STUDIES ON NEOTROPICAL FAUNA AND ENVIRONMENT
https://doi.org/10.1080/01650521.2021.1933699

Taylor & Francis
Taylor & Francis Group

ORIGINAL ARTICLE

Passive acoustic monitoring of the Ferruginous Pygmy-Owl (*Glaucidium brasilianum*) over a complete annual cycle: seasonality and monitoring recommendations

Cristian Pérez-Granados [a,b,c], Karl-L. Schuchmann [a,d,e] and, Marinez I. Marques [a,b,e]

[a]Computational Bioacoustics Research Unit (CO.BRA), National Institute for Science and Technology in Wetlands (INAU), Federal University of Mato Grosso (UFMT), Cuiabá, Brazil; [b]Postgraduate Program in Ecology and Biodiversity Conservation, Institute of Biosciences, Federal University of Mato Grosso, Cuiabá, Brazil; [c]Ecology Department, Alicante University, Alicante, Spain; [d]Ornithology, Zoological Research Museum A. Koenig (ZFMK), Bonn, Germany; [e]Postgraduate Program in Zoology, Institute of Biosciences, Federal University of Mato Grosso, Cuiabá, Brazil

ABSTRACT
Monitoring the vocal behavior of owls is challenging because of their nocturnal habits and limited vocal activity. Here, we evaluated the use of passive acoustic monitoring coupled with automated signal recognition software to monitor the spontaneous vocal activity of the Ferruginous Pygmy-Owl (*Glaucidium brasilianum*) over a complete annual cycle at five recording stations in the Brazilian Pantanal. The vocal behavior of this species was concentrated during the crepuscular periods, with highest vocal activity in the hours prior to sunrise. The Ferruginous Pygmy-Owl was vocally active throughout the year, but the species showed a peak of activity from June to August. Paired Ferruginous Pygmy-Owl males tend to perform territorial calls less often during the nestling period, which may partly explain the significant decrease in the vocal activity after August. Our results suggest that the breeding period of the species starts in June, and the nesting phase probably occurs from September onwards, when the wet season starts. The first rains in seasonal tropical areas are usually associated with an increase in food availability, which may explain the species´ breeding period onset. Future surveys aiming to monitor the species, avoiding the use of broadcast calls, should be performed before sunrise between June and August, when the vocal activity was maximal.

ARTICLE HISTORY
Received 26 June 2020
Accepted 18 May 2021

KEYWORDS
Acoustic monitoring; autonomous recording unit; Brazil; Pantanal; vocal activity

Introduction

The study of owls is difficult for human observers due to the owls' nocturnal habits, cryptic coloration, silent flight, and low population densities (König & Weick 2008). These characteristics may be a reason why there are still gaps in our ecological knowledge of many owls, especially in the Neotropics (see the example of geographical biases in Lincer et al. 2018). The detection of owls is mainly based on auditory cues, and as a result, monitoring programs frequently use broadcast calls to determine their presence, abundance, and population trends (Schmutz 2001; Flesch & Steidl 2006). The vocal activity of owls is usually low, and thus, traditional field surveys can be time-consuming (Shonfield et al. 2018). Broadcasting recorded calls is a practical solution to elicit territorial responses of conspecifics and increase the probability of detecting owls (Zuberogoitia & Campos 1998; Conway & Simon 2003). However, call-broadcast surveys have a series of drawbacks, including the movement of owls toward observers and into otherwise unused areas (Kissling et al. 2010), impacts on conclusions about the habitat associations of owls (Shonfield et al. 2018), variable detection probabilities according to calls recorded and equipment used (Freeman et al. 2006), and detection alterations of other owl species (Kissling et al. 2010). Therefore, several national monitoring programs do not broadcast recorded calls when surveying owls (e.g. the Noctua program in Spain, SEO/BirdLife 2019).

The use of autonomous sound recorders allows researchers to increase the spatial and temporal scales of studies through numerous scheduled recordings (Shonfield & Bayne 2017; Sugai et al. 2019). This technique increases the probability of detecting owls without the need for broadcasting recorded calls, thus not altering owls' vocal behaviors (Wood et al. 2019). This technique has proven to be an effective tool for monitoring several nocturnal bird species (Farnsworth & Russell 2007; Goyette et al. 2011; Pérez-Granados & Schuchmann 2020a,

CONTACT Cristian Pérez-Granados cristian.perez@ua.es

Published online 31 May 2021

2020b), including owls (Shonfield & Bayne 2017; Domahidi et al. 2019; Wood et al. 2019). However, there is a gap of knowledge in whether passive acoustic monitoring is effective for several species of owls, especially for those inhabiting Neotropical regions.

In this study, we employed passive acoustic monitoring for over one year at five sites in the Brazilian Pantanal. We aimed to (1) assess the utility of autonomous sound recorders for monitoring the presence and spontaneous vocal activity of the Ferruginous Pygmy-Owl (*Glaucidium brasilianum*); (2) describe the diel and seasonal variation in calling activity of the species to increase our knowledge of seasonal ecological impacts; and (3) provide useful guidelines and monitoring recommendations for future studies.

Methods

Study species

The Ferruginous Pygmy-Owl (hereafter FPO) is a - widespread year-round resident of lowlands from the southern United States to central Argentina (König & Weick 2008). The typical territorial call of the FPO is a long series of 8–30 monotonal hoots emitted at low frequencies (Figure 1). Both sexes utter territorial calls (Proudfoot et al. 2020), although females are less vocally active (Flesch & Steidl 2007). Males usually vocalize from a perch near the nest (Larsen 2012). The vocal activity of the species in the Brazilian Pantanal is positively associated with the percent of the moon illuminated, and is negatively related to nocturnal air temperature, with more vocal activity on nights with lower air temperature (Pérez-Granados et al. 2021). The range of the species has contracted in the southwestern United States (Johnson et al. 2003; Flesch & Steidl 2006). Although no data are available from Central and South America, it is desirable to develop an effective monitoring protocol to document population changes throughout the PFO's entire range (Holt et al. 2020).

Study area

The study was carried out near the SESC Pantanal (Poconé municipality, Mato Grosso, Brazil; 16°29′58″ S, 56°24′39″ W) in the Pantanal of Mato Grosso in the northeastern part of the Brazilian Pantanal (Figure 2). The study area is located within the floodplain of the Cuiabá River, which is one of the main tributaries of the Paraguay River in the Brazilian Pantanal. This floodplain is seasonally inundated due to flooding of the Paraguay River from October to April, with a terrestrial phase from May to September (Junk et al. 2006). The vegetation in the study area is composed of a mosaic of savanna (*Cerrado*) and forested areas, and it has a tropical and humid climate (average annual rainfall of 1,000–1,500 mm and mean annual temperature of ~ 24°C).

Acoustic recording

We performed acoustic monitoring over a complete annual cycle at five acoustic monitoring stations separated by 573–2,804 m (Figure 2). One Song Meter SM2 recorder (Wildlife Acoustics, USA) was placed at each site from 1 March 2015 to 29 February 2016 and was programmed to record (in stereo and wav formats) the first 15 minutes of each hour every day. The SM2 recorders have been shown to have an effective detection radius of approximately 150–160 m (Rempel et al. 2013; Pérez-Granados et al. 2019), which, together with the territorial behavior of the FPO (Campioni et al.

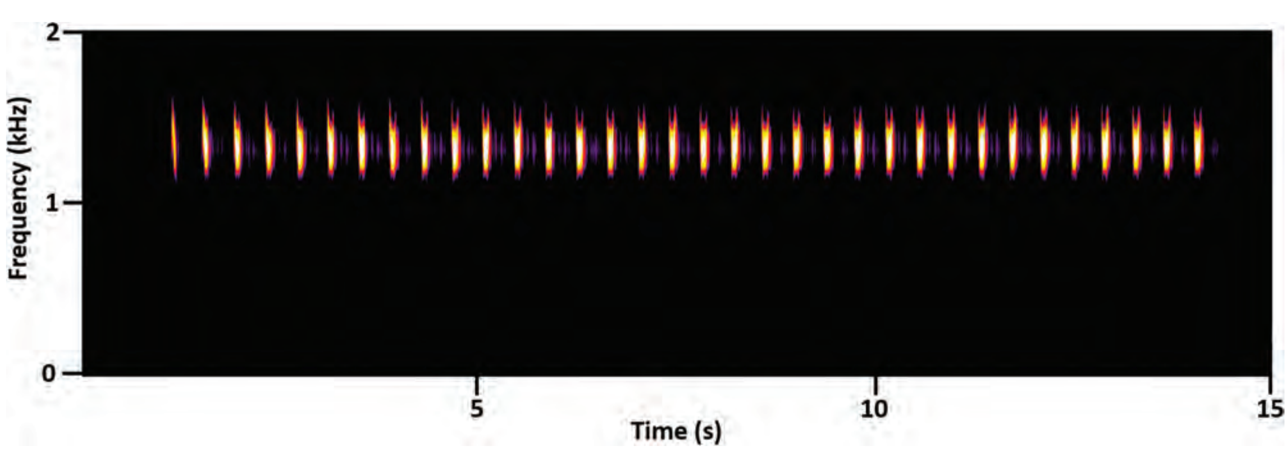

Figure 1. Sonogram of a typical call of the Ferruginous Pygmy-Owl in the Brazilian Pantanal.

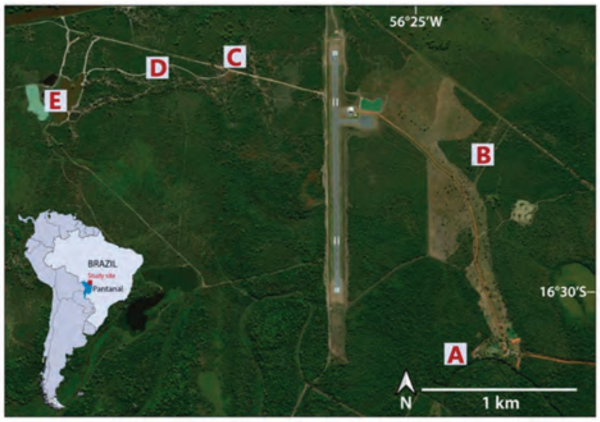

Figure 2. Location of the five acoustic monitoring stations in the Brazilian Pantanal (Pantanal of Mato Grosso, Poconé municipality, Mato Grosso, Brazil). The inset shows the location of the study area (red square) and the Brazilian Pantanal. Scale bar: 1 km.

2013), greatly reduces the risk of recording the same territorial male at two adjacent stations.

Acoustic data analyses

The left channel recordings were analyzed using Kaleidoscope Pro 5.1.9. Kaleidoscope Pro is an automated signal recognition software program (Wildlife Acoustics, USA) able to scan recordings for target signals according to signal parameters of the desired sounds for detection. To introduce the most adequate signal parameters, we characterized the call of the FPO in the study area (Figure 1 and see Table S1). The signal parameters introduced in Kaleidoscope were as follows: minimum and maximum frequency range: 1,150 and 1,450 Hz, respectively; minimum and maximum detection length: 2 and 24 s, respectively; maximum intersyllable gap: 0.7 s. The maximum intersyllable gap is considered the maximum allowable gap between syllables (hoots for the FPO) of the same call, and thus, hoots separated by less than 0.7 s were considered to be part of the same call. Therefore, in this study we considered the whole sequence of hoots as a unique call (Figure 1). The parameter ‘Maximum distance from the cluster center’, which ranges from 0 to 2, was fitted to 2 since we aimed to detect as many FPO calls as possible (see a quantitative analysis of bird calls detected employing variable values of the parameter distance from the cluster center in Pérez-Granados et al. 2020).

The signals detected by Kaleidoscope were visually and/or acoustically checked by the same observer (GPG) to differentiate false positives (undesired sounds) from true positives (correct classifications).

Statistical analyses

To identify times of significantly high calling activity by the FPO, we fitted a zero-inflated negative binomial generalized linear mixed model (ZIB-GLMM) using the total number of calls detected per hour at each site as the response variable, recording hour as a fixed effect (15 categorical levels) and acoustic monitoring stations (five categorical levels) as random effects to control for variation in the calling activity owing to site. Those recording hours between 9 a.m. and 5 p.m. were excluded from the analyses (only 0.7% of the detected calls occurred during this period, see results). We fitted another similar GLMM (Gaussian structure) to identify the months with significantly high calling activity by the species. The total number of calls detected per month at each site was used as the response variable (log transformed), the month (12 categorical levels) was considered a fixed effect and the acoustic monitoring stations (five categorical levels) were considered random effects to control for intersite variation. Tukey’s post hoc test was used to test differences among levels when a fixed effect was found to be significant ($p < 0.05$). All statistical analyses were performed with R 3.5.2 (R Development Core Team 2016) using the packages ‘glmmTMB’ (Brooks et al. 2017) for building the ZIB-GLMM, ‘lme4’ (Bates et al. 2015) for the GLMM construction, ‘lmerTest’ (Kuznetsova et al. 2014) to calculate the significance of fixed effects and ‘multcomp’ (Hothorn et al. 2008) for post hoc comparison tests.

Results

Kaleidoscope reported a total of 408,305 events that matched the introduced signal parameters. After checking every event, a total of 1,506 detections were classified as calls of the FPO and applied in the posterior analyses. The species was detected at all monitored stations, and the number of calls detected per station ranged between 178 and 394 (Table 1). A summary table showing the spontaneous calling activity of the FPO at each monitoring station over the annual cycle can be found in Table 1.

Diel pattern

The diel calling activity pattern of the FPO was mostly restricted to night and was concentrated during the crepuscular periods (0300–0500 and 1800–1900, see Figure 3). The species showed a first peak of vocal activity after dusk, with 17.6% of the calls detected between 1800 and 1900 and then showed relatively

Table 1. Summary of the vocal activity of the Ferruginous Pygmy-Owl over an annual cycle in the Brazilian Pantanal. Calling activity was monitored using autonomous sound recorders from 1 March 2015 to 29 February 2016 at five acoustic monitoring stations. Hours are expressed as UTC (−4).

Recording site	First Song	Last Song	Most active day	Most active hour	Most active month	Days detected	Calls detected
A	30 March	19 February	8 April	0500	February	30	254
B	7 March	29 January	30 June	2300	September	35	300
C	3 May	23 February	5 August	0500	August	26	380
D	18 March	6 October	2 August	0500	August	25	394
E	25 March	5 August	2 July	0400	July	5	178

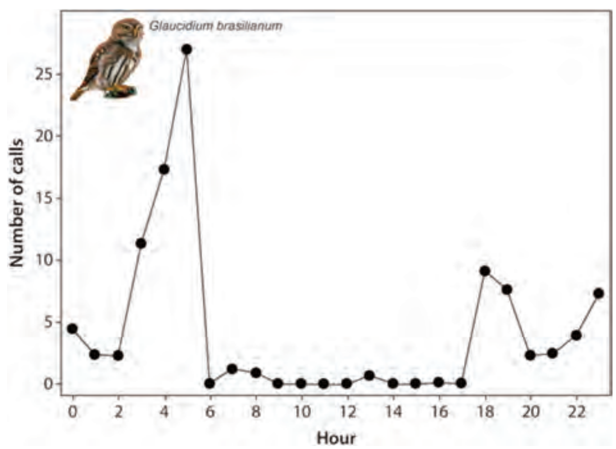

Figure 3. Diel calling activity pattern of the Ferruginous Pygmy-Owl in the Brazilian Pantanal. Calling activity was monitored using autonomous sound recorders from 1 March 2015 to 29 February 2016 at five acoustic monitoring stations. The diel pattern refers to the mean percentage of calls detected during each hour at all stations. Hours are expressed in winter local time (UTC −4). During the period of maximum vocal activity (July-September) sunrise occurred later than 0600 while sunset occurred later than 1700.

Table 2. Estimates of a zero-inflated negative binomial generalized linear mixed model testing the effects of recording time on the calling activity of the Ferruginous Pygmy-Owl in the Brazilian Pantanal. Calling activity was monitored using autonomous sound recorders from 1 March 2015 to 29 February 2016 at five acoustic monitoring stations.

	Estimate	Std. Error	Z value	P
(Intercept)	2.580	0.60	4.30	<0.001
Hour (1)	−0.606	0.86	−0.709	0.479
Hour (2)	−0.663	0.86	−0.775	0.439
Hour (3)	0.946	0.84	1.123	0.261
Hour (4)	1.371	0.84	1.630	0.103
Hour (5)	1.814	0.84	2.159	0.031
Hour (6)	−23.406	14887.2	−0.002	0.998
Hour (7)	−1.299	0.87	−1.491	0.136
Hour (8)	−1.624	0.88	−1.839	0.066
Hour (18)	0.730	0.84	0.866	0.386
Hour (19)	0.555	0.84	0.658	0.511
Hour (20)	−0.663	0.86	−0.775	0.438
Hour (21)	−0.578	0.86	−0.677	0.498
Hour (22)	−0.112	0.85	−0.132	0.895
Hour (23)	0.511	0.84	0.605	0.545

low and constant calling activity between 2000 and 0200 (25.1% of the calls detected) (see Table S2 for hourly call production at each station). The calling activity of the species increased continuously from 0300 to 0500 when the vocal activity of the species reached its maximum (26.9% of the calls detected at 0500, Figure 3). The diel calling activity of the species differed among the recording hours (Table 2), with 0500 being the recording time with the highest number of calls detected (see Fig. S1 for Tukey's post hoc comparison).

Seasonal pattern

The FPO was vocally active throughout the year, but the annual pattern of calling activity showed seasonal and inter-site differences. For example, the dates and months with the highest vocal activity varied greatly between stations (Table 1; see Table S3 for monthly call production at each station). The mean pattern of vocal activity of the species showed a peak between June and August, when 66.3% of the total calls were detected, and a strong reduction occurred from November onwards (Figure 4). The GLMM analyses showed that

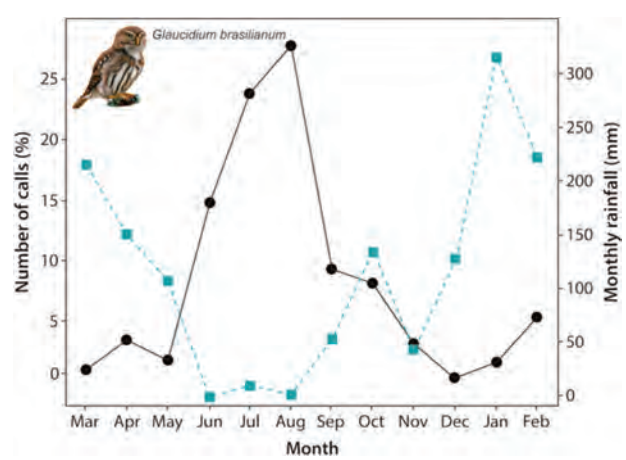

Figure 4. Seasonal calling activity pattern (black circles) of the Ferruginous Pygmy-Owl over an annual cycle in the Brazilian Pantanal. Calling activity was monitored using autonomous sound recorders from 1 March 2015 to 29 February 2016 at five acoustic monitoring stations. The seasonal pattern is expressed as the mean percentage of calls detected at all stations per month (left Y-axis). The monthly accumulated precipitation (mm) (blue squares) according to a weather station located at station B is shown on the right Y-axis.

Table 3. Summary table of type-III partitioning of variances testing the effect of month on the calling activity of the Ferruginous Pygmy-Owl in the Brazilian Pantanal. The effect of month was fitted using a generalized linear mixed model. Calling activity was monitored using autonomous sound recorders from 1 March 2015 to 29 February 2016 at five acoustic monitoring stations.

Fixed effect	Df	Den Df	Sum Sq	Mean Sq	F	P
Month	11	44	12.78	1.162	2.88	0.006

the calling activity of the species significantly differed between months (Table 3); it was significantly high during the months of July and August (see Fig. S2 for Tukey's post hoc comparison).

Discussion

In this study, we describe and analyze the spontaneous calling activity of the FPO over a complete annual cycle at five recording sites in the Brazilian Pantanal. Although several studies on the ecology of this species (e.g. Flesch & Steidl 2006, 2007, 2010; Lima & Lima-Neto 2008; Campioni et al. 2013) are currently available, only one study have assessed the spontaneous calling activity of the species (Pérez-Granados et al. 2021). Our results suggest that the employment of autonomous sound recorders can be a useful tool for monitoring FPOs and that this technique might be especially well suited for detecting population changes (Buxton et al. 2013). This assumption is in agreement with previous studies that found passive acoustic monitoring to be a useful methodology for surveying nocturnal bird species (Frommolt & Tauchert 2014; Schroeder & Mcrae 2020; Pérez-Granados & Schuchmann 2020a), including temperate owls (Shonfield & Bayne 2017; Domahidi et al. 2019; Wood et al. 2019). We would like to highlight that our study was based on a reduced number of sites (five) and thus some of our generalizations may require further research on a larger number of sites to obtain more robust conclusions about the vocal seasonality of the species in the region or in the Neotropics.

The diel pattern of vocal activity of the FPO was restricted to the nocturnal period, with most of the vocalizations uttered after sunset and a second peak (higher) before sunrise. This bimodal pattern is in agreement with those described for several owls (e.g. Lundberg 1980; Delgado & Penteriani 2007) but disagrees with other studies that found that owls were most vocal following sunset (Palmer 1987; Bull et al. 1989; Ganey 1990). Territorial vocal activity by this species during the daytime was almost absent, which is in contrast to the common daily calling activity of the Austral Pygmy-Owl in southern Chile (*Glaucidium nana*, Norambuena & Muñoz-Pedreros 2012). The nocturnal pattern of vocal activity with a large number of vocalizations before sunrise agrees with those found using the same monitoring technique in several nocturnal bird species in the study area, such as the Little Nightjar (*Setopagis parvula*), the Common Pauraque (*Nyctidromus albicollis*) (Pérez-Granados & Schuchmann 2020a), and the Great Potoo (*Nyctibius grandis*, Pérez-Granados & Schuchmann 2020b). It is noteworthy to mention the low number of days in which the FPO was vocally active throughout the monitored annual cycle since the number of vocally active days during the monitored year ranged between 25 and 35 at four of the five monitored stations (Table 1). At station E, the species was only detected on five monitoring days, suggesting that this area was not occupied by a territorial male. Our study suggests that the species might not be easily recorded when performing traditional field surveys without broadcasting calls. Therefore, call-broadcast surveys might be an attractive choice for studies aiming to detect species presence since the probability of detecting the FPO is increased when using recorded calls (Proudfoot & Beasom 1996).

The vocal activity of the FPO showed marked seasonality, with high vocal activity between June and August. This peak of vocal activity may correspond to the courtship, laying and incubation periods of the species in the study area in accordance with the typical increase in owls' vocal activity during these periods (Lundberg 1980; Delgado & Penteriani 2007; Barnes & Belthoff 2008; Zuberogoitia et al. 2019). In contrast, the decrease in vocal activity after August might be related to the fact that FPO males tend to vocalize less often during the onset of brooding and the nestling period than during other periods (Proudfoot & Johnson 2000; Flesch & Steidl 2007), which is likely because they invest more time hunting for and feeding the nestlings, consistent with patterns found in other owls during nesting periods (Delgado & Penteriani 2007; Zuberogoitia et al. 2019). This suggests that the nesting phase of the species in the Brazilian Pantanal starts at the end of the dry season (Figure 4), consistent with previous studies that declared that the FPO laid during the dry to early wet season (Holt et al. 2020). The FPO is considered to be a generalist predator that utilizes different prey according to region and season, but its diet is mainly composed of small mammals, birds, and insects (Proudfoot & Beasom 1997; Carrera et al. 2008; Sarasola & Santillán 2014). The proposed period of nesting activity occurred from September onwards, a period that corresponds with an increase in Coleoptera abundance in the Brazilian Pantanal (Marques et al. 2010, 2011; Carneiro et al. 2016) due to the positive effect of the first rainfalls (which took place in September during the monitored annual cycle, Figure 4) on insect abundance (Wolda 1978; Jetz et al. 2003). However, we have no observational data to confirm the proposed seasons of incubation and nesting activity.

According to our results, we recommend that park managers and scientists aiming to monitor the FPO use traditional techniques (e.g. broadcast calls to increase probability detection) or autonomous sound recorders and that future surveys should be carried out during the end of the dry season (June-August in the Brazilian Pantanal) and during the hour prior to sunrise since these months and hours are the optimal periods for detecting this species. The low spontaneous vocal activity of the species suggests that a combined methodology using autonomous sound recorders and playback equipment, programmed to broadcast at periods of interest, may be a good method to increase the probability of detecting the species.

This study improves our understanding of the vocal behavior of Neotropical nocturnal birds and the spontaneous vocal activity of owls, two topics that have been poorly studied to date (but see Odom & Mennill 2010; Baldo & Mennill 2011; Koloff & Mennill 2013; Zuberogoitia et al. 2019; Pérez-Granados & Schuchmann 2020b). Here, we demonstrated that the use of autonomous sound recorders, coupled with signal recognition software, can be a useful technique for monitoring the calling activity of owls without altering their behavior with broadcasted calls. Monitoring the vocal activity of the FPO would have been difficult using traditional field surveys due to the nocturnal habit of the species and its low vocal activity. This technique allows researchers to evaluate the relationships between the vocal activity of owls and weather conditions and moon phases, an interesting topic for which available information is very limited (Braga & Motta-Junior 2009; Pérez-Granados et al. 2021). Long-term monitoring programs aiming to monitor the FPO or other nocturnal bird species should evaluate passive acoustic monitoring as a reliable tool for detecting spatial movements (Blumstein et al. 2011) or population declines (Buxton et al. 2013) or assessing the habitat selection of the selected species (Ethier & Wilson 2019).

Acknowledgments

We thank the SESC Pantanal, Mato Grosso, for permission to conduct research on their property and their logistical help with our fieldwork. This study is part of the biodiversity monitoring project Sounds of the Pantanal–The Pantanal Automated Acoustic Biodiversity Monitoring of INAU, Cuiabá, Mato Grosso, Brazil, which was conducted under SISBIO permit no. 39095 (KLS). We also thank Iñigo Zuberogoitia and two anonymous reviewers whose comments helped to improve the manuscript.

Disclosure statement

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

Funding

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior–Brasil (CAPES)-Finance Code 01; Instituto Nacional de Ciência e Tecnologia em Áreas Úmidas (INAU/UFMT/CNPq); Centro de Pesquisa do Pantanal (CPP); and Brehm Funds for International Bird Conservation (BF), Bonn, Germany.

ORCID

Cristian Pérez-Granados http://orcid.org/0000-0003-3247-4182
Karl-L. Schuchmann http://orcid.org/0000-0002-3233-8917
Marinez I. Marques http://orcid.org/0000-0002-9890-8505

References

Baldo S, Mennill DJ. 2011. Vocal behavior of Great Curassows, a vulnerable Neotropical bird. J Field Ornithol. 82(3):249–258.
Barnes KP, Belthoff JR. 2008. Probability of detection of Flammulated Owls using nocturnal broadcast surveys. J Field Ornithol. 79:321–328.
Bates D, Maechler M, Bolker B, Walker S. 2015. lme4: linear mixed-effects models using Eigen and S4. R package version 1.1_7. Institute for Statistics and Mathematics of WU website. Available from: http://cran.r-project.org/package=lme4.
Blumstein DT, Mennill DJ, Clemins P, Girod L, Yao K, Patricelli G, Deppe JL, Krakauer AH, Clark C, Cortopassi KA, et al. 2011. Acoustic monitoring in terrestrial environments using microphone arrays: applications, technological considerations and prospectus. J App Ecol. 48(3):758–767. doi:10.1111/j.1365-2664.2011.01993.x.
Braga ACR, Motta-Junior JC. 2009. Weather conditions and moon phase influence on Tropical Screech Owl and Burrowing Owl detection by playback in southeast Brazil. Ardea. 97(4):395–401.
Brooks ME, Kristensen K, van Benthem KJ, Magnusson A, Berg CW, Nielsen A, Skaug HJ, Mächler M, Bolker BM. 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R J. 9:378–400.
Bull EL, Wright AL, Henjum MG. 1989. Nesting and diet of long-eared Owls in conifer forests, Oregon. Condor. 91 (4):908–912.

Buxton RT, Major HL, Jones IL, Williams JC. 2013. Examining patterns in nocturnal seabird activity and recovery across the Western Aleutian Islands, Alaska, using automated acoustic recording. Auk. 130(2):331–341.

Campioni L, Sarasola JH, Santillán M, Reyes MM. 2013. Breeding season habitat selection by Ferruginous Pygmy Owls *Glaucidium brasilianum* in central Argentina. Bird Study. 60(1):35–43.

Carneiro AC, Batistella DA, Battirola LD, Marques MI. 2016. Pitfall traps and mini-winkler extractor as complementary methods to sample soil Coleoptera. Neotrop Entomol. 45 (1):28–32.

Carrera JD, Fernández FJ, Kacoliris FP, Pagano L, Berkunsky I. 2008. Field notes on the breeding biology and diet of Ferruginous Pygmy-Owl (*Glaucidium brasilianum*) in the dry Chaco of Argent*ina*. Ornitol Neotrop. 19 (2):315–319.

Conway CJ, Simon JC. 2003. Comparison of detection probability associated with burrowing owl survey methods. J Wildlife Manage. 67(3):501–511.

Delgado MDM, Penteriani V. 2007. Vocal behaviour and neighbour spatial arrangement during vocal displays in eagle owls (*Bubo bubo*). J Zool. 2*71*(1):3–10.

Domahidi Z, Shonfield J, Nielsen S, Spence J, Bayne E. 2019. Spatial distribution of the Boreal Owl and Northern Saw-whet Owl in the Boreal region of Alberta, Canada. Avian Conserv Ecol. 14(2):14.

Ethier JP, Wilson DR. 2019. Using microphone arrays to investigate microhabitat selection by declining breeding birds. Ibis. doi:10.1111/ibi;12785.

Farnsworth A, Russell RW. 2007. Monitoring flight calls of migrating birds from an oil platform in the northern Gulf of Mexico. J Field Ornithol. 78(3):279–289.

Flesch AD, Steidl RJ. 2006. Population trends and implications for monitoring cactus ferruginous pygmy owls in northern Mexico. J Wildlife Manage. 70(3):867–871.

Flesch AD, Steidl RJ. 2007. Detectability and response rates of Ferruginous Pygmy-Owls. J Wildlife Manage. 71 (3):981–990.

Flesch AD, Steidl RJ. 2010. Importance of environmental and spatial gradients on patterns and consequences of resource selection. Ecol Appl. 20:1021–1039.

Freeman SN, Balmer DE, Crick HQP. 2006. On the censusing of Tawny Owl *Strix aluco*. Bird Census News. 19:58–62.

Frommolt KH, Tauchert KH. 2014. Applying bioacoustic methods for long-term monitoring of a nocturnal wetland bird. Ecol Inform. 21:4–12.

Ganey JL. 1990. Calling behavior of spotted owls in northern Arizona. Condor. 92(2):485–490.

Goyette JL, Howe RW, Wolf AT, Robinson WD. 2011. Detecting tropical nocturnal birds using automated audio recordings. J Field Ornithol. 82(3):279–287.

Holt DW, Berkley R, Deppe C, Enríquez Rocha P, Petersen JL, Rangel Salazar JL, Segars KP, Wood KL, Christie DA, Kirwan GM. 2020. Ferruginous Pygmy-owl (*Glaucidium brasilianum*). In: del Hoyo J, Elliott A, Sargatal J, Christie DA, De Juana E, editors. Handbook of the Birds of the world alive. Barcelona: Lynx Edicions.

Hothorn T, Bretz F, Westfall P. 2008. Simultaneous inference in general parametric models. Biometrical J. 50:346–363.

Jetz W, Steffen J, Linsenmair KE. 2003. Effects of light and prey availability on nocturnal, lunar and seasonal activity of tropical nightjars. Oikos. 103(3):627–639.

Johnson RR, Cartron JLE, Haight LT, Duncan RB, Kingsley KJ. 2003. Cactus ferruginous pygmy-owl in Arizona, 1872–1971. Southwest Nat. 48(3):389–401.

Junk WJ, Da Cunha CN, Wantzen KM, Petermann P, Strüssmann C, Marques MI, Adis J. 2006. Biodiversity and its conservation in the Pantanal of Mato Grosso, Brazil. Aquat Sci. 68(3):278–309.

Kissling ML, Lewis SB, Pendleton G. 2010. Factors influencing the detectability of forest owls in southeastern Alaska. Condor. 112(3):539–548.

Koloff J, Mennill DJ. 2013. Vocal behaviour of Barred Antshrikes, a Neotropical duetting suboscine bird. J Ornithol. 154(1):51–61.

König C, Weick F. 2008. Owls of the world. London: Christopher Helm.

Kuznetsova A, Brockhoff PB, Christensen RHB. 2014. lmerTest: tests for random and fixed effects for linear mixed effect models (lmer objects of lme4 package). R package version 2.0_11.

Larsen R. 2012. Ferruginous Pygmy-Owl (*Glaucidium brasilianum)*, version 1.0. In: Schulenberg TS, editor. Neotropical birds Online. Ithaca (NY): Cornell Lab of Ornithology.

Lima PC, Lima-Neto TNC. 2008. O comportamento reprodutivo do caburé *Glaucidium brasilianum* (Gmelin, 1788) no Litoral Norte da Bahia: um ensaio foto gráfico. Atualidades Ornitol. 141:65–86.

Lincer JL, Clark RJ, Fleming TL, Sieradzki A. 2018. A review of burrowing owl (*Athene cunicularia*) literature using bibliometric comparisons: topical bibliographies and online databases. J Raptor Res. 52:207–224.

Lundberg A. 1980. Vocalizations and courtship feeding of the Ural Owl *Strix uralensis*. Ornis Scandinavica. 11(1):65–70.

Marques MI, Souza O, Bb DS, Battirola LD, Anjos KC. 2010. Fauna de Artrópodes de Solo. In: Fernandez I, Signor C, Penha J, editors. Biodiversidade do Pantanal de Poconé. 1st ed. Manaus: Athema. p. 73–102.

Marques MI, Adis J, Battirola LD, Santos GB, Castilho ACD. 2011. Arthropods associated with a forest of Attalea phalerata Mart. (Arecaceae) palm trees in the northern Pantanal of the Brazilian state of Mato Grosso. In: Junk WJ, Da-Silva CJ, Nunes-da-Cunha C, Wantzen KM, editors. The Pantanal of Mato Grosso: ecology, biodiversity and sustainable management of a large neotropical seasonal wetland. 1st ed. Sofia-Moscow: Pensoft. p. 431–468.

Norambuena HV, Muñoz-Pedreros A. 2012. Diurnal activity of the Austral Pygmy Owl (*Glaucidium nana*) in southern Chile. Wilson J Ornithol. 124(3):633–635.

Odom KJ, Mennill DJ. 2010. A quantitative description of the vocalizations and vocal activity of the Barred Owl. Condor. 112(3):549–560.

Palmer DA. 1987. Annual, seasonal, and nightly variation in calling activity of Boreal and Northern Saw-whet owls. In: Nero RW, Clark RJ, Knapton RJ, Hamre RH, editors. Biology and conservation of northern forest owls. U.S. For. Serv. Gen. Tech. Rep. RM-142. Fort Collins (CO): Rocky Mountain Forest and Range Experiment Station. p. 162–169.

Pérez-Granados C, Bota G, Giralt D, Albarracín J, Traba J. 2019. Cost-effectiveness assessment of five audio recording systems for wildlife monitoring: differences between recording distances and singing direction. Ardeola. 66 (2):311–325.

Pérez-Granados C, Schuchmann K-L. 2020a. Illuminating the nightlife of two Neotropical nightjars: vocal behavior over a year and monitoring recommendations. Ethol Ecol Evol. 32(5):466–480.

Pérez-Granados C, Schuchmann K-L. 2020b. Monitoring the annual vocal activity of two enigmatic nocturnal Neotropical birds: the Common Potoo (*Nyctibius griseus*) and the Great Potoo (*Nyctibius grandis*). J Ornithol. 161 (4):1129–1141.

Pérez-Granados C, Schuchmann K-L, Marques MI. 2020. Vocal behavior of the Undulated Tinamou (*Crypturellus undulatus*) over an annual cycle in the Brazilian Pantanal: new ecological information. Biotropica. 52(1):165–171.

Pérez-Granados C, Schuchmann K-L, Marques MI. 2021. Vocal activity of the Ferruginous pygmy-owl (*Glaucidium brasilianum*) is strongly correlated with moon phase and nocturnal temperature. Ethol Ecol Evol. 33(1):62–72.

Proudfoot GA, Johnson RR. 2000. Ferruginous pygmy-owl. *Glaucidium brasilianum*. In: Poole A, editor. The birds of North America Online: Article 498. Ithica (NY): Cornell Lab of Ornithology.

Proudfoot GA, Johnson RR, Larsen R. 2020. Ferruginous Pygmy-Owl (*Glaucidium brasilianum)*, version 1.0. In: Billerman SM, editor. Birds of the World. Ithaca (NY): Cornell Lab of Ornithology.

Proudfoot GA, Beasom SL. 1996. Responsiveness of cactus ferruginous pygmy-owls to broadcasted conspecific calls. Wildlife Soc Bull. 24:294–297.

Proudfoot GA, Beasom SL. 1997. Food habits of nesting ferruginous pygmy-owls in southern Texas. Wilson Bull. 109(4):741–748.

R Development Core Team. 2016. R: a language and environment for statistical computing. Vienna (Austria): R Foundation for Statistical Computing. Available from: http://www.R-project.org.

Rempel RS, Francis CM, Robinson JN, Campbell M. 2013. Comparison of audio recording system performance for detecting and monitoring songbirds. J Field Ornithol. 84 (1):86–97.

Sarasola JH, Santillán MÁ. 2014. Spatial and temporal variations in the feeding ecology of ferruginous pygmy-owls (*Glaucidium brasilianum*) in semiarid forests of central Argentina. J Arid Environ. 109:39–43.

Schmutz JK. 2001. Burrowing Owl population-trend surveys in southern Alberta: 1991–2000. J Raptor Res. 35 (4):310–315.

Schroeder KM, Mcrae SB. 2020. Automated auditory detection of a rare, secretive marsh bird with infrequent and acoustically indistinct vocalizations. Ibis. 162:1033–1046. doi:10.1111/ibi.12805.

SEO/BirdLife. 2019. Programas de seguimiento y grupos de trabajo de SEO/BirdLife 2018. Madrid: SEO/BirdLife.

Shonfield J, Bayne EM. 2017. The effect of industrial noise on owl occupancy in the boreal forest at multiple spatial scales. Avian Conserv Ecol. 12(2):13.

Shonfield J, Heemskerk S, Bayne EM. 2018. Utility of automated species recognition for acoustic monitoring of owls. J Raptor Res. 52(1):42–55.

Sugai LSM, Silva TSF, Ribeiro Jr JW, Llusia D. 2019. Terrestrial passive acoustic monitoring: review and perspectives. BioScience. 69(1):15–25.

Wolda H. 1978. Fluctuations in abundance of tropical insects. Amer Nat. 112(988):1017–1045.

Wood CM, Gutiérrez RJ, Peery MZ. 2019. Acoustic monitoring reveals a diverse forest owl community, illustrating its potential for basic and applied ecology. Ecology. 100: e02764.

Zuberogoitia I, Burgos G, González-Oreja JA, Morant J, Martínez JE, Zabala Albizua J. 2019. Factors affecting spontaneous vocal activity of Tawny Owls *Strix aluco* and implications for surveying large areas. Ibis. 161 (3):495–503.

Zuberogoitia I, Campos LF. 1998. Censusing owls in large areas: a comparison between methods. Ardeola. 45 (1):47–53.