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# Use of response guilds of understory birds in threatened subtropical forest to monitor selective logging impact

Ever Tallei[a,c], Luis Rivera[b,c], Alejandro Schaaf[b], Constanza Vivanco[b,c], Natalia Politi[b,c,*]

[a] Biología de Aves, Instituto Argentino de Investigaciones de las Zonas Áridas (IADIZA), Centro Científico Tecnológico CONICET - Mendoza, Av. Ruiz Leal s/n, Parque General San Martin, 5500 Mendoza, Argentina

[b] Instituto de Ecorregiones Andinas (INECOA), Universidad Nacional de Jujuy - Centro Científico Tecnológico CONICET Salta-Jujuy, Av. Bolivia 1239, 4600 San Salvador de Jujuy, Jujuy, Argentina

[c] Fundación CEBio, Roca 44, San Salvador de Jujuy 4600, Jujuy, Argentina

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A B S T R A C T

Unplanned logging is one of the greatest current threats to native forests biodiversity. About 90% of the piedmont forest in the Southern Andean Yungas has been converted to other land-use types and the remaining forests fragments are being intensively logged without management plans. Bird species, especially understory birds, are good indicators of forest diversity and integrity. The aim of this study was to identify understory bird species associated with changes in the forest structure caused by selective logging and to explore whether it is possible to use these species as a monitoring tool. We observed that *Sittasomus griseicapillus*, *Turdus rufiventris*, *Lepidocolaptes angustirostris*, *Casiornis rufus*, *Thraupis sayaca,* and *Tolmomyias sulphurescens* were associated to unlogged sites with higher density of timber-yielding and standing dead trees. *Thamnophilus caerulescens*, *Leptotila megalura*, *Synallaxis scutata*, *Poecilotriccus plumbeiceps,* and *Catharus ustulatus* were favoured by logging activities and associated with understory visual obstruction. Mean cut-off abundance thresholds were 2.74 ind/ha for the avian guild associated with unlogged forest and 1.79 ind/ha for the guild associated with logged forest. Sustainable forest management schemes need to retain the understory visual obstruction at values similar to those of unlogged forest (43.75%), together with an adequate density (≥10 ind/ha) of standing dead trees with at least 19.5 cm in DBH, and a minimum of 210 ind/ha of timber tree species. Bird species identified in this study can be used in monitoring schemes to evaluate the implementation of these guidelines.

## 1. Introduction

Forests are the world's dominant terrestrial ecosystem and human impact is causing their degradation (FAO, 2020). These ecosystems not only harbour the greatest species richness, but also sustain one-third of mankind through the ecosystem services they provide (IPBES, 2018). At least 400 million hectares of tropical and subtropical forests worldwide (53% of the total forest area) are under forest management (Blaser et al., 2011). The lack of planning and sustainability criteria is leading to a rapid degradation of logging forests (Putz et al., 2012; Keenan et al., 2015). Unplanned logging represents one of the greatest current threats to global biodiversity (Edwards et al., 2014; Burivalova et al., 2015). In general, the richness of invertebrates, amphibians and mammals decline with increasing logging intensity, and this effect varies depending on the taxonomic group and continental location (Burivalova et al., 2014). Birds in contrast, exhibit an opposite pattern, in which species richness increase with logging intensity (Burivalova et al., 2014). This pattern, however, is mostly driven by the influx of habitat generalists in heavily logged areas, in detriment of forest interior specialist species (Sekercioglu, 2002; Edwards et al., 2011; Boyle and Sigel, 2015).

Understory birds are among the most vulnerable species to selective logging without forest management (Thiollay, 1992; Fimbel et al., 2001). This group of birds responds to disturbance-induced changes in vegetation structure and composition, and to resource availability (Zurita and Zuleta, 2009; Powell et al., 2015; Visco et al., 2015). Logging increases the understory light intensity and temperature, altering the habitat quality for understory birds (Chen et al., 1995; Patten and Smith-Patten, 2012). Habitat changes may exceed the birds physiological and behavioural tolerances, affecting population abundance and community composition (Barlow et al., 2006; Srinivasan and Banks-Leite, 2013).

* Corresponding author.
*E-mail address:* npoliti@conicet.gov.ar (N. Politi).

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Bird species react differently to changes produced by selective logging; some of them may benefit from these changes, whereas others may be negatively affected (Aleixo, 1999; Arcilla et al., 2015).

Monitoring programs in logged forests are essential for attaining sustainable forest management (SFM). Thus, with a monitoring program it is possible to assess the forest management quality and adjust the impact levels within acceptable limits (Lindenmayer, 1999; Bicknell and Peres, 2010). Monitoring programs have provided valuable information over the years for the SFM (Abbott et al., 2009). The application of different monitoring techniques allows evaluating bird population parameters such as occupancy, abundance, and behavioural traits (Pillay et al., 2019). The use of bird species in these monitoring programs is carried out assuming that responses of individual species may represent the response of other taxa within the community (Caro and O'Doherty, 1999; Ikin et al., 2016). Another strategy consists of monitoring the entire bird assemblage, but it requires complex methods together with many financial and human resources (Danielsen et al., 2005; Favreau et al., 2006). An alternative strategy involves using a combination of species with different habitat requirements, taxonomy, and behaviour based on response guilds that may increase the effectiveness of monitoring programs (Wilson, 1999; De Cáceres et al., 2012). Bird monitoring does not substitute for indicators of stand structure and forest attributes (Lindenmayer, 1999), but provides a time and cost effective complementary method for validating and comparing the effect of different types of forest management (Politi and Rivera, 2019). Indicator variability serves to determine the ecological significance of any change or pattern in order to evaluate management performance (Carignan and Villard, 2002; Niemi and McDonald, 2004).

Avian abundance thresholds are useful tools for assessing the impact of selective logging and the effectiveness of forest management plans. Bird response to habitat disturbance through the use of thresholds indicates that tropical species are more affected than temperate species (Melo et al., 2018). The threshold-based approach is booming because its results can be directly used in conservation strategies (Suding and Hobbs, 2009). Over the last decade, more countries have been adopting certified timber production, following the International Forest Stewardship Council (FSC) to achieve SFM (Blumroeder et al., 2019). Despite the SFM advantages, conventional practices continue to dominate the industry (Blaser et al., 2011; Politi and Rivera, 2019), making it necessary to establish simple tools like avian thresholds for monitoring vulnerable, threatened and productively important ecosystems, such as the piedmont forest of the Southern Yungas.

In Neotropical forests, previous studies analysing the effects of selective logging on bird assemblages have mainly focused on predefined guilds (Zurita and Zuleta, 2009, Politi et al., 2012), functional groups (Ruggera et al., 2016b), and uncommon species (Schaaf et al., 2019). However, less attention has been given to the abundance patterns of the most common bird species or to the use of response guilds (Burivalova et al., 2014; Visco et al., 2015). Thus, our objective was to characterize forest types with and without logging and to identify common understory bird species associated with forest structure in the piedmont forest of northwestern Argentina.

## 2. Material and methods

### 2.1. Study system

This study was carried out in the piedmont forest of Salta and Jujuy provinces, in Argentina. The piedmont forest is the lowest altitudinal level of the Southern Yungas, ranging from 400 to 700 m.a.s.l. Due to its very high percentage of species and deciduous individuals (>70%), the piedmont forest is one of the most seasonal forest systems in South America (Prado and Gibbs, 1993, Mogni et al., 2015) exhibiting the greatest hydric contrasts between the rainy summers (with mean monthly rainfall above 100–300 mm) and the dry winter-spring period (below 10 mm), with variable annual rainfall (800–1000 mm) (Brown et al., 2001). Mean annual temperature varies between 18 and 20 °C, with a minimum of 13.6 °C and a maximum of 26.1 °C (Bianchi et al., 2008). Estimates indicate that the floral richness of this level includes at least 278 woody species (Brown and Malizia, 2004). Distinctive tree species include *Phyllostylon rhamnoides*, *Calycophyllum multiflorum*, *Handroanthus impetiginosus*, *Anadenanthera colubrina*, *Myroxylon peruiferum*, *Cordia trichotoma*, *Amburana cearensis*, *Enterolobium contortisiliquum,* and *Myracrodruon urundeuva* (Brown et al., 2001).

The piedmont forest belongs to the Sierras Subandinas geological province. Soil types include entisols, inceptisols, alfisols, mollisols and aridisols irregularly distributed across the area. These soils are moderately developed and have a great spatial variability depending on lithological, geomorphological and climatic variations (Pereyra, 2012). The piedmont forest has the highest percentage of species exclusive to the Southern Yungas and it is the most threatened forest ecosystem in the Andean region (Brown, 2009). Its vulnerability is increasing since it is poorly represented in the system of protected areas. It is estimated that nearly 90% of the piedmont forest in Argentina has been transformed into agricultural lands (Brown and Malizia, 2004). Most of the remaining forests of this ecosystem (approximately 900.000 ha) are exploited by the forest industry (Brown et al., 2001). Selective logging without forest management and planning is currently one of the greatest threats to the Southern Andean Yungas of Argentina (Tejedor Garavito et al., 2012; Politi and Rivera, 2019). Intensive selective logging of commercial species has led to a large proportion of forests being impoverished and simplified, with basal area values less than half of their potential (Brown and Malizia, 2004). In addition, logged sites present low species richness and an increase in the number of vines which reduce the commercial value of trees (Blundo and Malizia, 2009; Malizia et al., 2009). To initiate logging, it is necessary to submit a management plan to the competent authorities (Balducci et al., 2012). On average, the volume of timber extraction is 4 $m^3$/ha, ranging from a minimum of 1 $m^3$/ha to a maximum of 13 $m^3$/ha. The largest volume of the harvested timber belongs to *M. peruiferum*, *A. colubrina*, *C. multiflorum*, *P. rhamnoides*, *C. balansae* and *H. impetiginosus* (Eliano et al., 2009; Balducci et al., 2012).

A total of six study sites were included in our research (Fig. 1), three of which had not been logged for five years before the beginning of our study (2010) but had previously been logged for 45 years (logged sites). The other three sites had not been logged for 45 years (unlogged sites) before the study. At logged sites, wood extraction had been carried out selectively, without sustainability criteria. Elevation of sampled sites ranged from 550 y 650 m.a.s.l. and presented areas with steep slopes. At each site, we conducted fieldwork within a 100 ha grid that was embedded in a continuous forest matrix to avoid possible additional effects of other anthropic disturbances. We assumed that locations within each forest type have similar environmental characteristics and a reasonable distance from each other to ensure sampling independence. Unlogged sites were located at Finca Yuchán (23°56′11″S; 64°54′59″W), Finca San Martín (23°45′58″S; 64°48′55″W), and Calilegua National Park (23°38′11″S; 64°35′15″W), whereas logged sites pertained to Finca Higueritas (23°56′42″S; 64°57′10″W), Finca Río Seco (22°27′16″S; 63°58′47″W), and Finca Itiyuro (22°05′30″S; 63°45′04″W).

### 2.2. Habitat structure

We assessed the vegetation structure in 86 circular plots of 12.6 m radius in each forest type, in coincidence with the bird point counts (Bibby et al., 2000). Thus, we established 30 circular plots per site in four locations (sites 1, 2, 5 and 6), and 26 plots in each of the remaining two sites (sites 3 and 4, Fig. 1). The visual obstruction of the understory was determined with a 2 m pole marked every 20 cm, and located 10 m away from the centre of the plot at the four cardinal points. In addition, we estimated the canopy cover by averaging 12 measurements obtained with a densitometer located at 1, 5, and 10 m away from the plot center, in the four cardinal points. We identified all trees >10 cm diameter at

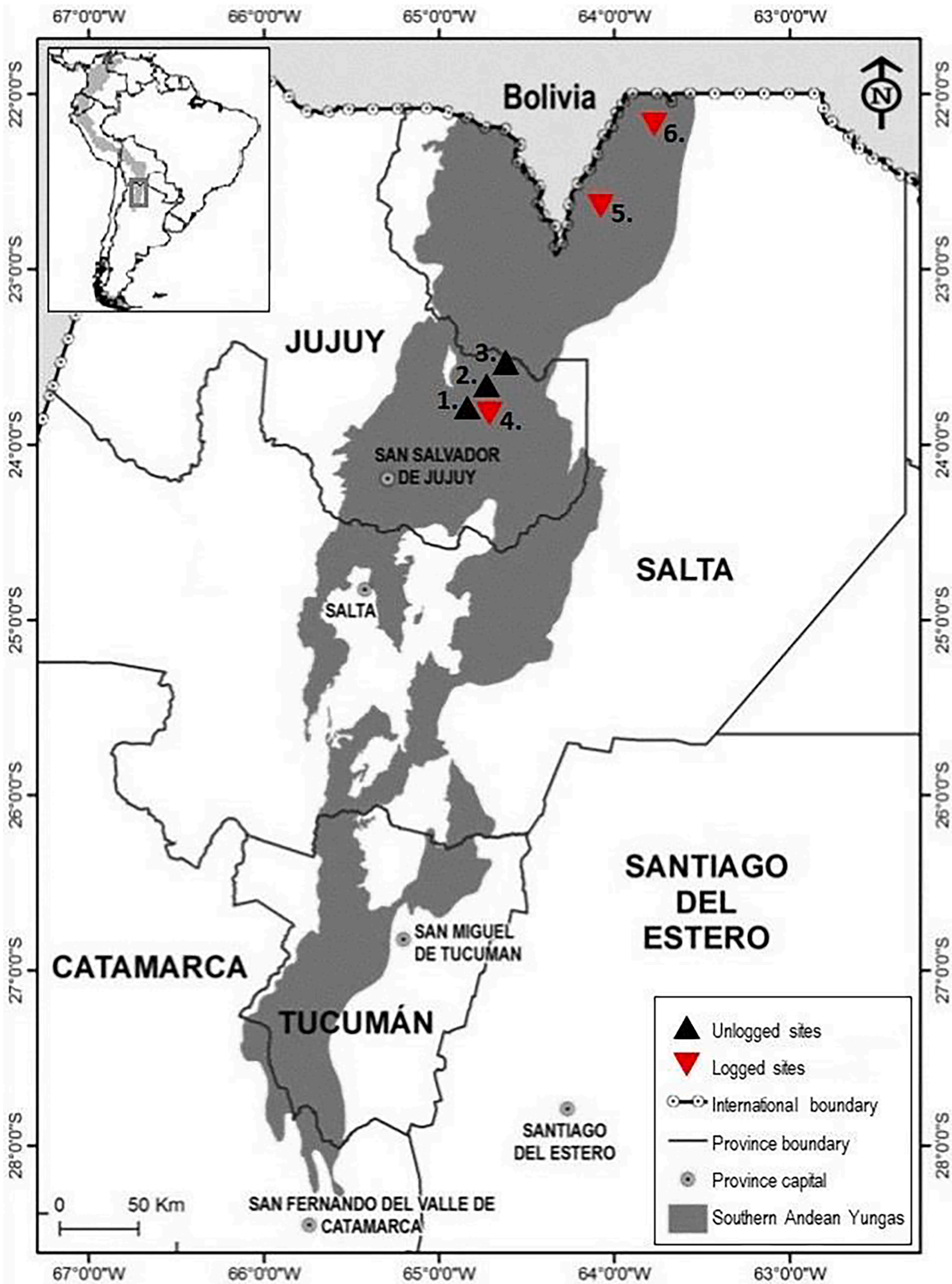


**Fig. 1.** Location of unlogged study sites (black triangles) and logged sites (red triangles) in the Southern Yungas of Argentina. 1) Finca Yuchan, 2) Finca San Martín, 3) Calilegua National Park, 4) Finca Higueritas, 5) Finca Río Seco, and 6) Finca Itiyuro. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

breast height (DBH) and recorded the DBH value, and total height of each tree (Higgins et al., 1996). In addition, we identified each tree to the species level and classified it according to its status into alive (healthy), decaying (at least with one dead primary or secondary branch), or dead (standing tree >1.6 m in height without leaves and with almost all its branches). According to their commercial forest value, trees species were categorized into valuable (*Calycophyllum multiflorum*, *Cedrela balansae*, *Enterolobium contortisiliquum*, *Handroanthus impetiginosus*, *Myracrodruon urundeuva, Phyllostylon rhamnoides*, and *Amburana cearensis*) and non-valuable timber (Blundo and Malizia, 2009).

### 2.3. Bird surveys

We conducted a total of 516 bird point counts (logged sites: 258; unlogged sites: 258) during three breeding seasons (2015–2017). We used 50 m fixed-radius point counts of 10 min duration (Bibby et al., 2000). Thus, we sampled between 26 and 30 point counts at each site (30 point counts in sites 1, 2, 5, and 6, and 26 in sites 3 and 4, Fig. 1), all of which were located inside the forest at ≥150 m from roads or edges. Samplings were carried out during the morning (from 7:00 a.m. to 11:00 a.m.) to match the peaking periods of bird activity. We identified and recorded the abundance of all bird species seen or heard. In this study, we considered to be understory all of those bird species which forage and nest in the understory (including ground-foraging/nesting species), regardless if they use another vegetation layer (Auer et al., 2007; Blendinger and Álvarez, 2009). Understory birds are the group with the highest population density within the piedmont forest bird assemblage (Politi et al., 2012). Although they are a small part of the species richness, common species define the ecosystem structure and dynamics (Gaston, 2011).

### 2.4. Statistical analysis

#### 2.4.1. Vegetation characterization

We determined the density of tree species (ind/ha), basal area ($m^2$/ha), and the dominance value obtained from the basal area. The visual obstruction of the understory and the canopy cover were obtained by averaging of the vegetation marks. We compared the variables of the vegetation structure between logged and unlogged sites using the Kolmogorov-Smirnov test. A Mann Whitney *U* test was used to determine whether or not there were significant differences in the dominance of tree species in logged and unlogged sites.

#### 2.4.2. Response guilds

We used an Analysis of similarities (ANOSIM) to examine the differences between the assemblages of logged and unlogged sites. Additionally, we use the Bray-Curtis index to calculate dissimilarity because it is more sensitive to differences in the most abundant species and less sensitive to uncommon species (Magurran and McGill, 2011). The statistical significance of the ANOSIM was assessed using a permutation test with a significance level of $\alpha = 0.05$. In order to obtain the response guilds of understory birds, we performed the dominance value species analysis (Pinzón and Spence, 2010) and the indicator species analysis (De Cáceres et al., 2012). The dominance value analysis is the result of obtaining a dominance index calculated from the proportional presence ($w$) and proportional abundance ($PA$) of each species per sampling unit. From the values of $w$ and $PA$, we draw a graph to show the degree of dominance of the bird species (Pinzón and Spence, 2010). Common species are those which were dominant, sub-dominant or common species because of their dominance value index. In the indicator species analysis, species were determined based on the relationship between their frequency and abundance in logged or unlogged sites. This index varies between 0 and 100% and high values indicate a high abundance and occurrence of the species within logged or unlogged sites (Dufrêne and Legendre, 1997). A species was considered to be associated with logged or unlogged sites when its indicator value was statistically significant ($p < 0.05$) by a random permutation test.

Response guilds of understory bird species for logged and unlogged sites had to meet two criteria to be classified: (1) be common species according to the dominance value analysis; and (2) be indicator species with an index ≥50 (IndVal = indicator value) and statistically significant. The Mann Whitney *U* test was used to compare the abundance of bird guilds between logged and unlogged sites. The potential of response guilds was tested to discriminate logged and unlogged sites by analysing the Receiver Operating Characteristic (ROC) curves (Dos Santos et al., 2011). The ROC methodology is a valuable tool for objectively comparing the diagnostic capabilities of different tests as well as for obtaining decision thresholds. The purpose of the test is to classify individuals in a population in two groups: one showing an event of interest and another one which does not (Zweig and Campbell, 1993). This discriminating ability is subject to the cut-off threshold (or threshold value) chosen amongst all the possible outcomes of the decision variable, i.e. the variable by whose outcome each individual is classified into one group or another. A desired property of the threshold value is high sensitivity and specificity (Dos Santos et al., 2011).

#### 2.4.3. Vegetation relationships with bird guilds

We quantified the association between vegetation variables using correlation matrix, discarding those with high collinearity ($r > 0.7$). The variables discarded were tree DBH, total tree density and total basal area (Appendix A). To determine the most suitable direct gradient analysis, we first carried out a Detrended Correspondence Analysis (DCA). Then, due to the linear response of the response guilds, we performed a Redundancy Analysis (RDA) to evaluate the association between these guilds and the vegetation variables. Bird species abundance data were transformed using the Hellinger method (Legendre and Gallagher, 2001). We calculated inertia and used a Monte Carlo test with 999 permutations to test for the significance of the model, the RDA axes, and the vegetation variables (Legendre et al., 2011). The model was built only with the variables which were statistically significant ($p < 0.05$). The analyses were performed using the *indicspecies*, *pROC*, *vegan*, *caret*, and *corrplot* packages and the graphs were drawn with *ggplot2* and *ggord*, for R version 4.0.1 (R Development Core Team 2020).

## 3. Results

### 3.1. Vegetation characterization

In logged sites, we identified 47 tree species belonging to 25 families and in unlogged sites, 45 tree species corresponding to 22 families (Appendix A). Logged sites had significantly lower basal area of valuable timber species compared to unlogged sites (Appendix A). Logged sites also showed greater density and basal area of non-valuable timber species, average height of the trees, and visual obstruction of the understory (Table 1). Unlogged sites, however, had a higher density of valuable timber species and standing dead trees. In addition, unlogged areas showed higher values in the DBH of standing dead trees, total basal area, and basal area of valuable timber species (Table 1).

### 3.2. Response guilds

We recorded 2051 individuals from 53 understory bird species in logged sites and 1706 individuals from 41 understory bird species in unlogged sites (Appendix B). Bird assemblages differed between logged and unlogged sites according to species composition and abundance (ANOSIM $R = 0.34$; $p < 0.01$). The dominant species in logged sites were *Catharus ustulatus* and *Thamnophilus caerulescens*; whereas in unlogged sites dominant species included *Sittasomus griseicapillus* and *Lepidocolaptes angustirostris*. Additionally, two dominant understory bird species (*Turdus rufiventris* and *Myothlypis bivittata*) were found in both logged and unlogged sites (Appendix B). Common species in the logged sites were *Leptotila megalura*, *Poecilotriccus plumbeiceps*, *Synallaxis*

**Table 1**
Structural variables of the vegetation (mean ± standard error) in logged (n = 86) and unlogged sites (n = 86) in the piedmont forest of the Argentinean Southern Yungas. Kolmogorov – Smirnov (KS) statistic values and their significance level (*p*). *indicates significant differences: ** = $p < 0.01$; * = $p < 0.05$.

| Variables of the vegetation | Logged | | | Unlogged | | | KS | *p* | |
|---|---|---|---|---|---|---|---|---|---|
| Tree density (ind/ha) | 320 | ± | 11 | 348 | ± | 11 | 0.16 | 0.2 | |
| Live | 254 | ± | 9 | 273 | ± | 10 | 0.12 | 0.2 | |
| Decaying | 47 | ± | 4 | 51 | ± | 4 | 0.19 | 0.2 | |
| Dead | 19 | ± | 3 | 24 | ± | 3 | 0.21 | <0.05 | * |
| Valuable | 167 | ± | 11 | 250 | ± | 12 | 0.34 | <0.01 | ** |
| Non-valuable | 153 | ± | 11 | 98 | ± | 7 | 0.29 | <0.01 | ** |
| Diameter at breast height (cm) | 27.7 | ± | 0.6 | 27.1 | ± | 0.3 | 0.08 | 0.2 | |
| Live | 26.7 | ± | 0.7 | 25.9 | ± | 0.4 | 0.12 | 0.2 | |
| Decaying | 25.3 | ± | 1.9 | 29.8 | ± | 0.4 | 0.20 | 0.1 | |
| Dead | 16.6 | ± | 1.9 | 22.6 | ± | 2.1 | 0.23 | <0.02 | * |
| Valuable | 34.4 | ± | 2.0 | 30.3 | ± | 0.6 | 0.14 | 0.2 | |
| Non-valuable | 21.0 | ± | 0.8 | 20.1 | ± | 0.9 | 0.15 | 0.2 | |
| Basal area ($m^2$/ha) | 26.0 | ± | 1.8 | 26.4 | ± | 1.2 | 0.21 | <0.05 | * |
| Live | 19.0 | ± | 1.6 | 18.3 | ± | 0.9 | 0.09 | 0.2 | |
| Decaying | 5.3 | ± | 0.8 | 5.7 | ± | 0.8 | 0.17 | 0.2 | |
| Dead | 1.7 | ± | 0.3 | 2.4 | ± | 0.4 | 0.15 | 0.2 | |
| Valuable | 17.6 | ± | 1.7 | 21.8 | ± | 1.1 | 0.30 | <0.01 | ** |
| Non-valuable | 8.4 | ± | 1.0 | 4.5 | ± | 0.5 | 0.26 | <0.01 | ** |
| Total height of trees (m) | 14.3 | ± | 0.4 | 13.0 | ± | 0.2 | 0.28 | <0.01 | ** |
| Visual obstruction of the understory (%) | 48.5 | ± | 2.3 | 40.6 | ± | 2.2 | 0.21 | <0.05 | * |
| Canopy cover (%) | 80.2 | ± | 1.6 | 82.8 | ± | 0.1 | 0.17 | 0.2 | |

*scutata*, *S. griseicapillus,* and *L. angustirostris*; whereas in the unlogged sites common species included *Casiornis rufus*, *T. caerulescens*, *Thraupis sayaca*, and *Tolmomyias sulphurescens*. The remaining bird species were categorized as rare in the assemblages and we found no sub-dominant species.

In total, 20 bird species showed a significant indicator value in logged sites (Appendix B). Five bird species with the highest indicator values made up the response guild of logged sites (*T. caerulescens*, *L. megalura*, *S. scutata*, *P. plumbeiceps*, and *C. ustulatus*). These bird species were the more abundant in logged sites compared to unlogged sites (3.38 ± 0.17 vs 1.40 ± 0.13, respectively; $U = 5345$; $p < 0.01$; Fig. 2). The response guild of unlogged sites was composed of six bird species (*S. griseicapillus*, *T. rufiventris*, *L. angustirostris*, *C. rufus*, *T. sayaca*, and *T. sulphurescens*) which were more abundant in unlogged sites compared to logged sites (3.53 ± 0.13 vs. 2.37 ± 0.12, respectively; $U = 11248$; $p < 0.01$; Fig. 2).

The ROC curve analysis showed a level of accuracy of AUC = 0.84 (95% CI = 0.78–0.89) for the response guild of logged sites (Fig. 3a) and AUC = 0.75 (95% CI = 0.68–0.81) for the unlogged sites response guild in (Fig. 3b). The ROC curves of response guilds in logged and in unlogged sites were significantly different ($p < 0.01$). The cut-off threshold value of average abundance was 1.79 ind/ha for the response guild from logged sites and 2.74 ind/ha for the bird species from unlogged sites.

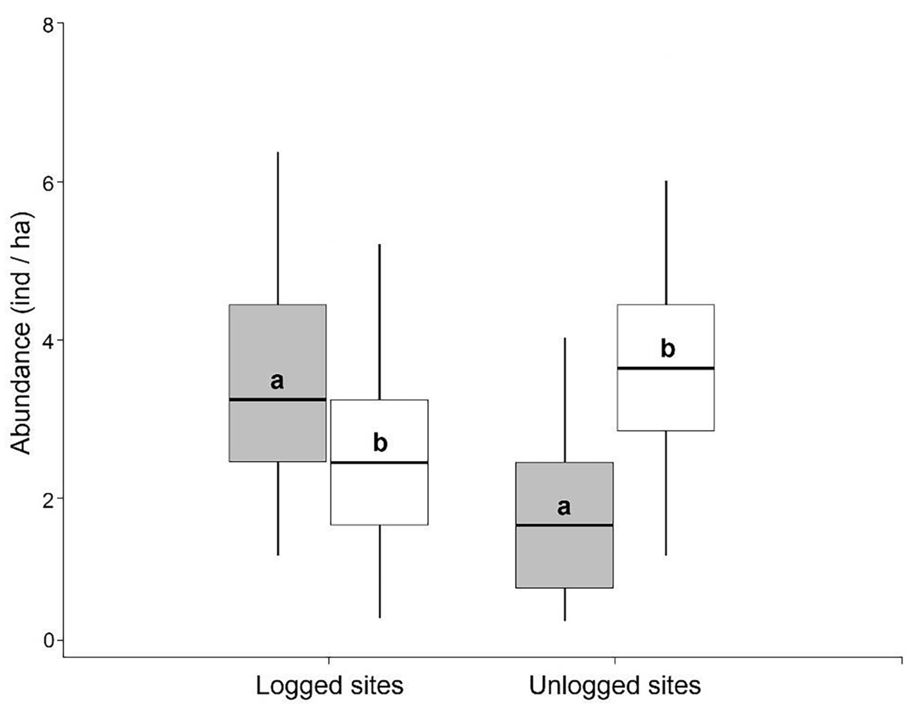


**Fig. 2.** Abundance (mean ± standard error) of logged (a) and unlogged (b) understory bird response guilds in logged and unlogged sites of the piedmont forest of the Southern Yungas, Argentina.

 

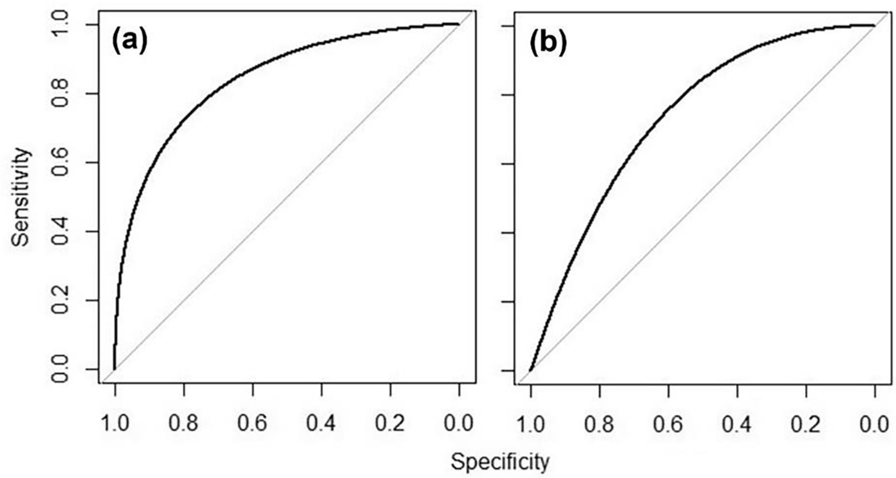


**Fig. 3.** Receiver Operating Characteristic (ROC) curves of the logged (a) and unlogged (b) understory bird response guilds in the piedmont forest of the Southern Yungas, Argentina.

### 3.3. Vegetation relationships

The redundancy analysis (RDA) showed a significant relationship between the understory bird species of the response guilds and the forest structural variables (inertia: 1.29; $p < 0.01$). The first two axes were statistically significant (eigenvalue Axis 1 = 0.66, $p < 0.01$; Axis 2 = 0.36, $p < 0.01$) explained 79% of the variation in the abundance of understory bird species (Fig. 4) In general, the bird species of the response guild from unlogged sites were associated with a higher density of valuable timber tree species and density of standing dead trees (explanatory variables: 0.45, $p < 0.01$; and 0.14, $p < 0.01$, respectively). The bird species of the response guild from logged sites were associated with a greater visual obstruction in the understory (0.18; $p < 0.01$). The cut-off threshold value for visual obstruction of the understory was 43.75%, for the density of valuable timber trees was 210 ind/ha (>10 cm DBH), and for the density of standing dead trees was 10 ind/ha and a DBH of 19.5 cm.

## 4. Discussion

Selective logging activities as currently performed in the piedmont forest change the vegetation structure and the understory bird assemblage. These changes are mainly reflected in the varying dominance of certain bird species and valuable timber species (Lambert, 1992; Stouffer et al., 2011). We found an association between understory bird species and vegetation characteristics, resulting in two response guilds. Variation in response may occur because even when birds depend on the same resources, selective logging may affect a common resource (e.g., standing dead trees), although not equally conditioning for all species in the guild (i.e., it greatly affects resource specialists).

The conservation status of bird species from both response guilds is of Least Concern, both nationally (MAyDS and AA, 2017) and internationally (IUCN, 2021) since they currently maintain stable populations and are all endemic to South America, except for *Sittasomus griseicapillus*, *Tolmomyias sulphurescens*, and *Catharus ustulatus* which have a broader distribution range (IUCN, 2021). The use of common species in monitoring programs is beginning to gain relevance (Gregory and van Strien, 2010; Lindenmayer et al., 2018), as small population declines can have important effects on the ecosystem processes and services. These effects, such as those produced by logging, can be quantified through the analysis of species abundance distribution (Baker et al., 2019). For example, *T. sulphurescens* and *C. rufus* are aerial-foliage insectivores and were more abundant in sites with less visual obstruction of the understory, which suggests the need for certain sites to capture preys using aerial hunting techniques (Malizia et al., 2005).

Bird species belonging to the response guild from logged forest (i.e., *Thamnophilus caerulescens*, *Leptotila megalura*, *Catharus ustulatus*, *Poecilotriccus plumbeiceps*, and *Synallaxis scutata*) were primarily associated with sites having greater understory visual obstruction, a feature that increases as canopy cover decreases in intensively logged forest (Blundo and Malizia, 2009). These species are foliage-insectivores (*T. caeruslens*, *P. plumbeiceps* and *S. scutata*), foliage frugivore-insectivores (*C. ustulatus*), and ground granivores (*L. megalura*), and are favored by increased foliage density (Malizia et al., 2005), as greater visual obstruction of the understory may decrease the risk of predation and increase food availability in this stratum (e.g., insects, fruits, seeds, etc.; Pacheco and Grau 1997; Zurita and Zuleta, 2009). These changes increase the resources available for forest bird species with greater ecological plasticity in logged forests (Greenberg, 1990; Webster and Lefebvre, 2001).

Birds in the response guild from unlogged forests (i.e., *Casiornis rufus*, *Thraupis sayaca*, *Tolmomyias sulphurescens*, *Turdus rufiventris, Lepidocolaptes angustirostris,* and *Sittasomus griseicapillus*) were related to sites with higher density of valuable timber species and standing dead trees, attributes that are more abundant in unlogged sites (Brown, 2009). This guild is composed of three bird species (*C. rufus*, *L. angustirostris*, and *S. griseicapillus*) which use cavities of valuable timber trees as roosts and/or nests, mainly of *Calycophylum multiflorum*, standing dead trees, *Amburana cearensis,* and *Anadenanthera colubrina* (Schaaf, unpublished data). At logged sites, however, standing dead trees and *C. multiflorum* had a lower basal area, *A. cearensis* was not recorded, and only *A. colubrina* had a similar basal area in both logged and unlogged sites. Intensive selective logging may increase the susceptibility to local extinction of valuable timber species, as in the case of *A. cearensis* (Politi et al. 2015). Moreover, other valuable timber species such as *Phyllostylon rhamnoides* and *Myracrodruon urundeuva* which are less frequently used by birds (Ruggera et al., 2016b), had lower basal areas in logged sites. Although non-cavity nesters in the unlogged forest response guild (i.e., *T. sayaca*, *T. sulphurescens*, and *T. rufiventris*) do not depend on valuable timber species for roosting or nesting, their association to sites with greater availability of these trees could result from increased habitat complexity and heterogeneity given by these species and with it, greater resource availability (Kupsch et al., 2019; Heidrich et al., 2020; Schnitzer et al., 2020).

Two bird species (*L. angustirostris* and *S. griseicapillus)* have a specialized foraging behaviour and use standing dead trees as an important foraging resource (Rodrigues et al., 2016). In logged sites, standing dead trees are frequently removed (e.g., as a method of stand

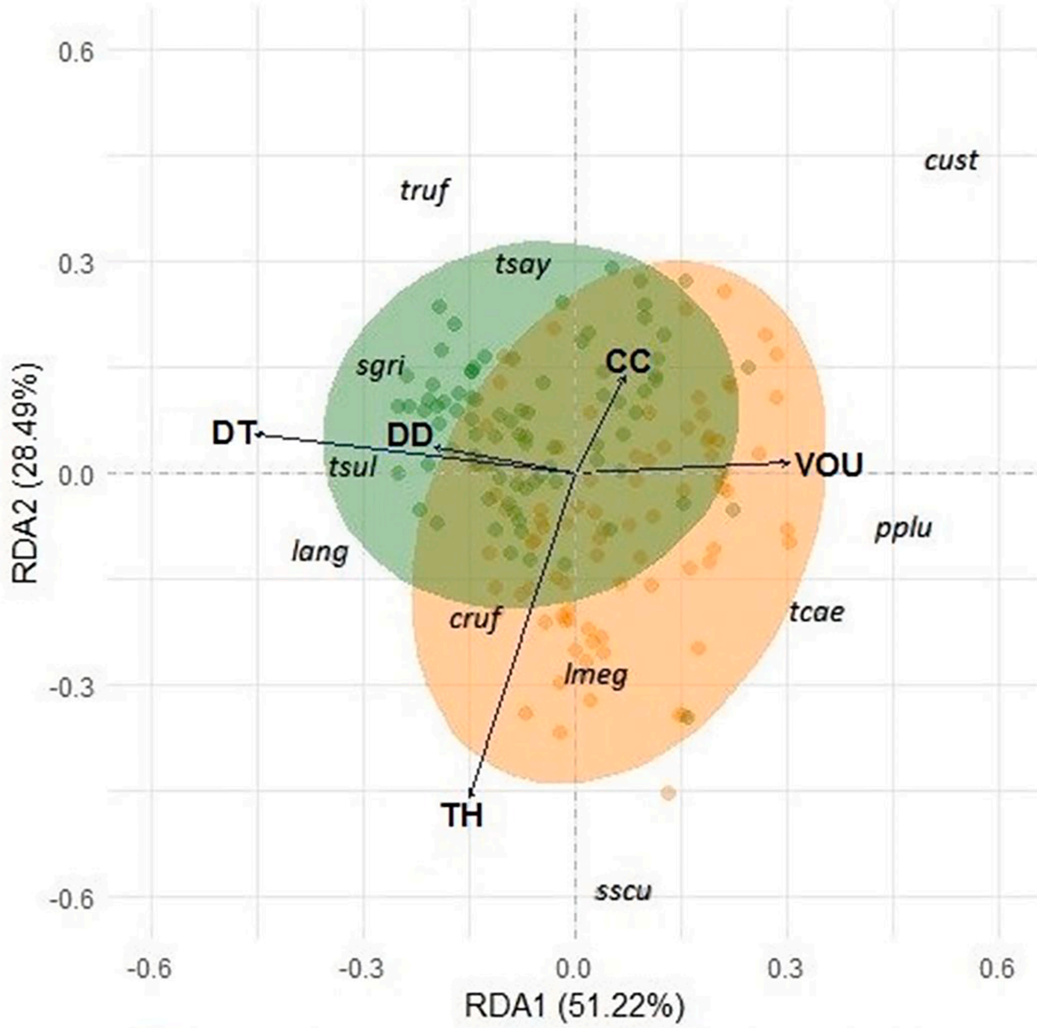


**Fig. 4.** Ordination diagram showing the first two axes of the Redundancy Analysis (RDA) for understory bird species that formed the response guilds and their association to the vegetation structural variables in logged (orange) and unlogged sites (green) in the piedmont forest of the Southern Yungas. DT = density of valuable timber species; DD = density of standing dead trees; VOU = visual obstruction of the understory; CC = canopy cover; TH = tree height. Logged response guild species correspond to: tcae = *Thamnophilus caerulescens*, lmeg = *Leptotila megalura*, cust = *Catharus ustulatus*, pplu = *Poecilotriccus plumbeiceps,* sscu = *Synallaxis scutata*. Unlogged response guild species correspond to: truf = *Turdus rufiventris*, sgri = *Sittasomus griseicapillus*, tsay = *Thraupis sayaca*, cruf = *Casiornis rufus*, tsul = *Tolmomyias sulphurescens*, lang = *Lepidocolaptes angustirostris.* (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

sanitation practice or for charcoal use) and a small number of trees reach a senescent stage because part of the adult population is removed (Fredericksen et al., 2001). In logged sites there was 20% less of standing dead trees and their size were also reduced by 26%. Bird species of mature forests with specialized habitat requirements for nesting, food resources and foraging microhabitats are more vulnerable to changes in the vegetation structure (Sigel et al., 2006; Stratford and Stouffer, 2013; Edwards et al., 2013).

*Thraupis sayaca* and *Turdus rufiventris* were strongly associated with a greater canopy cover, an attribute characterizing sites that have not been recently disturbed. *Tolmomyias sulphurescens* is only distributed in association with mature piedmont forests (Blendinger and Álvarez, 2009) in coincidence with birds with greater habitat specialization which tend to avoid disturbed areas (Sigel et al., 2010). It has been shown that disturbed forests favour species using the middle-stratum (Walther, 2002), the forest edge and secondary forest (Blendinger and Álvarez, 2009) and also migratory species (Leisler, 1990, 1992; Conway et al., 1995) such as *C. ustulatus* and *L. megalura*, which were dominant in logged sites (Le Borgne et al., 2018).

Changes generated by selective logging in bird species might affect ecological interactions, threatening the ecosystem integrity (Matuoka et al., 2020). The decrease in dominance of *T. sayaca* and *T. rufiventris* at logged sites might influence seed dispersal in the forest (Michel et al., 2020) since both species are foliage frugivore-insectivores and are considered as core species in the seed dispersal network (Ruggera et al., 2016a). The decrease in density of the furnariids *S. griseicapillus* and *L. angustirostris* may have a negative impact, affecting the wood quality since both species are insectivorous, feeding mainly on larvae and beetles associated with tree bark (Chapman and Rosenberg, 1991; Stouffer and Bierregaard, 1995). Therefore, these species might play an important role as biological controllers of the beetle populations which produce economic loss (Avery and Leslie, 2010; Bereczki et al., 2014).

Selective logging increased the visual obstruction of the understory by 20% and this it is associated with the changes in the understory bird assemblages and should be managed to reduce the impact. This could maintain the density of species associated with mature forests which play a major role within the forest (Michel et al., 2020). The understory visual obstruction is a structural attribute which may decrease by reduced impact logging (Bicknell et al., 2015). Current studies show that reduced impact logging has fewer negative effects on biodiversity than conventional logging (Bicknell et al., 2014; West et al., 2014). Reduced impact logging techniques decrease the open canopy areas and, consequently, the forest gaps, which favour greater understory visual obstruction (Putz et al., 2008; Putz et al., 2012). Management of the understory visual obstruction may also be used to promote the natural regeneration of commercially valuable tree species (Lieffers et al., 1999).

In the present study, we define abundance thresholds for the response guilds of the understory birds in order to propose schemes for monitoring the effect of logging. Both bird guilds showed opposite abundance patterns in response to logging activities. Politi et al. (2012) also found significant variation in the density of species in logged forests, some of which formed the guilds in the present study (i.e., *L. angustirostris*, *S. griseicapillus*, *T. caerulescens* and *P. plumbeiceps*). Other studies showed that bird thresholds determined by ROC curves were optimal for management and conservation strategies in logged forests (Guénette and Villard, 2005). The next step is to validate and calibrate response thresholds for different intensity of selective logging impact. Calibration may be necessary to account for geographic variation in vegetation types across the piedmont forest, such as the transition to the Chaco ecoregion (Brown, 2009). Due to the high transformation rate of the piedmont forest, we believe that determining the thresholds for several taxa will help integrate harvesting practices and biodiversity conservation to achieve sustainable forest management.

## 5. Conclusions

We found groups of understory bird species potentially useful for monitoring the impact of selective logging: a bird guild sensitive to logging (i.e., *Sittasomus griseicapillus*, *Turdus rufiventris*, *Lepidocolaptes angustirostris*, *Casiornis rufus*, *Thraupis sayaca,* and *Tolmomyias sulphurescens*) and a bird guild favoured by logging (i.e., *Thamnophilus caerulescens*, *Leptotila megalura, Synallaxis scutata, Poecilotriccus plumbeiceps,* and *Catharus ustulatus*).

Selective logging activities as currently performed in the piedmont forest modifies the tree structure and composition, changing the understory visual obstruction. The decrease in density of valuable timber species and standing dead trees together with the increase in the understory visual obstruction were the attributes that most influenced the understory bird assemblage. To ensure the conservation of understory birds in logging forests, it is necessary to implement schemes that minimize the negative impact of the activity in conjunction with monitoring programs that provide feedback for adaptive management (Chaves et al., 2017).

## CRediT authorship contribution statement

**Ever Tallei:** Writing – original draft, Conceptualization, Formal analysis, Visualization, Investigation. **Luis Rivera:** Conceptualization, Supervision, Writing – review & editing, Methodology. **Alejandro Schaaf:** Writing – review & editing, Investigation. **Constanza Vivanco:** Writing – review & editing, Investigation. **Natalia Politi:** Conceptualization, Supervision, Writing – review & editing, Methodology.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2021.108264.

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