INS	GU	19.0	39	48	87
Hypocnemoides maculicauda (Pelzeln, 1868)	Band-tailed Antbird	INS	GU (U)	11.8	23	0	23
Furnariidae							
Sittasomus griseicapillus (Vieillot, 1818)	Olivaceous Woodcreeper	INS	MC	13.1	4	5	9
Dendrocolaptes platyrostris (Spix, 1825)	Planalto Woodcreeper	INS	UM	61.7	0	2	2
Xiphorhynchus guttatus (Lafresnaye, 1850)	Buff-throated Woodcreeper	INS	UMC	59.7	5	0	5
Dendroplex picus (Gmelin, 1788)	Straight-billed Woodcreeper	INS	UM	41.3	12	13	25
Campylorhamphus trochilirostris (Lichtenstein, 1820)	Red-billed Scythebill	INS	MC	32.6	3	3	6
Lepidocolaptes angustirostris (Vieillot, 1818)	Narrow-billed Woodcreeper	INS	UM	29.6	1	0	1
Furnarius leucopus (Swainson, 1838)	Pale-legged Hornero	INS	GU (G)	54.8	42	24	66
Furnarius rufus (Gmelin, 1788)	Rufous Hornero	OMN	GU (G)	46.4	6	0	6
Phacellodomus rufifrons (Wied, 1821)	Rufous-fronted Thornbird	INS	UMC	24.6	6	1	7
Phacellodomus ruber (Vieillot, 1817)	Greater Thornbird	INS	GU	41.0	1	1	2
Cranioleuca vulpina (Pelzeln, 1856)	Rusty-backed Spinetail	INS	MC	15.7	28	1	29
Pseudoseisura unirufa (d'Orbigny and Lafresnaye, 1838)	Rufous Cacholote	INS	GUMC (GUM)	44.9	6	0	6
Certhiaxis cinnamomeus (Gmelin, 1788)	Yellow-chinned Spinetail	INS	GU	15.2	2	1	3
Synallaxis albilora (Pelzeln, 1856)	White-lored Spinetail	INS	GU	14.9	47	43	90
Synallaxis hypospodia (Sclater, 1874)	Cinereous-breasted Spinetail	INS	GU (U)	16.9	0	7	7
Synallaxis frontalis (Pelzeln, 1859)	Sooty-fronted Spinetail	INS	GU	14.0	2	7	9
Pipridae							
Neopelma pallescens (Lafresnaye, 1853)	Pale-bellied Tyrant- Manakin	OMN	UM	18.2	1	0	1
Antilophia galeata (Lichtenstein, 1823)	Helmeted Manakin	FRU	MC	21.5	2	0	2
Pipra fasciicauda (Hellmayr, 1906)	Band-tailed Manakin	FRU	UM	15.9	1	0	1
Tityridae							
Pachyramphus viridis (Vieillot, 1816)	Green-backed Becard	INS	MC	21.0	1	0	1
Pachyramphus polychopterus (Vieillot, 1818)	White-winged Becard	INS	MC	20.8	3	0	3
Tyrannidae							
Leptopogon amaurocephalus (Tschudi, 1846)	Sepia-capped Flycatcher	INS	UM	11.7	3	0	3
Tolmomyias sulphurescens (Spix, 1825)	Yellow-olive Flycatcher	INS	MC	14.3	0	1	1
Hemitriccus striaticollis (Lafresnaye, 1853)	Stripe-necked Tody-Tyrant	INS	MC (M)	8.6	13	8	21
Hemitriccus margaritaceiventer (d'Orbigny and Lafresnaye, 1837)	Pearly-vented Tody-Tyrant	INS	UM	8.4	2	8	10
Poecilotriccus latirostris (Pelzeln, 1868)	Rusty-fronted Tody-Flycatcher	INS	GU (U)	8.1	18	14	32
Todirostrum cinereum (Linnaeus, 1766)	Common Tody-Flycatcher	INS	UMC	6.3	2	16	18

Table A1. *Cont.*

Order/Family/Species	Name	Guild	Strata	Body Mass (g)	Unburned Areas	Burned Areas	Total
Passeriformes							
Tyrannidae							
Inezia inornata (Salvadori, 1897)	Plain Tyrannulet	INS	MC	12.0	0	4	4
Euscarthmus meloryphus (Wied, 1831)	Fulvous-crowned Scrub-Tyrant	INS	GU (U)	6.8	1	6	7
Camptostoma obsoletum (Temminck, 1824)	Southern Beardless-Tyrannulet	OMN	MC	8.1	7	22	29
Elaenia flavogaster (Thunberg, 1822)	Yellow-bellied Elaenia	OMN	UMC	24.8	1	1	2
Elaenia parvirostris (Pelzeln, 1868)	Small-billed Elaenia	OMN	UMC	13.8	1	0	1
Elaenia chiriquensis (Lawrence, 1865)	Lesser Elaenia	OMN	UMC	15.4	0	1	1
Myiopagis gaimardii (d'Orbigny, 1839)	Forest Elaenia	OMN	MC (C)	12.0	4	3	7
Myiopagis viridicata (Vieillot, 1817)	Greenish Elaenia	OMN	MC	11.5	0	1	1
Phaeomyias murina (Spix, 1825)	Mouse-colored Tyrannulet	OMN	UMC	10.0	2	2	4
Attila bolivianus (Lafresnaye, 1848)	Dull-capped Attila	INS	MC	39.5	1	0	1
Legatus leucophaius (Vieillot, 1818)	Piratic Flycatcher	FRU	MC	22.2	1	0	1
Pitangus sulphuratus (Linnaeus, 1766)	Great Kiskadee	OMN	GUMC	62.9	15	20	35
Philohydor lictor (Lichtenstein, 1823)	Lesser Kiskadee	INS	UMC	25.5	1	0	1
Megarynchus pitangua (Linnaeus, 1766)	Boat-billed Flycatcher	OMN	MC	69.9	8	2	10
Myiodynastes maculatus (Statius Muller, 1776)	Streaked Flycatcher	INS	MC	43.2	2	0	2
Myiozetetes cayanensis (Linnaeus, 1766)	Rusty-margined Flycatcher	INS	UMC	25.9	9	6	15
Empidonomus varius (Vieillot, 1818)	Variegated Flycatcher	INS	MC	27.1	1	0	1
Tyrannus savana (Daudin, 1802)	Fork-tailed Flycatcher	OMN	UMC	31.9	1	0	1
Casiornis rufus (Vieillot, 1816)	Rufous Casiornis	INS	UMC	24.8	3	3	6
Myiarchus ferox (Gmelin, 1789)	Short-crested Flycatcher	INS	UM	27.5	12	28	40
Myiarchus tyrannulus (Statius Muller, 1776)	Brown-crested Flycatcher	INS	UM	35.5	0	5	5
Myiophobus fasciatus (Statius Muller, 1776)	Bran-colored Flycatcher	INS	GU (U)	9.9	0	14	14
Pyrocephalus rubinus (Boddaert, 1783)	Vermilion Flycatcher	INS	UM	14.4	0	2	2
Cnemotriccus fuscatus (Wied, 1831)	Fuscous Flycatcher	INS	UM	13.6	19	31	50
Lathrotriccus euleri (Cabanis, 1868)	Euler's Flycatcher	INS	GU (U)	11.3	0	1	1
Vireonidae							
Cyclarhis gujanensis (Gmelin, 1789)	Rufous-browed Peppershrike	OMN	UMC	28.8	0	2	2
Hylophilus pectoralis (Sclater, 1866)	Ashy-headed Greenlet	INS	MC	11.6	11	0	11
Vireo chivi (Vieillot, 1817)	Chivi Vireo	OMN	MC	16.1	8	0	8
Corvidae							
Cyanocorax cyanomelas (Vieillot, 1818)	Purplish Jay	OMN	MC	207.0	20	4	24

Table A1. *Cont.*

Order/Family/Species	Name	Guild	Strata	Body Mass (g)	Unburned Areas	Burned Areas	Total
Passeriformes							
Hirundinidae							
Stelgidopteryx ruficollis (Vieillot, 1817)	Southern Rough-winged Swallow	INS	UM	16.1	2	0	2
Progne tapera (Linnaeus, 1766)	Brown-chested Martin	INS	UMC	32.0	0	1	1
Tachycineta albiventer (Boddaert, 1783)	White-winged Swallow	INS	UM	17.7	1	0	1
Troglodytidae							
Troglodytes aedon (Naumann, 1823)	House Wren	INS	GU (U)	10.9	0	1	1
Campylorhynchus Turdinus (Wied, 1831)	Thrush-like Wren	INS	MC	32.6	23	0	23
Pheugopedius genibarbis (Swainson, 1838)	Moustached Wren	INS	GU (U)	19.2	31	0	31
Cantorchilus leucotis (Lafresnaye, 1845)	Buff-breasted Wren	INS	GU (U)	19.4	34	25	59
Polioptilidae							
Polioptila dumicola (Vieillot, 1817)	Masked Gnatcatcher	INS	MC	7.0	16	24	40
Donacobiidae							
Donacobius atricapilla (Linnaeus, 1766)	Black-capped Donacobius	INS	GU (U)	36.8	5	3	8
Turdidae							
Turdus rufiventris (Vieillot, 1818)	Rufous-bellied Thrush	OMN	GUMC (GUM)	69.4	1	1	2
Turdus amaurochalinus (Cabanis, 1850)	Creamy-bellied Thrush	OMN	GUMC	57.9	8	13	21
Fringillidae							
Euphonia chlorotica (Linnaeus, 1766)	Purple-throated Euphonia	FRU	MC	11.0	7	16	23
Passerellidae							
Arremon flavirostris (Bonaparte, 1850)	Saffron-billed Sparrow	OMN	GU	26.1	8	2	10
Icteridae							
Psarocolius decumanus (Pallas, 1769)	Crested Oropendola	OMN	MC	206.3	7	1	8
Cacicus solitarius (Vieillot, 1816)	Solitary Black Cacique	OMN	UM	79.8	20	11	31
Cacicus cela (Linnaeus, 1758)	Yellow-rumped Cacique	OMN	MC	85.5	8	9	17
Icterus croconotus (Wagler, 1829)	Orange-backed Troupial	OMN	MC	40.0	6	0	6
Icterus pyrrhopterus (Vieillot, 1819)	Variable Oriole	OMN	MC	35.4	5	0	5
Amblyramphus holosericeus (Scopoli, 1786)	Scarlet-headed Blackbird	OMN	GU (U)	70.4	0	6	6
Agelaioides badius (Vieillot, 1819)	Grayish Baywing	OMN	GU (G)	45.3	0	1	1
Parulidae							
Geothlypis aequinoctialis (Gmelin, 1789)	Masked Yellowthroat	INS	GU (U)	13.1	8	5	13
Setophaga pitiayumi (Vieillot, 1817)	Tropical Parula	OMN	MC (C)	6.8	0	3	3
Myiothlypis flaveola (Baird, 1865)	Flavescent Warbler	INS	GU	13.2	22	18	40
Thraupidae (Cabanis, 1847)							
Nemosia pileata (Boddaert, 1783)	Hooded Tanager	OMN	MC	16.0	0	2	2
Hemithraupis guira (Linnaeus, 1766)	Guira Tanager	FRU	MC	12.0	0	1	1

Table A1. *Cont.*

Order/Family/Species	Name	Guild	Strata	Body Mass (g)	Unburned Areas	Burned Areas	Total
Passeriformes Thraupidae (Cabanis, 1847)							
Conirostrum speciosum (Temminck, 1824)	Chestnut-vented Conebill	INS	UMC	8.8	6	8	14
Volatinia jacarina (Linnaeus, 1766)	Blue-black Grassquit	GRA	GU	9.9	1	13	14
Tachyphonus rufus (Boddaert, 1783)	White-lined Tanager	FRU	UMC	34.4	1	2	3
Eucometis penicillata (Spix, 1825)	Gray-headed Tanager	OMN	UM	27.0	7	0	7
Ramphocelus carbo (Pallas, 1764)	Silver-beaked Tanager	OMN	UMC	25.9	30	25	55
Sporophila angolensis (Linnaeus, 1766)	Chestnut-bellied Seed-Finch	GRA	GU (U)	13.0	2	2	4
Sporophila caerulescens (Vieillot, 1823)	Double-collared Seedeater	GRA	GU	9.7	0	2	2
Sporophila collaris (Boddaert, 1783)	Rusty-collared Seedeater	GRA	GU	13.5	1	0	1
Saltator coerulescens (Vieillot, 1817)	Bluish-gray Saltator	OMN	UMC	54.9	22	37	59
Thlypopsis sordida (d'Orbigny and Lafresnaye, 1837)	Orange-headed Tanager	OMN	UMC	17.0	0	1	1
Coereba flaveola (Linnaeus, 1758)	Bananaquit	OMN	UMC	10.0	13	29	42
Paroaria capitata (d'Orbigny and Lafresnaye, 1837)	Yellow-billed Cardinal	OMN	GUMC (GUM)	37.8	2	3	5
Thraupis sayaca (Linnaeus, 1766)	Sayaca Tanager	FRU	MC	32.5	6	25	31
Thraupis palmarum (Wied, 1821)	Palm Tanager	OMN	MC	39.0	0	1	1

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