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Fire and distance from unburned forest influence bird assemblages in Southern Andean Yungas of Northwest Argentina: a case study

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Abstract

Background: Wildfires affect vegetation structure, functions, and other attributes of forest ecosystems. Among these attributes, bird assemblages may be influenced by the distance from undisturbed to fire-disturbed forests. Information about this influence is essential for designing management plans aimed at conserving birds' diversity in undisturbed forests, which contributes to their sustainability. In Northwest Argentina, timber extraction and man-caused fires threaten the sustainability of Southern Andean Yungas forests. In this region, we evaluated, in relation to a reference unburned forest, the effects of close and distant fire-disturbed patches on bird assemblages, exploring also relationships between burned and unburned forest structures on bird assemblages. On each site, we determined forest structural variables, and twice per year, from 2015 to 2017, we recorded birds seen or heard on every site, from dawn to 1000 hours, at 30 0.5 ha counting points.

Results: Abundance and richness of bird species were lower in the unburned reference site than in close- and distant-burned sites; the farther the distance of burned sites to the unburned site, the less similarity in bird assemblages. Bird assemblage abundance appeared to be associated with snag height and basal area. However, bird species in mature forests were present at all sites and outnumbered those typically found in forest edges, or secondary or disturbed forests.

Conclusions: Connected areas between unburned and burned forest patches provide habitat for birds living in both environments. Preventing forest fragmentation by reducing the number and size of wildfires, promoting selective timber logging, and banning post-fire snag removal will help promote suitable habitat for different bird assemblages and contribute to Yungas forests' sustainability. This study is the first step toward understanding how fire-patch distances to unburned forests may affect bird assemblages in subtropical Southern Andean Yungas forests in South America and provide a basis for comparison with other subtropical ecosystems around the world.

Keywords: climate change, connectivity, fire ecology, forest management, neotropic, piedmont forests

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Resumen

Antecedentes: Los incendios afectan la estructura de la vegetación, las funciones, y otros atributos de los ecosistemas forestales. Entre esos atributos, los ensambles de aves pueden estar influenciados por la distancia entre bosques no quemados y quemados. La información sobre esta influencia es esencial para diseñar planes de manejo orientados a conservar la diversidad de aves en bosques no quemados y que contribuyan a su sustentabilidad. En el noroeste de Argentina, la extracción de madera y los incendios antropogénicos amenazan la sustentabilidad de los bosques de las Yungas Australes. En esta región evaluamos, en relación a un bosque de referencia no quemado, los efectos de parches quemados cercanos y alejados sobre el ensamble de aves, explorando también las relaciones entre las estructuras del bosque quemado y no quemado y el ensamble de aves. En cada sitio determinamos las variables estructurales y dos veces al año, desde 2015 a 2017, registramos las aves vistas u oídas en cada sitio, desde el amanecer hasta las 1000 horas, en 30 puntos de 0,5 ha cada uno.

Resultados: La abundancia y riqueza de especies de aves fue menor en el sitio de referencia (no quemado) que en los sitios quemados cercanos y alejados. A mayor distancia entre el no quemado y los sitios quemados, se encontró menor similitud en los ensambles de aves. La abundancia de los ensambles de aves parece estar asociada con la altura y área basal de árboles muertos en pie. Sin embargo, las especies de aves típicas de bosques maduros estuvieron presentes en todos los sitios y sobrepasaron en número a aquellas encontradas típicamente en los bordes del bosque, o en bosques secundarios o disturbados.

Conclusiones: Las áreas conexas entre bosques no quemados y parches de bosques quemados proveen de hábitat para aves que viven en ambos ambientes. El prevenir la fragmentación de bosques mediante la reducción del número y tamaño de los incendios, la promoción de cortas selectivas, y la prohibición de remover árboles muertos en pie, va a ayudar a promover hábitats adecuados para diferentes ensambles de aves y contribuir así a la sustentabilidad de los bosques de las Yungas. Este estudio es un primer paso hacia el entendimiento de cómo la distancia entre parches de bosques quemados con no quemados puede afectar los ensambles de aves en los bosques subtropicales de las Yungas Australes de América del Sur y pude proveer de base para comparación con otros ecosistemas tropicales alrededor del mundo.

Abbreviations

AM: birds of disturbed environments
BBS: birds associated with forest edges or secondary environments
BM: birds that inhabit the interior of mature forests
CCA: Canonic Correspondence Analysis
dbh: diameter at breast height
GLM: General Linear Models
NMDS: Nonmetric MultiDimensional Scaling
PERMANOVA: PERmutational Multivariate ANalysis Of VAriance
QC: close-burned site
QL: distant-burned site
R: unburned forest site

Introduction

Wildfires are frequent disturbances that help maintain the structure and function of many forest ecosystems (Agee 1993), playing a key role in establishing and preserving habitat for several plant and animal species (Fontaine et al. 2009). However, fires occurring in forests not adapted to fire, or outside of their historical fire frequency range, may produce changes in forest structure and create a post-fire environment that could negatively affect forest biodiversity (Sodhi et al. 2011). Fires usually increase heterogeneity at landscape level, although they may simplify forest structures if stand scales are considered (Ponce Calderón et al. 2012). Bird assemblages constitute ideal groups for studying the effects of fire disturbances, mainly because they rapidly respond to changes in vegetation structure (Fontaine et al. 2009). After a wildfire, bird species inhabiting or depending on mature forests could be replaced by other species whose habitat is linked to forest edges, or by those living in secondary forests affected by fires or other disturbances (Sodhi et al. 2011). The effects of forest fires on bird assemblages have been studied exhaustively in temperate regions, but in subtropical regions of southern South America, these kinds of studies are still scarce (Sodhi et al. 2011).

The proximity, or distance between, burned and unburned forest patches may influence post-fire bird assemblages (Sodhi et al. 2011; Watson et al. 2012). Unburned forests act as a refuge and habitat for many bird species during a fire, and may facilitate recolonization of fire-affected forests (Watson et al. 2012). Some bird species respond in specific ways to forest fires, and these responses could be dependent upon the distance between burned and unburned forest patches (Law et al. 2018).

The piedmont forest of the Southern Andean Yungas (*i.e.,* the mountain forest of northern Argentina and southern Bolivia) is one of the most threatened ecosystems of the Neotropic ecozone, presumably because of uncontrolled human-caused fires and unsustainable logging (Brown et al. 2009; Martinuzzi et al. 2017). However, little is known about the fire ecology of these piedmont forests. Knowledge of fire effects on bird assemblages, including consideration of the distance between fire-affected and unaffected forests, will be crucial for designing long-term conservation strategies for maintaining bird biodiversity at landscape scale. The understanding of fire ecology in this ecosystem is very important, since predictions for climatic change in the region foresee increases in mean temperatures that could, in turn, increase fire occurrence and effects (Scholze et al. 2006; Flannigan et al. 2009). Under this scenario, remnant undisturbed forests could be key to helping preserve biodiversity in the region and to designing appropriate conservation strategies (Mayhew et al. 2019). These strategies will help assure a continuous provision of ecosystem services in a changing climate. The objective of this study was to evaluate how the distance between burned and unburned forest patches influences bird assemblages in the piedmont forest of the Southern Andean Yungas in Northwest Argentina. This objective was achieved by: (1) determining and comparing the bird assemblages in fire-disturbed forest patches in relation to the distance to a reference unburned forest; (2) surveying and comparing structural forest variables among burned and reference unburned sites; and (3) exploring relationships between bird assemblages and forest structures in burned and unburned forest sites.

Methods

Study area

The Southern Andean Yungas is a tropical and subtropical moist broadleaf forest ecoregion stretching from southern Bolivia to northwestern Argentina (Cabrera and Willink 1973; Cabrera 1994; Oyarzabal et al. 2018). The Southern Andean Yungas possess an important conservation value because of their high biodiversity, which includes several endemic and threatened species (Pidgeon et al. 2015). The lower elevation zone (*i.e.,* 400 to 900 m.a.s.l.) of the Southern Andean Yungas ecoregion constitutes the so-called "piedmont forest" and is part of the neotropical seasonal dry forests (Prado et al. 2000). This piedmont forest shows a monsoonal rainfall regime with a marked seasonality (rainy season from October to March and dry season from April to September). Annual precipitation varies from 800 to 1000 mm (Brown et al. 2009), and mean annual temperature is 21.1 °C (Arias and Bianchi 1996). The most characteristic tree species of this piedmont forest are *Calycophyllum multiflorum* Griseb., *Phyllostylon rhamnoides* Taub., *Handroanthus impetiginosus* Mattos., *Anadenanthera colubrina* Griseb., *Myroxylon peruiferum* L. f., *Cordia trichotoma* Steud., *Cordia americana* Gottschling & Mill., *Cedrela angustifolia* DC., *Enterolobium contortisiliquum* Morong, and *Myracrodruon urundeuva* Allemão (Lomáscolo et al. 2010). More than 90% of the area of this forest in Argentina had been disturbed by anthropogenic activities (agriculture, logging, cattle grazing, and fires), while some relatively small undisturbed stands remained in the northwestern provinces of Salta and Jujuy (Brown et al. 2009). Some remnant stands of the piedmont forest, however, are severely threatened by arson fires, especially during the dry season, when about 70% of the trees lose their foliage (Brown and Malizia 2004).

This study was carried out at the piedmont Southern Andean Yungas forest, Jujuy province, Argentina. We selected three stands considered representative of burned and unburned forests. The first stand was selected on the basis of having a good conservation status, as it had not been affected by fire for 40 years. This stand was defined as our reference site (longitude: −23.64°; latitude: −64.59°). The second stand, of approximately 1000 ha, was located near our reference site, and was affected by a fire in 2013. This stand was designated as our close-burned site (longitude: −23.69°; latitude: −64.58°). The third stand, of about 1000 ha, was located 3.4 km away from our reference site and was affected by the same fire as the close-burned site in 2013. It was defined as our distant-burned site (longitude: −23.66°; latitude: −64.55°).

Bird assemblages

On each site, we delimited an area of about 100 ha and established 30 bird point counts of 50 m radius separated by at least 150 m from one another (Ralph et al. 1996; Malizia et al. 2005). From December 2015 to August 2017, we recorded bird presence twice per year at each counting point: during the bird reproductive season (October to March), and during the non-reproductive season (April to September). At each point count, we registered all birds seen or heard for 10 min between dawn and 1000 hours (Malizia et al. 2005). We did not record birds during heavy rains or strong winds. We also did not include birds associated with wetlands, nor those that were passing through the point count. Birds were identified according to the South American Classification Committee (Remsen et al. 2018).

We determined bird abundance by counting individuals of all bird species recorded at each point count, and then calculated the mean and standard deviation of the abundance per site. Based on Stotz et al. (1996), and Blendinger and Álvarez (2009), we grouped bird species according to the type of environment they lived in (AM, birds of disturbed sites; BBS, birds of forest edges or secondary environments; and BM, birds of mature forests; Additional file 1). We calculated the mean and standard deviation of the abundance of each bird group per site. We determined differences in abundance among sites, and bird groups within each site, by running General Linear Models (GLM), using the `glm.nb` function of the `MASS` statistical package (Venables and Ripley 2002), and then doing Tukey multi-comparisons with `multcomp` statistical package (Hothorn et al. 2008). For the GLM of birds grouped by environment, we treated the total abundance of the surveys as a compensatory variable (offset). To compare abundance among sites, we also drew bar figures with `ggplot2` (Wickham 2016) and `lattice` (Sarkar 2008) packages. To analyze bird diversity at each site, we drew re-refraction-extrapolation curves with the `iNEXT` package, developed for species richness (Hill number: order 0). We determined equitativity with Shannon exponential entropy (order 1), and species dominance through the inverse of Simpson (order 2), with 95% confidence intervals (Jost 2006; Chao et al. 2014). We also identified bird species that were exclusive to each site. We determined similarities in structure and composition of bird communities among sites with nonmetric multidimensional scaling (NMDS), run with the `vegan` package (Clarke and Warwick 2001; Oksanen et al. 2018). We evaluated bird assemblage similarities by running a multivariate nonparametric analysis of variance (PERMANOVA), adjusting distance matrices to a linear model (`ADONIS` function of `vegan` package; Anderson 2001; Oksanen et al. 2018). For NMDS and PERMANOVA analyses, we used quantitative (based on abundance and on the Bray-Curtis index) and qualitative data (based on species richness and on the Jaccard index) (Clarke and Warwick 2001). Stress of 2-dimensional plots was measured by Kruskal's stress formula I and the Spearman rank correlation was calculated in order to point out which sites were more correlated to NMDS axes (Clarke and Warwick 2001). To ordinate NMDS, we performed Hellinger transformations in the matrix of bird species to reduce the weight of more abundant species in the analysis (Legendre and Gallagher 2001).

Forest structure variables

For characterizing the forest structure of the three sites, we established 500 m^2 concentric circular plots at every bird point count (Husch et al. 2003). Within these plots, we measured total height and diameter at breast height (dbh), 1.3 m above the ground, of each tree, and noted whether they were dead or alive. These measurements were taken for trees with dbh > 10 cm (Husch et al. 2003). We estimated the percentage of canopy cover with a densiometer at 12 points in each plot, located 4, 8, and 12 m from the center, in the direction of each cardinal point (Bullock 1996; Newton 2007). We also determined the visibility of the horizon through the understory up to 2 m from the ground. To do this we placed a 2 m tall stick, marked every 20 cm, 10 m from the plot center in the direction of each cardinal point. We registered the number of marks seen on the stick in each direction (Higgins et al. 1996). For each site, we calculated mean and standard deviation of number of trees per hectare, basal area (m^2 ha^{-1}), dbh (cm), and height of live and standing dead (snag) trees (m), as well as percent (%) of canopy cover and percent (%) of understory visibility. We analyzed structural differences between live and dead trees (snags) among sites with the Kruskal-Wallis and Tukey tests using the `DescTools` package (Signorell et al. 2018).

Relationships between bird assemblage and forest structural variables

We explored the relationship between bird assemblage and forest structural variables by running Canonic Correspondence Analysis (CCA) with the `vegan` package. We also performed a graphic analysis with the `ggord` package (Marcus 2017). The CCA presents an inertia component that could be analogically interpreted as the variance of data sets. The proportion of variation explained by bird species, partial components of the inertia, was computed with the `inertcomp` function provided by the `vegan` package (Oksanen et al. 2018). Previous to running the CCA, we centered and standardized vegetation variables with the `caret` package (Kuhn et al. 2016) and determined if they were correlated to the `corrplot` package (Wei and Simko 2017). To ordinate the CCA, we performed Hellinger transformations in the matrix of bird species (Legendre and Gallagher 2001).

Results

Bird assemblages

Abundance and richness of all bird species was lower in the unburned reference site. There was no difference between the close-burned and distant-burned sites (Figs. 1 and 2). Bird diversity was higher at the close-burned site than at the other two sites (Fig. 2). At both burned sites, species richness and diversity of birds typical of disturbed environments were higher than at the reference site (Fig. 2). Abundance of birds typical of disturbed environments was higher at the distant-burned site than at the other two (Fig. 1). Abundance and richness of bird species typical of forest edges or secondary environments were higher at the distant burned site (Figs. 1 and 2). Bird assemblages in distant-burned and reference sites showed the least similarity, considering both quantitative data (abundance) and qualitative data (species richness) (Fig. 3). Only 5% of the bird species were

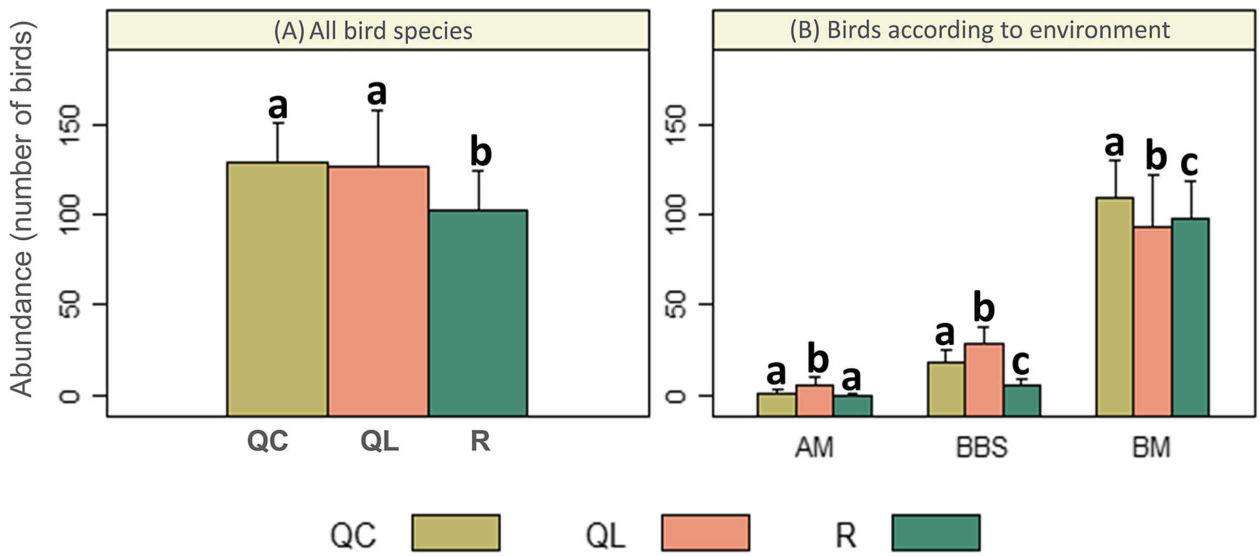

Fig. 1 Abundance (mean ± standard deviation) of birds in the unburned reference site (R; green), close-burned site (QC; brown), and distant-burned site (QL; orange) surveyed from December 2015 to August 2017 at the piedmont Southern Andean Yungas forest, Jujuy province, Argentina, according to (**A**) the complete bird species assemblage; and (**B**) bird species associated with disturbed environments (AM); forest edge or secondary environments (BBS); and interior of mature forests (BM). Bars with same letter do not differ significantly ($P \geq 0.05$)

exclusive to the reference site, 6% to the close-burned site, and 14% to the distant-burned site (Additional file 1).

Structural variables

As expected, structural variables (dbh, basal area, mean height, density) of live trees, canopy cover, and understory vegetation visibility were different among the three sites, being greater for those with more trees (reference site > close-burned site > distant-burned site), except for tree height, which did not differ between the reference site and close-burned site (Table 1). Snag structural variables were lower for the reference site than the close- and distant-burned sites (Table 1).

Relationship between bird assemblage and forest structural variables

Diameter at breast height and density of snags and live trees were highly correlated (r > 0.7) with other variables, and were not included in the CCA (Additional file 2). We found a relationship between bird assemblage and forest structural variables (inertia = 0.34; $P = 0.001$). High values in visibility of the understory vegetation, canopy cover, basal area, and height of live trees were highly associated with bird assemblages at the reference site ($P < 0.05$; Fig. 4). High values in tree height and basal area of snags were highly associated with bird assemblages at burned sites ($P < 0.05$; Fig. 4). The bird species *Myiothlypis bivitta* Zimmer was highly associated with the reference site, while *Saltator coerulescens* Vieillot, *Coryphospingus cucullatus* Müller, and *Phacellodomus rufifrons* Wied were associated with the distant-burned site (Fig. 4).

Discussion

This is the first study evaluating the influence of forest fires on bird assemblages at the piedmont of the Southern Andean Yungas in Northwest Argentina. The higher bird species richness at post-fire sites can be explained by the presence of bird species typical of mature unburned forests and the addition of species associated with disturbed, edge, or secondary forests (Banks et al. 2010). In a study conducted on semi-arid shrublands at the Murray Mallee region in southeastern Australia, Watson et al. (2012) found that up to five years after fire, species richness was higher at nearby unburned vegetation patches, but these differences disappeared after ten years. The burned sites included in our study have greater bird variety than in unburned vegetation. These results, different from Watson's results, may be related to the dissimilitude between forest structure and dynamics, as well as habitat requirements of the bird species inhabiting both continents.

The difference in bird species composition at burned sites may be a consequence of the proximity to the unburned site, since birds from unburned forests tend to recolonize burned places (Law et al. 2018). The high similarity in bird species found between reference and close-burned sites might be due to the higher number of bird species belonging to mature forests that inhabit both sites. The presence of birds associated with forest edges or secondary environments at the distant-burned site can explain the difference we found between burned sites in terms of bird assemblages. Differences in bird assemblages among sites appear to be more related to the

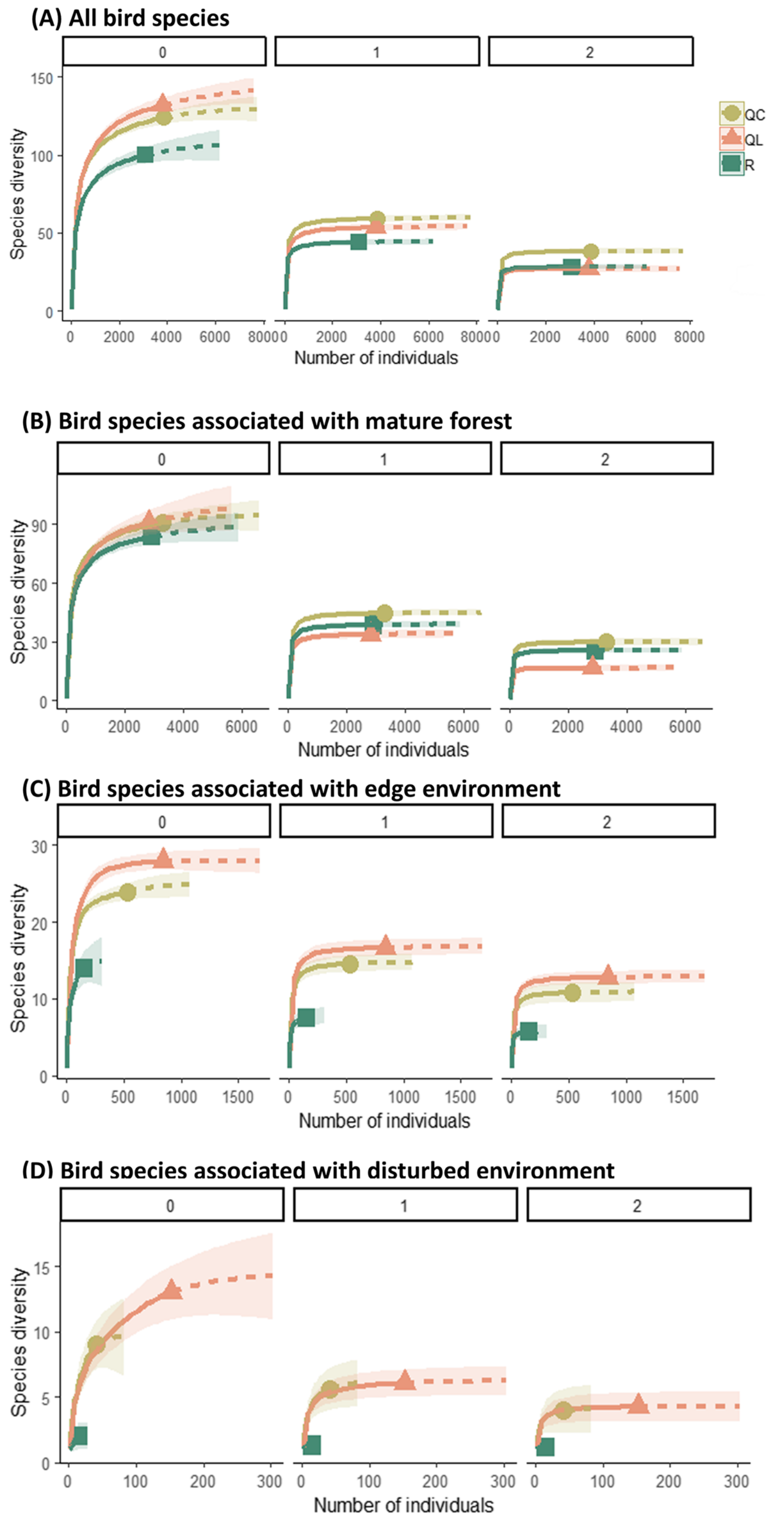

Fig. 2 Rarefaction species curves of diversity values (number of species) for (**A**) all bird species, (**B**) birds associated with mature forest, (**C**) birds associated with edge or secondary environments, and (**D**) birds associated with disturbed environments in the unburned reference site (R; green), close-burned site (QC; brown), and distant-burned site (QL; orange), as recorded in surveys from December 2015 to August 2017 at the piedmont Southern Andean Yungas forest, Jujuy province, Argentina. Curves under the 0 represent diversity values for Hill numbers, under the 1 for species richness, and under the 2 for the exponential of Shannon entropy. Solid lines represent interpolation from data, dotted lines extrapolation from data, and shaded areas represent the 95% confidence intervals. Confidence intervals that overlap do not show significant difference ($P > 0.05$)

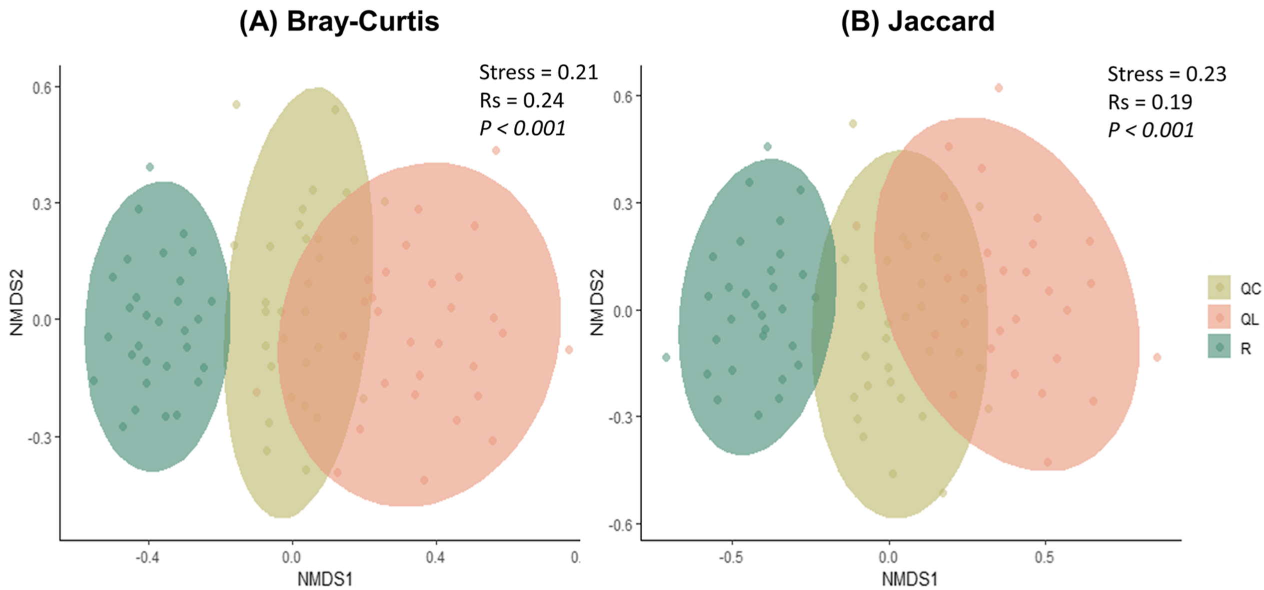

Fig. 3 Nonmetric multidimensional scaling ordination of two axes (NMDS1 and NMDS2) using (**A**) Bray-Curtis and (**B**) Jaccard similarity of the bird assemblages surveyed from December 2015 to August 2017 at the piedmont Southern Andean Yungas forest, Jujuy province, Argentina, in the unburned reference site (R; green), close-burned site (QC; brown), and distant-burned site (QL; orange). Ellipses show 95% confidence interval from 999 permutations; Stress refers to the sum of inaccuracies, Rs denotes Spearman rank correlation, and *P* is the probability value of Rs for each ordination

distance between the unburned and burned sites, rather than to the influence of the fire itself, as other authors have also pointed out (Hutto 1995, 2008; Nappi et al. 2003; Koivula and Schmiegelow 2007). The association of bird assemblages with forest structure has been mentioned in similar studies (Pearson 1993; Díaz et al. 2005; Fontaine et al. 2009). Birds inhabiting the reference site were associated with basal area and height of live trees, whereas birds inhabiting the more distant burned site were closely related to basal area and height of snags. Birds inhabiting the close-burned site, however, were related to number of live trees and high number of snags. Snags play an important ecological role for different bird species (Saab et al. 2009). Woodpeckers (Picidae, Vigors) excavate cavities in the trunks of snags for refuge or nesting, while other bird species use dead branches for perching (Politi et al. 2010). In the Southern Andean Yungas of Argentina, fire patches and their distance to undisturbed forest are important factors in conservation of bird diversity, at least during the first post-fire

Table 1 Forest structural variables (diameter at breast height [dbh], basal area, height, and density) of live and standing dead (snags) trees, canopy cover, and understory visibility (Under vis) at the unburned reference site (R), close-burned site (QC), and distant-burned site (QL), measured between December 2015 to August 2017 at the piedmont Southern Andean Yungas forest, Jujuy province, Argentina. Values indicate mean ± standard deviation; same letter (a, b, c) next to the values denotes no significant difference ($P \geq 0.05$)

Forest attribute	Variable	R				QC				QL			
Live trees	dbh (cm)	33	±	13	a	17	±	9	b	5	±	11	c
	basal area (m^2 ha^{-1})	10	±	7	a	2	±	3	b	0	±	2	c
	height (m)	14	±	4	a	14	±	8	a	3	±	8	b
	density (individuals ha^{-1})	86	±	39	a	64	±	63	b	8	±	19	c
Snags	dbh (cm)	2	±	6	a	17	±	7	b	16	±	8	b
	basal area (m^2 ha^{-1})	0	±	0	a	2	±	1	b	3	±	3	b
	height (m)	1	±	3	a	13	±	7	b	12	±	6	b
	density (individuals ha^{-1})	1	±	5	a	70	±	69	b	90	±	66	b
Canopy cover (%)		51	±	12	a	31	±	14	b	17	±	8	c
Under vis (%)		87	±	12	a	54	±	21	b	16	±	13	c

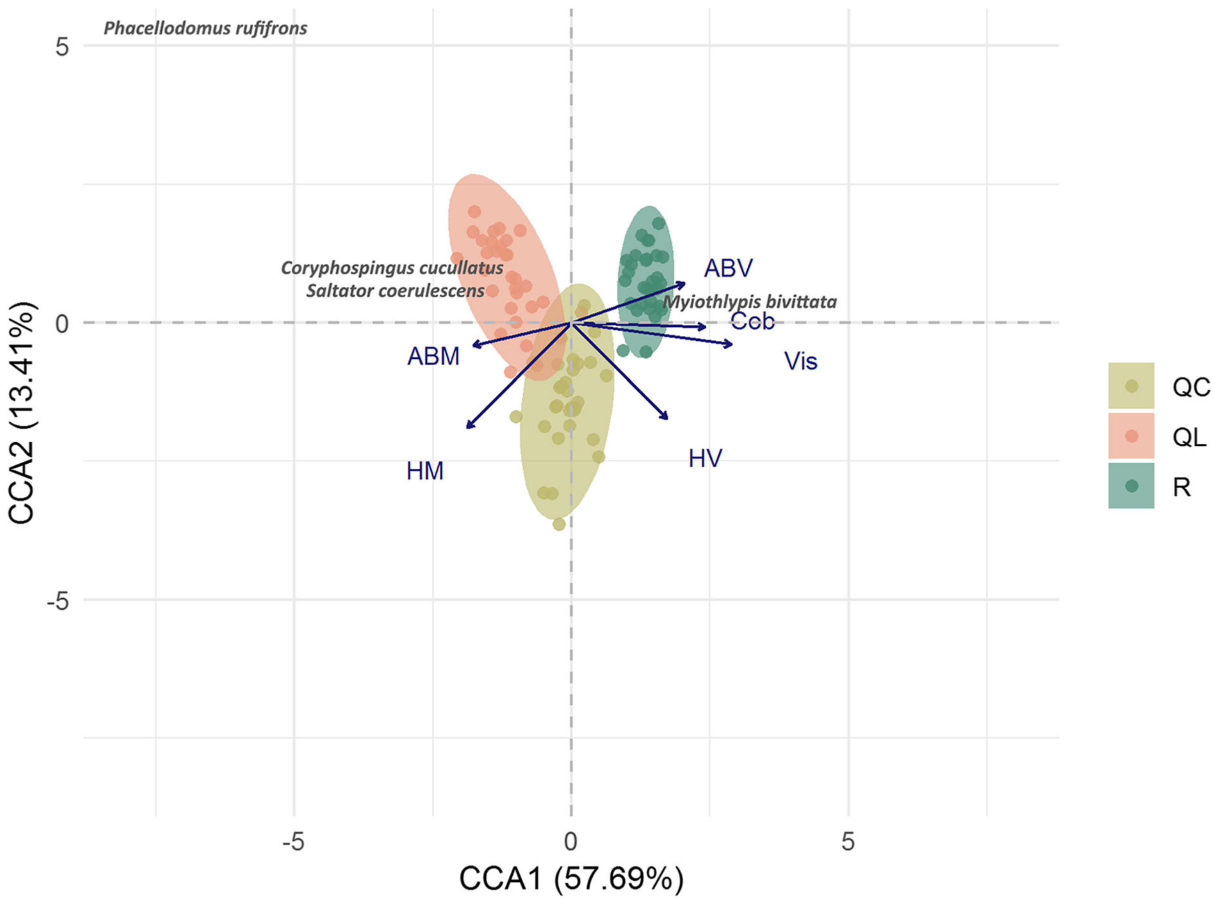

Fig. 4 Representation of the first two axes (CCA1 and CCA2) of the canonical correspondence analysis (CCA) of the bird assemblages with the forest structural variables surveyed from December 2015 to August 2017 at the piedmont Southern Andean Yungas forest, Jujuy province, Argentina, in the unburned reference site (R; green), close-burned site (QC; brown), and distant-burned site (QL; orange). Shown in parentheses after each axis is the percent of variability contribution of that axis. Blue arrows indicate the direction of the strength of the forest structural variables: ABM = basal area of standing dead trees (snags), AltM = height of standing dead trees (snags), ABV = basal area of live trees, AltV = height of live trees, Cob = canopy cover, and Vis = understory visibility. Bird species strongly associated with each axis are shown. Resolution of this image remains poor

successional stages (<5 yr after fire). The high proportion of bird species typical of unburned forests found at the three study sites can indicate that they all provide the refuge that Southern Andean Yungas birds need after fire. Thus, a patchy burned environment close to unburned forest may facilitate bird recolonization of mature forests (Mayhew et al. 2019), while at the same time providing habitat for other bird species as post-fire succession proceeds. Forest managers and policy makers should carefully consider these aspects, since within the current era of climate change, different models predict an increasing incidence of wildfires in neotropical forests in the near future (Scholze et al. 2006).

Conclusions

In the Southern Andean Yungas forests of Northwest Argentina, fire-disturbed patches and their distance to undisturbed forest are important factors in bird assemblage conservation. Bird assemblage abundance and richness was higher at burned sites, and differences in bird assemblages increased with distance to unburned patches. The high proportion of bird species characteristic of undisturbed forest in the three sites indicated, however, that they collectively constitute a substantial refuge for Southern Andean Yungas forest birds. Maintenance of continuous, unburned forests patches during the first successional stages after fires (<5 yr) may help bird assemblages to recover quickly. This is because, as the distance from unburned forest increases (as in the distant-burned site), bird assemblage characteristics of fire-disturbed or secondary forests increase, and may delay the recovery process of those typical of undisturbed forests. Lack of connectivity and fragmentation, due mainly to man-caused fires and timber extraction, and the threat of climate change, are the main problems compromising sustainability of Southern Andean Yungas forests in Argentina. Two key aspects should be considered to help preserve bird assemblages: (1) restrict the use of fire to increase forest connectivity and reduce fragmentation; and (2) promote selective timber logging and ban post-fire snag removal to assure the recovery of habitat for bird assemblages. These recommendations could be extrapolated to other ecosystems sharing similar structures and functions.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s42408-020-00074-0.

Additional file 1. Bird species, grouped by family, recorded (X) in the unburned reference site, close-burned site, and distant-burned site surveyed from December 2015 to August 2017 at the piedmont Southern Andean Yungas forest, Jujuy province, Argentina. Environment with which each species was associated is shown as: AM = disturbed environments; BBS = forest edge or secondary environments; and BM = interior mature forests. Asterisk (*) indicates that the bird species is exclusive to the site.

Additional file 2. Correlation values for forest structural variables measured from December 2015 to August 2017 at the piedmont Southern Andean Yungas forest, Jujuy province, Argentina. Forest structural variables: DAPM = diameter at breast height of standing dead trees (snags); DenM = density of snags; ABM = basal area of snags; HM = height of snags; DAPV = diameter at breast height of live trees; DenV = density of live trees; ABV: basal area of live trees; HV = height of live trees; Cob = canopy cover; Vis = understory visibility. In the color ramp, dark red indicates a high negative correlation, white indicates no correlation, and dark blue indicates a high positive correlation.

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Authors' contributions

M. Morales: study design, data collection, analyses, and manuscript writing; C. Vivanco: data collection and manuscript revision; G. Defossé, N. Politi, and L.O. Rivera: study design, manuscript writing and revision. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated or analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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