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Effects of forest structure and human influence on the call rate of owls in the Piedmont Forest of Northwestern Argentina

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ABSTRACT

Owls (Strigiformes) play an important ecological role as predators that structure and organize biological communities. Specialized owl species dependent on old-growth forests have suffered declines because of forest loss or degradation by human activities. Few studies have been conducted on Neotropical owls, especially in the Piedmont Forest of Northwestern Argentina. The scarcity of information on habitat requirements and the effect of human impacts preclude the establishment of conservation and management activities. The human footprint index (HFI) is a tool for mapping human impacts on biodiversity that is used at global and regional scales, based on the estimated and standardized contribution of different human impact variables (e.g. road networks, urban centers, agricultural land, etc.). The objectives of this work were to: 1) Determine the call rate of five owl species in the Piedmont Forest of Northwestern Argentina, 2) relate forest structure to the call rate of owl species, and 3) relate human footprint index to the call rate of owls. We placed 28 automatic recorders in the Piedmont Forest, in sites with low and high Human influence, and characterized the forest structure around each recorder within a circular plot of 25 m diameter. We obtained 241 vocalizations in 168 intervals of 2 h for Ferruginous pygmy owl (*Glaucidium brasilianum*), Tropical screech-owl (*Megascops choliba)*, Black-banded owl (*Ciccaba huhula*), Spectacled owl (*Pulsatrix perspicillata*), and Buff-fronted owl (*Aegolius harrisii)*. We found that for Tropical screech-owl live tree basal area had a positive and diameter at breast height standard deviation had a negative influence on call rate. While for Black-banded owl, the dead tree density had a positive and human footprint index >1 had a negative influence on call rate. For Spectacled owl, dead tree density and human footprint index >1 had a negative influence on call rate. We provide first insights into the effects of forest structure and human influence on the call rate of owls in the Piedmont Forest of Northwestern Argentina, information that may guide forest management guidelines and conservation strategies.

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Owls; acoustic monitoring; vocalizations; human footprint; forest structure

Introduction

Raptors (i.e. birds of prey) are globally distributed, commonly used as ecological indicators due to their high trophic level, often serve as umbrella or flagship species for conservation programs, and serve as important cultural icons linking humans to the natural world [1,2]. Their high trophic level and generally slow life history make raptors sensitive to anthropogenic threats, and raptor species associated with forests are particularly vulnerable [1]. Although owls (Strigiformes) account for a large percentage of all raptor species (42.4%) and have high research priority, owls are the least-studied group of raptors, and have the highest overall priority for future research [3]. Some owl species have persisted despite persecution by humans, or have successfully adapted to the use of buildings and human constructions. However, highly specialized owl species dependent on old-growth forests have suffered declines because of forest loss or degradation since disturbances can reduce the availability of key resources for nesting, foraging, and other activities [4,5]. Therefore, highly specialized owl species are sensitive to changes in forest structure and human influence [6].

Neotropical forests harbor 80 owl species and there is little information on their ecology, habitat use, distribution, and conservation status [7]. In Argentina, 22 owl species (Tytonidae and Strigidae) have been identified, of which nine species are under some conservation risk category. One of the most important regions for owl conservation is the Southern Yungas due to its high species richness and the presence of threatened and restricted-range species [8]. The Piedmont Forest corresponds to the most threatened forest type of the Southern Yungas, which extends from Bolivia to northwestern Argentina, between 400 and 700 m above sea level. Approximately 75% of the original area of the Piedmont Forests has been transformed into other

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land uses [9] and the current intact forest measures around 1 million hectares. Protected areas encompass only 8% of the remaining Piedmont forest and a far lower proportion (4%) of the original ecosystem in Argentina [10]. There is very little information on abundance, habitat use, and habitat requirements on the five owl species found in the Piedmont Forest, Tropical screech-owl (*Megascops choliba*), Ferruginous pygmy-owl (*Glaucidium brasilianum*), Black-banded owl (*Ciccaba huhula*), Buff-fronted owl (*Aegolius harrisii*), and the Spectacled owl (*Pulsatrix perspicillata*) [11–15]. These owl species are secondary cavity nesters that depend on cavities excavated by other species or produced by wood decay processes [7,16]. Only Black-banded owl seems an exception since the nesting site reported consists of a platform set in a major fork of a living tree, found at 15.2 m above the ground [17]. The Tropical screech-owl is widely distributed in the Neotropical region between Costa Rica and Argentina [18] and is a common species found in forest fragments, edges of riparian forests, forest plantations, and urban environments [5,6,19,20]. The Ferruginous pygmy-owl ranges from the southern United States to Argentina inhabiting a variety of landscapes, from tropical and subtropical dry forest to semiarid, open-forest in the southern limits of its range. Several studies on the diet and foraging ecology of Ferruginous pygmy-owl indicate that it is a generalist predator [21]. The Black-banded owl is a species with low abundance [19], categorized as Threatened in Argentina [22,23] and associated with old-growth forests [24]. The Buff-fronted owl is a little-known species distributed from Venezuela to Argentina in the subtropical and temperate forests of the Andes [25] with few occasional records and is one of the least abundant owl species in fragments of the Atlantic forest in Brazil [5]. Furthermore, the Buff-fronted owl species has been reported, in both primary and secondary forests [26]. The Spectacled owl is a large Neotropical owl that occurs from southern Mexico to northern Argentina and inhabits dense tropical rainforest and gallery forest along streams [27] and can also be found in drier forests, such as savannah woodlands, and in coffee plantations [28]. The existing information for Spectacled owl suggests that this species is a generalist.

Animal vocalizations that are identified with passively recorded audio represent the individual's response to its environment without direct human influence, allowing researchers to draw much stronger inferences about its behavior than can be done from direct observations [29]. Call rate (number of vocalizations per unit time) can be used to estimate abundance if multiple conspecifics are within range of a single recording unit [30]. Call rate can also be used as a behavioral metric to assess pair status, habitat selection, and competition [31]. In areas of younger and more open forest, generally considered lower-quality habitat, territorial vocalization for California Spotted Owl (*Strix occidentalis occidentalis*) tended to be farther in time from daylight, longer, and less frequent [29].

In this study, we used the human footprint map recently developed for the Southern Yungas to assess the effect of human influence on owls call rate comparing high and low human influence areas [32]. The human footprint index (HFI) is a tool for mapping human impacts on biodiversity and used at global [33] and regional [34] scales. The HFI is based on the estimated and standardized contribution to different human impact variables (e.g. road networks, urban centers, agricultural land, etc.). The sum of these values is used to determine an index where 0 represents wilderness areas (there is no influence of the human impact variables) and index over 1 represents areas with human influence [33].

Due to the important ecological role of owl species and the scarcity of information for these species in the Piedmont Forests of Northwestern Argentina, we aimed: 1) to determine the call rate of five owl species in the Piedmont Forest of Northwestern Argentina, 2) relate forest structure and HFI to the call rate of owl species. We consider this study as exploratory since there is little knowledge about these species in the region.

Material and methods

Study area

We conducted the study at the Piedmont Forest of Northwestern Argentina in Salta and Jujuy provinces (Figure 1). The Piedmont Forest of Argentina extends from 22° S to 29° S, along the Subandean Mountains, and from 400 to 700 m asl in the low slopes of the mountains of Alto Bermejo with rains of 800 to 1,000 mm per year, which concentrates in the summer period; i.e. 90% occurs from November to March [9]. The Piedmont Forest is characterized by the dominance of two tree species: *Calycophyllum multiflorum* and *Phyllostylon rhamnoides* [9]. The Piedmont Forest is part of the Neotropical Dry Seasonal forests and is considered a biogeographical relict that extends over a narrow belt in South America [35]. More than 70% of the plant species in the Piedmont Forest lose their foliage during the dry seasons, between June and October, which makes this forest type one of the most seasonal forest ecosystems in South America [35]. Mature Piedmont Forest has a continuous canopy with a height of 25–35 m, a basal area of 25 to 30 m^2/ha, 35 to 40 tree species/ha, two or three forest strata, and an important layer of woody lianas [9,36]. Besides deforestation, other disturbances, such as unsustainable logging, grazing, and fires, have degraded most of the Piedmont Forest [36].

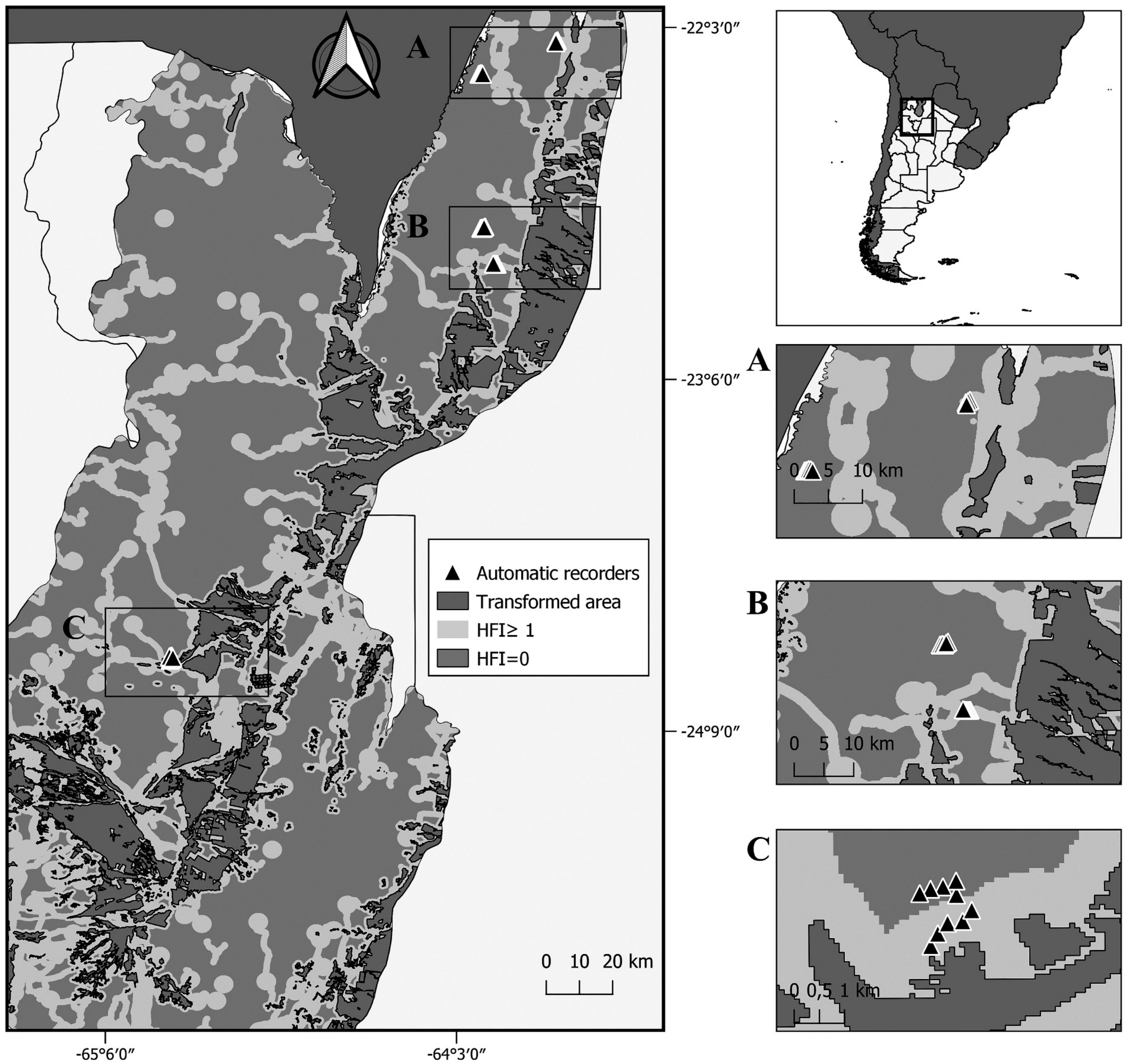

Figure 1. Study area showing the human footprint (HFI [32];) and the location of the automatic recorders at the Piedmont Forest in 3 areas (A, B and C). The HFI was considered at low human influence (HFI = 0) and high human influence (HFI ≥1).

Fieldwork

We carried out this study between late August 2018 and early January 2019, which coincide with the breeding season of most of the bird species in the area [15,37], and considering that all owl species are residents [12], we assume no seasonality effects on the detection probability. In three areas (A, B, and C, Figure 1), we selected two sites for each level (six sites total) on the human footprint map for the Southern Yungas [32], three with HFI = 0 values and three with HFI ≥1 (1 to 5), and in each of these sites, we conducted surveys of owls (Figure 1). We used only two categories of HFI to compare the pooled categories of HFI from 1 to 5 in a single category named HFI ≥1 because some categories had a low number of recorders. We did not sample sites with HFI between 6 and 10 since values equal to 6 represent agricultural lands with no forest cover and values of 7 to 10 are completely transformed areas where human disturbances are very high (e.g. cities). At each site, we placed five fourth-generation SM4 Song Meter automatic recorders (Wildlife Acoustics, Maynard, Ma, USA) to simultaneously record owl vocalizations. Recorders were active for three consecutive nights and after that, we moved them to another site. We randomly spaced recorders by more than 300 m and attached them to a tree 1.5 m above the ground within a continuous forest matrix to avoid fragmentation effects [38,39]. We programmed recorders to be active for two 2-h intervals separated by 2 hours as a minimum: one approximately 1 hour after sunset (~9:00 PM) and another at 1:00 AM during three consecutive nights; i.e. all recorders had 12 h of recording time. We set recorders to record in stereo, 44.1 kHz sampling frequency, a 16-bit sample size, and we stored files in WAV format on a 32 GB memory card [40,41].

In this study, we assume that the call rate by owls could be related to habitat use, with a higher call rate associated with increased habitat use or quality

[29,42,43]. We characterized the forest structure around each recorder within a circular plot of 25 m diameter (0.05 ha), where we measured the diameter at breast height (DBH) of live, standing, and fallen dead trees >10 cm DBH. We measured DBH of live tree and standing dead tree at 1.30 m from the ground and DBH of fallen dead trees at a distance of 1.30 m from the widest end.

Data analysis

We processed and edited the recordings with Song Scope 4.1.5 (Wildlife Acoustics Inc. Maynard, MA, U.S.A) and Raven Pro 1.5 Bioacoustics Research Program, Cornell Lab of Ornithology). We identified owl species by listening at maximum volume and displaying apparent spectrogram [44]. We define a call rate for each species as the numbers of independent vocalization in an interval of two hours and we considered a vocalization as independent when 1) two vocalizations were separated by at least two hours, 2) vocalizations from two individuals can be differentiated spatially, or 3) two or more vocalizations were simultaneous. We verified vocalizations of owl species using the Xenocanto database [45] and performed a spectrogram and oscillogram of the species identified with the package "seewave" (Figure 2) in R software version 4.2.1 [46].

We calculated the dead tree density (standing and fallen trees), mean DBH (including live and dead trees), DBH standard deviation (SD), live tree basal area, and dead tree basal area for each forest plot [47]. The standard deviation of the DBH is considered a more reliable indicator than the average of (a) distribution of tree-age classes in a stand, (b) stand structural complexity, and (c) the diversity of micro-habitats for owls and their prey [48]. Also, DBH SD frequently increases with stand age [49].

To assess the association between call rate of owl species with forest structure variables and HFI, we constructed Generalized Linear Mixed Models (GLMM). As a response variable, we considered the call rate for each owl species in each recorder and used the Poisson error structure and link log function. We considered recorders from same site and the 2-h intervals from the same recorder as non-independent. To address non-independence and interaction of both variables, we considered the 2-h intervals as a random effect nested within the random effect "site" [50,51]. We assessed the multicollinearity of all numerical explanatory variables with Pearson's Correlations [52]. We included in the models the following explanatory variables that were not redundant ($r < 0.6$) (Table S1) and had biological significance: dead tree density (standing and fallen), live tree basal area, and DBH SD. We included the HFI into account as a categorical explanatory variable and HFI = 0 as the reference group. We evaluated the dispersion parameter for each model. For each owl species, we ran a total of six models: one for each of the explanatory variables (numerical and categorical), a complete model that included all of the explanatory variables in an additive form, and a null model that did not include explanatory variables (Table 2). We selected the best and most complete model by performing a likelihood ratio test (LRT) to prevent overparametrization. For each model, we calculated the Akaike Information Criterion corrected for small sample sizes (AICc). To assess the strength of support for each model, we compared the models based on the ΔAICc [53], and we considered the best models of those models <2 ΔAICc. We determined the 95% confidence intervals of the selected model for each species. We considered explanatory variables to be statistically significant when $p < 0.05$. We fitted all models with "glmmTMB" [54] and estimated the R^2 of the best models with "performance" [55], in R version 4.2.1.

Results

Of the 30 recorders placed, we processed only 28 recorders because two recorders had errors at the time of recording. We obtained 336 hs of passive recordings, which included 241 independent vocal records of five owl species: Ferruginous pygmy-owl, Tropical screech-owl, Black-banded owl, Spectacled owl, and Buff-fronted owl (Table 1). Most of the records obtained were of Tropical screech owl (n = 151), and was the most common owl species since it was recorded in almost all the recorders (Table 1). We also recorded Ferruginous pygmy-owl and Black-banded owl in almost half of the recorders with an intermediate number of records (n = 42 and n = 35, respectively) and were assigned as common owl species (Table 1). Finally, we obtained very few records of Buff-fronted owls and Spectacled owls in less than 25% of the recorders, these were the rarest owl species (Table 1).

We obtained the following mean values for the 28 plots for the forest structure variables: dead tree density 3.214 ± 2.357 ind/0.050 ha, live tree basal area 0.990 ± 0.348 m^2/0.050 ha, and DBH SD 0.120 ± 0.034 m. We found that for the Tropical screech-owl (Table 2), the first best model included live trees basal area (R^2 = 0.275), and the second model, live trees basal area and SD DBH (R^2 = 0.284). The best models that explained the influence of variables on call rate of Black-banded owl (Table 2) included dead tree density and HFI (Dead tree density + HFI R^2 = 0.495, HFI R^2 = 0.416, Dead tree density R^2 = 0.494). Similarly, for the Spectacled owl, the best model included, dead tree density and HFI (R^2 = 0.431) (Table 2). For Ferruginous pygmy-owl and the Buff-fronted owl the null models were the best models (Table 2).

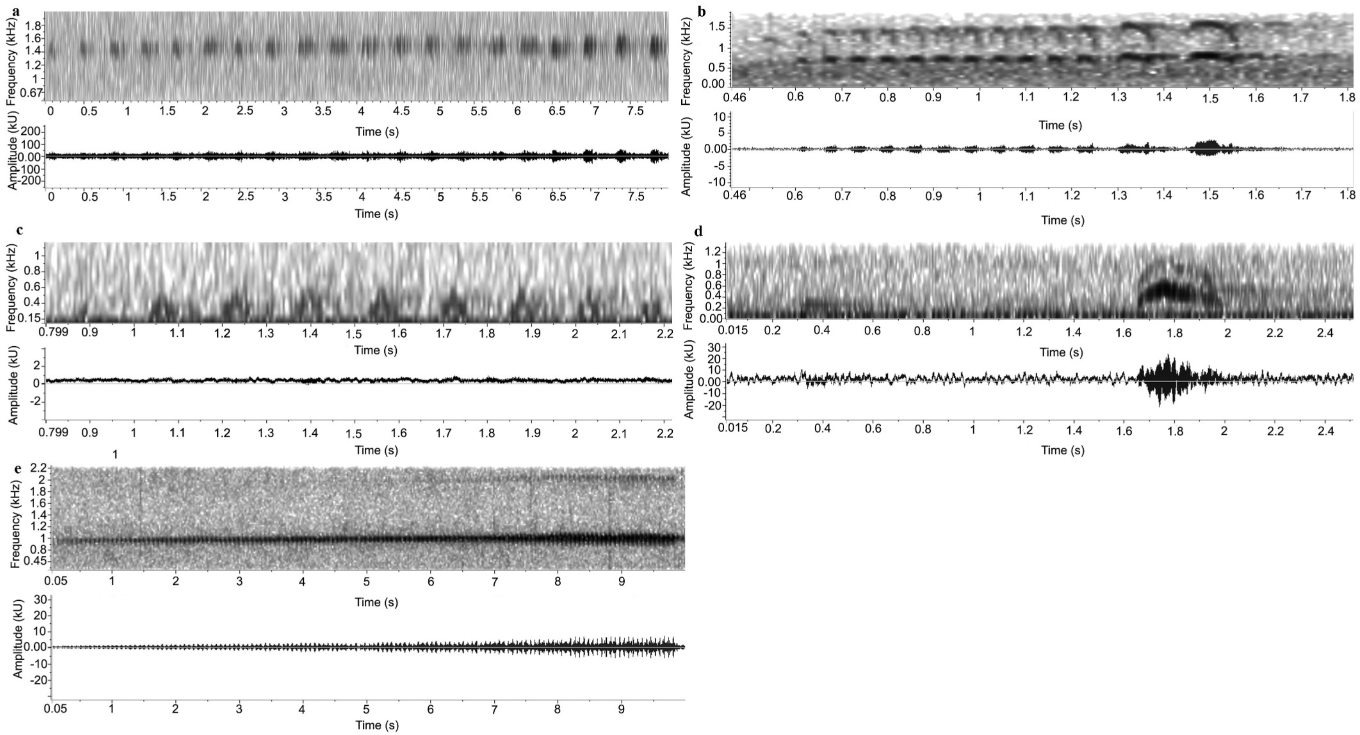

Figure 2. Spectrogram and oscillogram for owl species recorded with automatic recorders placed in the Piedmont Forest of Northwestern Argentina. a) Ferruginous pygmy-owl (*Glaucidium brasilianum)*, b) Tropical screech-owl *(Megascops choliba)*, c) Spectacled owl *(Pulsatrix perspicillata)*, d) Black-banded owl *(Ciccaba huhula)*, e) Buff-fronted owl *(Aegolius harrisii)*.

Table 1. Mean and SD of all vocalization records in 168 intervals of 2 h and number of recorders with occurrence for five owl species in the Piedmont Forest of Northwestern Argentina.

	Buff-fronted owl	Ferruginous pygmy-owl	Tropical screech-owl	Spectacled owl	Black-banded owl
All Records (mean ± SD)	4 (0.024 ± 0.153)	42 (0.250 ± 0.533)	151 (0.899 ± 0.926)	9 (0.054 ± 0.226)	35 (0.208 ± 0.523)
Recorders with occurrence	3 (11%)	15 (54%)	26 (93%)	6 (21%)	12 (43%)

Table 2. Generalized linear mixed models of the call rate for five owl species associated with different forest structure variables and HFI in the Piedmont Forest of Northwestern Argentina. For each species, we showed the best models <2 δaicc.

Owl species	Predictor variables	k	AICc	ΔAICc
Ferruginous pygmy-owl	NULL	3	175.626	0.000
	Dead tree density	4	176.424	0.798
	HFI	4	177.290	1.665
	DBH SD	4	177.342	1.716
Tropical screech-owl	Live tree basal area	4	392.597	0.000
	Live tree basal area + SD DBH	5	392.702	0.105
	NULL	3	394.168	1.570
Black-banded owl	Dead tree density + HFI	5	162.637	0.000
	HFI	4	163.737	1.101
	Dead tree density	4	164.076	1.439
Spectacled owl	Dead tree density + HFI	5	66.030	0.000
	Dead tree density	4	66.852	0.821
	NULL	3	67.426	1.396
	DBH SD	4	67.763	1.733
Buff-fronted owl	NULL	3	37.073	0.000
	Live tree basal area	4	38.172	1.099
	HFI	4	38.418	1.344
	Dead tree density	4	38.780	1.706
	DBH SD	4	38.843	1.770

Discussion

In this study, we identified the rarest and the most common owl species in the Piedmont Forest of Northwestern Argentina, determined the influence of forest structure variables and the human influence on the call rate of these species for the first time. We found that Tropical screech-owl is the most common owl species, detected in almost all the recorders and with the highest call rate in the Piedmont Forest of Northwestern Argentina. The rarest species was the Buff-fronted owl showing the lower occurrence and call rate. Ferruginous pygmy-owl and Black-banded owl, had an intermediate call rate, between Tropical screech owl and Buff-fronted owl. Other authors reported Black-banded owl as rare and one of the least known species in the Neotropics [18,24,56]. The Spectacled owl and especially Buff-fronted owl were rare and detected in very few recorders in the study area. Our findings for Spectacled owl contrast with other reports that qualify the species from quite common [57] to very abundant [19]. Our results are in agreement with others that report to Buff-fronted owl as rare, threatened, and data deficient for most of its distribution [5], and this could be due to its low detectability because it vocalizes in short periods and at a different season of the year, responding to playback only under specifics circumstances [26,58,59].

In the Piedmont Forest of Northwestern Argentina [60], the majority of the cavities available for non-excavating cavity nesters are from decay process in live trees. As live tree basal area increase, the density of suitable cavities for birds also increase [37]. Tropical screech-owl call rate was positively influenced by live trees basal area. However, DBH SD was negatively associated with the call rate for Tropical screech-owls (Table S2), which would indicate that this species uses younger forests and with less structural complexity [49]. For Rufous-legged owls (*Strix ruficeps*) a positive association was reported between presence and DBH SD in a temperate forest of southern Chile [48]. HFI >1 showed a negative influence and density of dead trees a positive relationship with call rate of Black-banded owl (Table S2), which suggest that this species could be affected by human impact and habitat quality, since density of dead trees can be considered as an indicator of forest maturity. Areas with HFI ≥1 are closer to human infrastructure like roads, agricultural lands, human settlements, illegal logging areas and wood collection areas, etc., all factors that can affect forest structure and composition [32]. Our results for Black-banded owl are in agreement with other studies from Brazil where the species was associated with mature forests [23]. However, the subspecies, *Ciccaba huhula albomarginata* from the Atlantic forest has been reported to occur in a range of forest conditions including primary forest, selectively logged forest, remnant forest in a farming area, and plantations of Paraná pine [17]. More information on the habitat requirements of Black-banded owl are needed to disentangle the specific characteristics or resources that can be affected leading to the species to be sensitive in areas with higher human impacts. The Spectacled owl call rate was negatively influenced by HFI >1 (Table S2), suggesting that the species is sensitive to human impacts at large scale (e.g. road networks, urban centers, agricultural land, etc.). However, Spectacled owl call rate was negatively affected by dead tree density suggesting it is tolerant to a wide range of forest conditions [57]. In the montane forests of northwestern Argentina, for example, Spectacled Owls use secondary growth, which replaces the dense forest after extensive clearing being more tolerant to forest loss and degradation than other forest owl species [61,62]. Although this species requires continuous forest for breeding, there are records between 2011 and 2016 in urban areas in one sector of Colombia, including nesting records [63].

We consider this study as exploratory and we express some caveats on the interpretation of our results. The low sample size (n = 28) could have limited the analysis of the data, especially for rare or hard to detect species. The extended sampling period can bias results if owls change the rate of vocalizations along the seasons. We consider detections of records to be perfect [64], which could bias results because we did not perform a detectability analysis. Additionally, we did not consider rain and wind as plausible variables influencing recording and detection of the owl species, as was found in other studies. Despite the limitations of this study, we highlight that the information gathered can serve as a baseline to follow research on this very little-known avian group.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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