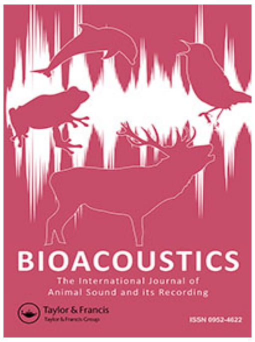

Bioacoustics

The International Journal of Animal Sound and its Recording

ISSN: 0952-4622 (Print) 2165-0586 (Online) Journal homepage: www.tandfonline.com/journals/tbio20

Acoustic activity monitoring of the Magellanic Woodpecker, an indicator species from the temperate forests of South America

Felipe N. Moreno-Gómez, Javiera Carrasco-Rojas, José Bartheld, Rodrigo Gutiérrez & Mario Penna

To cite this article: Felipe N. Moreno-Gómez, Javiera Carrasco-Rojas, José Bartheld, Rodrigo Gutiérrez & Mario Penna (19 Oct 2025): Acoustic activity monitoring of the Magellanic Woodpecker, an indicator species from the temperate forests of South America, Bioacoustics, DOI: 10.1080/09524622.2025.2571647

To link to this article: https://doi.org/10.1080/09524622.2025.2571647

BIOACOUSTICS
https://doi.org/10.1080/09524622.2025.2571647

Acoustic activity monitoring of the Magellanic Woodpecker, an indicator species from the temperate forests of South America

Felipe N. Moreno-Gómez[a], Javiera Carrasco-Rojas[a], José Bartheld[b], Rodrigo Gutiérrez[c] and Mario Penna[d]

[a]Laboratorio de Ecología y Bioacústica, Departamento de Biología y Química, Facultad de Ciencias Básicas, Universidad Católica del Maule, Talca, Chile; [b]STRIX, Monitoreo Biológico, Puerto Montt, Chile; [c]Departamento de Matemática, Física y Estadística, Facultad de Ciencias Básicas, Universidad Católica del Maule, Talca, Chile; [d]Programa de Fisiología y Biofísica, Instituto de Ciencias Biomédicas, Facultad de Medicina, Universidad de Chile, Santiago, Chile

ABSTRACT
Woodpeckers are a bird group having a key role in ecosystems and which also serve as indicators of habitat quality. Woodpeckers are easily detected by characteristic sounds that comprise vocalisations and drumming. The analyses of massive data resulting from passive acoustic monitoring (PAM) requires sound automated recognition methods, among which BirdNET is becoming the most used algorithm. The Magellanic Woodpecker is an endemic species from the temperate forests in Chile and Argentina. It is the largest woodpecker from South America and its role as an indicator of forest condition and also as an ecosystem engineer has been well established. The current study has two main objectives: 1) to describe the acoustic activity patterns of the Magellanic Woodpecker through PAM and 2) to evaluate the use of BirdNET for the automated analysis of data resulting from PAM on this species. Our data indicate that the sounds produced by the Magellanic Woodpecker have different temporal patterns and our analyses suggest that a manual processing of PAM data is needed for a preliminary characterisation of the sound activity patterns. Our study indicates that training BirdNET with local data enhances the recognition of Magellanic Woodpecker sounds.

ARTICLE HISTORY
Received 10 March 2025
Accepted 2 October 2025

KEYWORDS
Campephilus magellanicus; BirdNET; deep learning; acoustic activity patterns

Introduction

Several bird species use acoustic signals to mediate social interactions occurring in a variety of contexts including mating, parental care, foraging and territory defence (e.g. Marler and Slabbekoorn 2004; Podos and Webster 2022). In general, species produce distinctive signals that can be used to assess the occurrence of those taxa in a given area. These signals are more often produced at specific times of the day, leading to diel patterns that are also subjected to seasonal variation (Tremain et al. 2008; Pérez-Granados and Schuchmann 2021; Morales et al. 2022; Moreno-Gómez et al. 2024). Establishing such acoustic activity patterns contributes a behavioural baseline needed

CONTACT Felipe N. Moreno-Gómez ✉ f.n.moreno.gomez@gmail.com

for the assessment of monitoring trends, allowing to determine the occurrence of perturbations on the ecosystems in which species dwell, and also to design proper conservation measures by considering the time frames when higher acoustic activity occurs (Ducrettet et al. 2020; Lewis et al. 2021; Mariton et al. 2023; Cretois et al. 2024; Oestreich et al. 2024; Wrege et al. 2024).

Recent developments of ecoacoustic tools (Sueur and Farina 2015) based on passive acoustic monitoring (PAM) allow to study acoustic activity patterns without disrupting the normal behaviour of individuals (e.g. Folliot et al. 2022). The analyses of massive data obtained with PAM require automated recognition methods, among which deep convolutional neural networks have yielded leading results in bird sound classification tasks (Stowell 2022; Xie et al. 2022). Currently, the use of these algorithms for sound recognition has highly increased due to the development of BirdNET, an informatics tool readily accessible to the scientific community as it can be implemented without programming skills (Kahl et al. 2021; Pérez-Granados 2023; Sethi et al. 2024). The default BirdNET model can recognise more than 6000 species worldwide, however most of the taxa included are from the Northern Hemisphere. In addition, the BirdNET algorithm can be trained with local data to obtain customised models that may enhance its detection performance (Kahl et al. 2021; Symes et al. 2024). Recent assessments have revealed that this recogniser requires cautious use in order to obtain reliable monitoring trends, especially for rare species (Pérez-Granados 2023; Funosas et al. 2024). Although signals automatically recognised by BirdNET can be easily validated by researchers, allowing to calculate performance metrics associated to correct and wrong detections (i.e. true positives and false positives, respectively), analysing the performance on manually annotated datasets is needed to obtain performance metrics involving signals missed by the recogniser (i.e. false negatives), which is of importance to evaluate the uncertainty in the classifying task. As such, an evaluation of BirdNET default and custom models with manual annotated datasets is necessary to obtain a more accurate assessment of its potential when serving as a tool for ecoacoustic studies on rare bird species.

Woodpeckers are a bird group having a key role in forest ecosystems (e.g. Virkkala 2006). These birds are known as ecosystem engineers as they excavate trees for nesting and the cavities are thereafter used by other species as resources for different activities (e.g. Hammond and Theimer 2020; Hardin et al. 2021; Trzcinski et al. 2022; Alaniz et al. 2024). In addition, woodpeckers are highly susceptible to forest successional stages and degradation, as old-growth forests provide crucial food and nesting resources for some species. Their dependence on habitat quality allows us to use woodpeckers as bioindicators (e.g. Virkkala 2006; Stachura-Skierczyńska and Kosiński 2016; Walsh et al. 2019; Alaniz et al. 2021; Menon and Shahabuddin 2021). Woodpeckers are easily detected by characteristic sounds that comprise vocalisations and drumming (Short and Sandstrom 1982). Woodpecker vocalisations can be variable and have different functions related to reproduction, socialisation and territoriality (Soto et al. 2016). Drumming is a non-vocal acoustic signal associated with mate attraction and territoriality, allowing communication over longer distances relative to vocalisations (Stark et al. 1998; Tremain et al. 2008).

Studies using PAM describing the acoustic activity patterns of woodpeckers are still being developed. The study of Folliot et al. (2022) performed in Alpine Forest, France, reported that most drumming activity occurred within three months, following a diurnal pattern with the highest activity after sunrise, nevertheless the study did not discriminate among the three local species Black Woodpecker (*Dryocopus martius*), Great Spotted Woodpecker (*Dendrocopos major*) and Three-toed Woodpecker (*Picoides tridactylus*). The study of Singer et al. (2025) in Lower Saxony, Germany, include six species and found that all of them were diurnal, however, while most acoustic activity occurred after sunrise for the Lesser Spotted Woodpecker (*Dryobates minor*), the Great Spotted Woodpecker (*Dendrocopos major*) and the Grey-headed Woodpecker (*Picus canus*), for the Middle Spotted Woodpecker (*Dendrocoptes medius*) the highest activity also encompassed morning hours, and for the Black Woodpecker (*Dryocopus martius*) and the European Green Woodpecker (*Picus viridis*) an additional peak may be observed during the afternoon or near sunset hours. However, this study did not differentiate between signal types produced by the different species. Another study by Zeller et al. (2024) on the Pileated Woodpecker (*Dryocopus pileatus*) from Alberta, Canada, reported a seasonal drumming pattern related to breeding that has a main peak of activity one hour after sunrise and a secondary peak around dusk. The study of Gaylord et al. (2023) on the White-headed Woodpecker (*Dryobates albolarvatus*) in Oregon, USA, reported a diurnal vocalisation pattern having two peaks, around sunrise and sunset. These acoustic activity patterns can be accounted for by complementary hypotheses such as the Acoustic adaptation hypothesis (AAH, Morton 1975) and the Sound transmission hypothesis (STH). While the AAH proposes that signal characteristics should enhance transmission and as such low-frequency sounds are favoured for long-distance communication, the STH predicts that stable atmospheric conditions around dawn would favour signal propagation (reviewed in Bradbury and Vehrencamp 2011; Gil and Llusia 2020).

The Magellanic Woodpecker *Campephilus magellanicus* (King 1828) is an endemic species from the temperate forests in Chile and Argentina, being the largest woodpecker from South America (Short 1970; Stotz 1996). The species generally inhabits old-growth *Nothofagus* spp. forests using nests excavated in tree trunks, and feeds mainly on wood-boring larvae and other insects. The breeding season occurs between spring and summer. They are monogamous and show extended parental care, as juveniles can stay with their parents for about two years (reviewed in Chazarreta and Ojeda 2020). Its role as an indicator of forest condition and also as an ecosystem engineer has been well established, this is because different properties of its population dynamics depend on habitat quality and because is the largest primary cavity excavator of these forests (Ojeda 2004; Schlatter and Vergara 2005; Ojeda et al. 2011; Vergara et al. 2016, 2017, 2019; Altamirano et al. 2017; Alaniz et al. 2021; Wynia et al. 2025). This species produces different vocalisations in social contexts and in response to predators' threats. Non-vocal sound includes a distinctive double drum (hereafter drumming) that has a territorial function, and a rhythmic tapping (hereafter tapping) when foraging (Short 1970). This last sound may be confounded with the sound produced by the sympatric Striped Woodpecker (*Veniliornis lignarius*), however this species has a softer, rhythmic and faster sound (reviewed in Chazarreta and Ojeda 2020). Regarding the conservation status, the IUCN classifies the Magellanic Woodpecker as Least Concern, but also indicates that its abundance shows a decreasing trend due to the reduction in forest coverage (IUCN 2024). In Chile, this bird is listed as Endangered or Vulnerable throughout its distribution (Servicio Agrícola y Ganadero 2015). As the Magellanic Woodpecker is considered an indicator of old-growth forest condition and also an ecosystem engineer, and because it can be detected by its acoustic signals, using ecoacoustic monitoring tools may contribute to obtain valuable information for its conservation and for the ecosystem functions that provides. In particular, the description of the acoustic activity patterns would constitute a behavioural baseline for the assessment of monitoring trends, and the use of easily implemented automated recognition tools such as BirdNET would facilitate the analysis of large datasets produced by PAM. As such, the current study has two main objectives: 1) to describe the acoustic activity patterns of the Magellanic Woodpecker through PAM and 2) to evaluate the use of BirdNET for the automated analysis of data resulting from PAM on this species. We expect that this information will contribute appropriate methodology for ecoacoustic monitoring of endemic species serving as ecological indicators.

Methods

Study site and acoustic monitoring

The study was conducted in the Altos de Lircay National Park (35°36’21.11”S, 70° 57’58.56”W), located in Región del Maule, Chile, during three months within the austral spring and summer seasons. The study was conducted under the authorisation of Corporación Nacional Forestal, CONAF. PAM was performed during 10 consecutive days of each month, specifically between 6 and 15 of December 2020, between 4 and 13 of January 2021, and between 4 and 13 of February 2021. Six acoustic recording units (ARUs) SM4 (Wildlife Acoustics) were installed attached to tree trunks at a height of around 5 m. The distance between neighbouring recorders was at least 300 m, and also a distance of at least 50 m was kept from the walking trail (S1: 35°35'30.17'S, 70° 59'32.28'W; S2: 35°35'37.09'S, 70°59'42.02'W; S3: 35°35'41.34'S, 70°59'55.84'W; S4: 35° 35'36.26'S, 71° 0'6.48'W; S5: 35°35'31.69'S, 71° 0'17.77'W; S6: 35°35'37.86'S, 71° 0'29.05'W, Figure 1). ARUs were set to record 1 min every 10 min 24/7, although the Magellanic Woodpecker is described as a diurnal species (reviewed in Chazarreta and Ojeda 2020), such that the recording schedule employed would contribute to the characterisation of its diel activity pattern. Recordings were made at a sampling rate of 44,100 Hz, which allows to record frequencies up to 22,050 Hz, a range that encompasses the birds occurring in Chilean forest ecosystems (e.g. Bartheld et al. 2011; Moreno-Gómez et al. 2024) and therefore may foster further studies on other species using these recordings. One ARU (S1) failed to record during the last month. The recordings were made during COVID-19 restrictions on the entrance of tourist access to the national park, and therefore anthropogenic perturbations were likely reduced during sampling.

Analysis of audio files

The files were manually analysed using Raven Pro 1.5 (Bioacoustics Research Programme 2011). Spectrograms were used to annotate the occurrence of sounds produced by the Magellanic Woodpecker. These sounds were classified as vocalisation, drumming or tapping (Figure 2). However, the latter may also include sounds of the Striped Woodpecker, a species that can be found in the study area. A 1-s interval was the minimum time allowed between consecutive selections. In total, 24,477 1-min audio files were analysed. The R (R Core Team, 2014) library suncalc (Thieurmel and

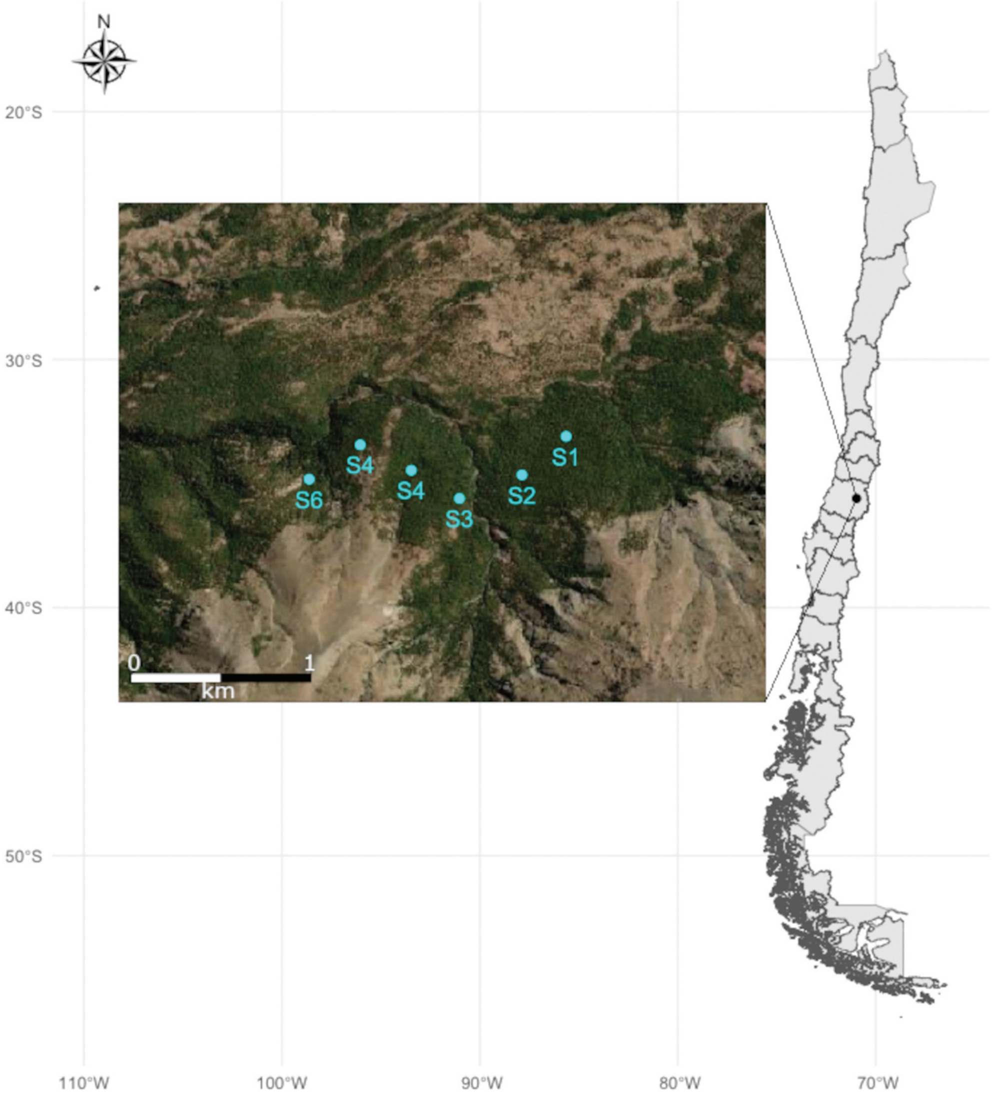

Figure 1. ARUs sampling stations within the Altos de Lircay National Park, Región del Maule, Chile.

Elmarhraoui 2022) was used to obtain the sunrise and sunset time of each recording day, allowing to compute the time each audio file as hours after sunrise and to obtain the daylight length.

Acoustic diel patterns

The diel pattern of vocalisations, drumming and tapping for each month was estimated by cyclic cubic spline hierarchical generalised additive mixed-effects models using the bam function from the mgcv R library (Wood 2017) and following the recent guide of Iannarilli et al. (2024), which allowed more versatile analyses of activity patterns as compared to kernel density estimators (Gilbert and Dominoni 2025). For each sound

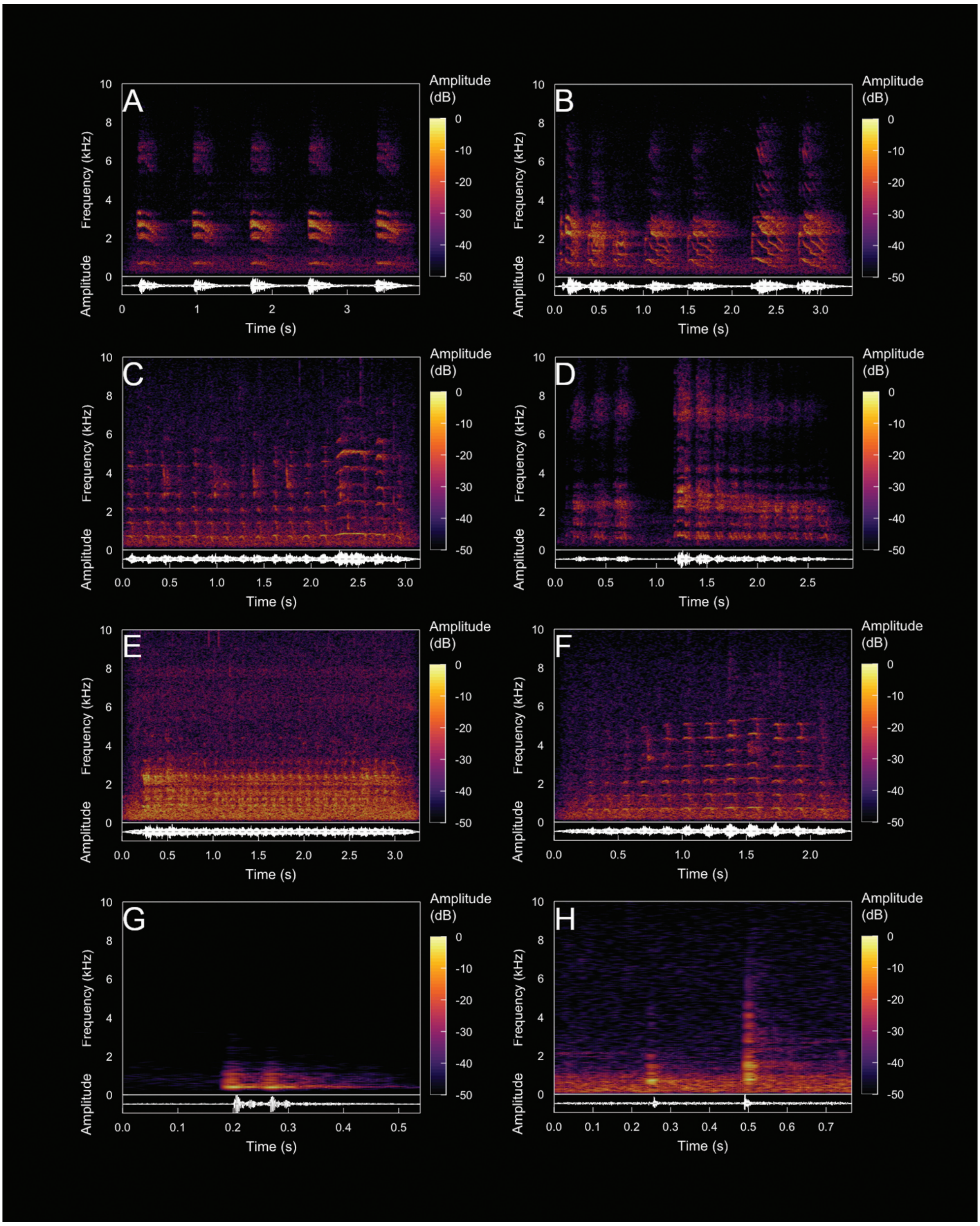

Figure 2. Examples of sounds produced by the Magellanic Woodpecker. From A to F: vocalisations, G: drumming, H: tapping.

type, three models were fitted considering a binomial family distribution. The first model (M1) included a cyclic cubic smoother for the hour, which also varied across months, therefore this model represents a case in which each month shows a different diel pattern. The second model (M2) included only a smoother for the hour, representing a case in which the diel pattern does not vary throughout months. The third model (M3) did not include any temporal smoother, therefore corresponding to the null model, in which no temporal variation occurs. In all models, a smoother for the sampling station was included as a random intercept. The model set for each type of sound was evaluated by Akaike Information Criteria using the function AICtab from the bbmle library (Bolker and R Development Core Team 2023). Plots for the best ranked model were made by using the library ggplot2 (Wickham 2016).

Evaluation of the BirdNET algorithm

We used BirdNET model V2.4 as implemented by the BirdNET Analyzer GUI 1.3.1, which by default includes the Magellanic Woodpecker among the list of species that can be recognised. In addition, we trained a custom BirdNET model with our dataset. To achieve this, the manual annotations were first revised to avoid highly masked sounds. This led to a dataset of 257 1-min files containing vocalisations and 395 1-min files containing drumming. The tapping was not considered for this analysis as these sounds are not species specific. Thereafter, the audio files having detections of vocalisations and drumming were randomly partitioned into a train (70%) and test (30%) datasets using the function ‘sample’ from R. Also, a subset of 340 1-min audio files devoid of sounds of Magellanic Woodpecker (hereafter ‘noise files’) were randomly obtained and partitioned considering this same proportion. A custom R script was used to extract all the audio segments having vocalisations, drumming and noise (3 s). In addition, a list of potential bird species occurring in the study site for the entire year according to the eBird database (Sullivan et al. 2009) was obtained using a function implemented in the BirdNET Analyser GUI. This list was then used to download all the available calls recorded in Chile from the xeno-canto database (www.xeno-canto.org., accessed on 27 December 2024) using the R function query_xc from the warbleR library (Araya-Salas and Smith-Vidaurre 2017), hereafter ‘other species’. In total, 3811 audio files from other species were downloaded. The custom BirdNET model was trained to recognise vocalisations and drumming, and the noise and other species audio files were considered as non-target sounds (Symes et al. 2024). The training was performed with autotune for hyperparameter search considering 50 trials and 10 executions per trial. In addition, a frequency filter between 0 and 4.5 kHz was employed in order to exclude frequencies outside the range of the most important frequency range of the target acoustic signals. The confidence score was set to the default value, i.e. 0.5.

Thereafter, the test datasets were used to evaluate the performance of both our custom model and the default model for the Magellanic Woodpecker. To achieve this, the files from the noise test dataset were included into both vocalisation and drumming test datasets in order to include files devoid of Magellanic Woodpecker sounds. Then, we tested separately the performance in detecting files of the vocalisations and drumming test datasets. A manual review of all detections was made using the Review tab implemented in the BirdNET Analyzer GUI. The classification performance was assessed by two metrics: precision and recall. Precision was calculated by TP/(TP+FP) and recall by TP/(TP+FN) (e.g. Cole et al. 2022), where true positives (TP), false positives (FP), and false negatives (FN). TPs were obtained by considering at least one correct sound identification in the 1-min recording. FPs were obtained from wrong detections. FNs were obtained from the number of 1-min recordings having target sounds but where none was detected. Both metrics yield values between 0 and 1, but for an easier interpretation both metrics are also expressed as percentages. While precision indicates how good the model is in terms of correct identification, recall indicates how good the model is to identify all target acoustic signals contained in the data set (e.g. Buckland and Gey 1994).

Results

Diel sound patterns

Magellanic Woodpecker sounds were manually detected in 1071 audio-files, corresponding to 4.4% of the total files that were audio-visually analysed. Within these files, vocalisations occurred in 371 files, drumming in 512 and tapping in 302 files. For all three sound types, the top ranked model corresponded to M1 having delta-AIC values and weights providing high support for the effects of hour and month, thus showing diel patterns with peaks at specific hours that may differ between months (Table 1). Neither sound type was detected at night hours indicating a diurnal pattern of activity, however some detections occurred around crepuscular hours (Figure 3). For vocalisations, the pattern was slightly bimodal during December, having peaks around sunrise and around 12 hours after sunrise. During January, the pattern changed showing three peaks, i.e. around sunrise, 4 hours after sunrise and around sunset. In February, the vocalisation pattern also showed three peaks, i.e. around 2, 8 and 13 hours after sunrise. For drumming, the pattern in December was relatively homogeneous during sunlight hours, while in January a more pronounced peak was observed around one hour after sunrise, and during February the larger peak occurred at around sunrise hour. The tapping sound showed three peaks during December, i.e. around sunrise, 4 and 13 hours after sunrise. During January, these three peaks were less marked. During February, a fourth peak appeared around 7 hours after sunrise.

BirdNET performance

Results for the evaluation of the BirdNET algorithm show that the custom model outperformed the default model. While the custom model correctly recognised 61.0% of the vocalisation test dataset and 38.7% of the drumming test dataset, the

Table 1. Model selection to evaluate models aiming to estimate the diel activity pattern of sounds produced by the Magellanic Woodpecker (the tapping may also correspond to sounds produced by other woodpeckers in the study area, see text).

Sound type	Model	Delta AIC	df	Weight
Vocalisation	M1	0	38.7	1
	M2	27.5	19.0	<0.001
	M3	364.8	5.7	<0.001
Drumming	M1	0	44.4	1
	M2	25.9	20.5	<0.001
	M3	655.2	6.0	<0.001
Tapping	M1	0	38.8	0.991
	M2	9.4	18.9	0.009
	M3	335.7	5.9	<0.001

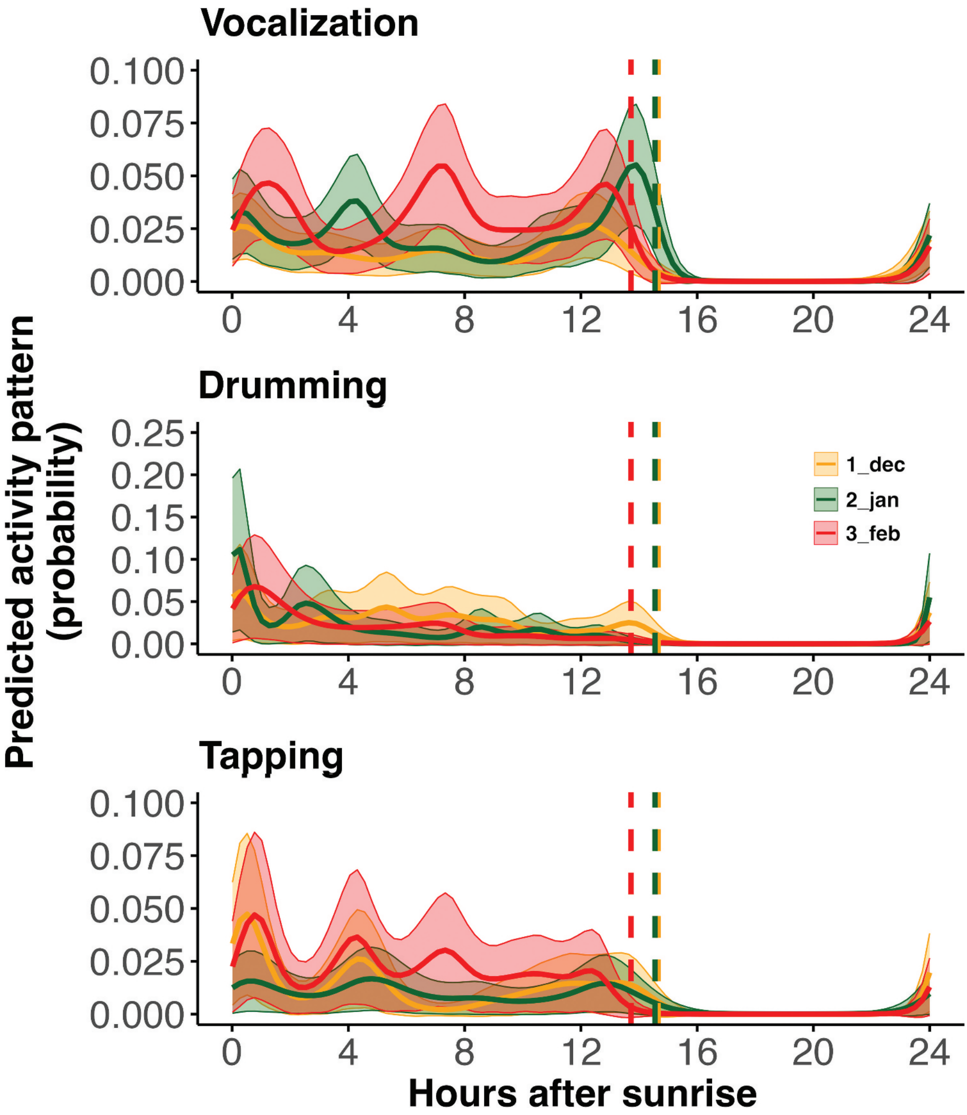

Figure 3. Diel sound patterns of the Magellanic Woodpecker during the austral summer. Vertical dashed lines correspond to the hour at which sunset occurs for each month. 1_dec: December, 2_jan: January, 3_feb: February. The tapping may also correspond to sounds produced by other woodpeckers in the study area, see text.

default model recognised 2.6% and 1.7%, respectively. The precision and recall for the custom model on the vocalisation dataset were 0.82 (82%) and 0.61 (61%), respectively. For the custom model on the drumming dataset, the precision was 1.00 (100%) and the recall was 0.39 (39%). The default model performance on the vocalisation dataset showed a precision of 1.00 (100%) and a recall of 0.03 (3%). For the drumming test dataset these values were to 1.00 (100%) and 0.02 (2%), respectively. Note however that these high precision values were because although

Table 2. Performance of the custom and default BirdNET models to recognise the sounds of the Magellanic Woodpecker. TP = true positive, FP = false positive, FN = false negative. Percentages are provided within parentheses.

Model	Data set	TP	FP	FN	Precision	Recall
Custom	Vocalisation	47	10	30	0.82 (82%)	0.61 (61%)
	Drumming	46	0	73	1.00 (100%)	0.39 (39%)
Default	Vocalisation	2	0	75	1.00 (100%)	0.03 (3%)
	Drumming	2	0	117	1.00 (100%)	0.02 (2%)

only two true positives occurred for each of the test datasets, no false positives occurred (Table 2).

Discussion

We studied by means of ARUs the diel pattern during three months of sounds produced by the Magellanic Woodpecker, a species recognised as an indicator of forest condition and as an ecosystem engineer from the temperate forests of South America (Ojeda 2004; Schlatter and Vergara 2005; Ojeda et al. 2011; Vergara et al. 2016; Altamirano et al. 2017; Vergara et al. 2017, 2019; Alaniz et al. 2021; Wynia et al. 2025). Overall, the number of detections was low relative to the total number of audio files that were manually analysed. Vocalisations, drumming and tapping show diurnal diel patterns that vary during the months monitored. In addition, we evaluated the use of the BirdNET algorithm for the automated analysis of acoustic recordings; the results indicate that the custom model trained with local sounds outperformed by far the default model. Also, our custom model had a better performance for vocalisation detection relative to drumming detection.

Acoustic activity patterns

In a previous study (Moreno-Gómez et al. 2024), we described the diel pattern of a forest bird assembly in natural reserve from Southern Chile, however in that study, the Magellanic Woodpecker was detected only in one out of 2929 recordings, and thus, its acoustic activity patterns remained unknown. In that study, most bird sound detections occurred around sunrise and sunset, and most species showed diurnal patterns, some of which had peaks of activity while others were amodal. In that study we did not differentiate among the vocalisations contained within the repertoire of each species. In the current study, our data indicate that the sounds produced by the Magellanic Woodpecker show different diel patterns, vocalisations having two or three daily peaks (see subsection: *Limitations and potential further studies*), while drumming generally shows one peak of activity around sunrise. Tapping showed three or four peaks, being more similar to the pattern of vocalisations, however this sound, associated with foraging activity, may be confused with the tapping produced by other woodpeckers present in the study area (see section: *Limitations and potential further studies*). The variations throughout months sampled may be related to the stage of the reproductive period. The sampling started in December and ended in February, probably encompassing times from nestling to fledging stages (reviewed in Saavedra et al. 2011). The drumming diel pattern of the Magellanic Woodpecker is similar to the pattern reported by Folliot et al. (2022), of woodpeckers of Alpine Forest, France. By contrast, the study of Zeller et al. (2024) on a woodpecker from Alberta, Canada, reports an additional activity peak around dusk. Regarding vocalisations, the study of Gaylord et al. (2023) reports a pattern with two peaks around sunrise and sunset for a woodpecker from Oregon, USA. The study of Singer et al. (2025) reported the acoustic activity patterns of six species from Lower Saxony, Germany, and found that while most acoustic activity occurred after sunrise for most species, one species shows an additional peak during the afternoon or near sunset hours. However, this study did not differentiate between signal types.

Insights to account for the diel patterns of acoustic signals produced by woodpeckers may be drawn from two complementary hypotheses. The first is the Acoustic adaptation hypothesis (Morton 1975), which proposes that signal characteristics should enhance transmission and where low-frequency sounds are expected for long-distance communication. The second is the sound transmission hypothesis, which indicates that around dawn atmospheric conditions are more stable relative to other times of the day, thus favouring signal propagation (reviewed in Bradbury and Vehrencamp 2011; Gil and Llusia 2020). Considering these factors, it is likely that acoustic signals of woodpeckers with different functions and frequency content show different diel patterns of activity, specifically that low-frequency drumming used for long-distance communication show a more pronounced peak of activity at dawn, compared to higher frequency vocalisations that are used at shorter communication distances.

PAM of the Magellanic Woodpecker

Establishing the acoustic activity patterns of birds of interest for conservation is likely to be a first step for the design of PAM to evaluate long-term trends of their acoustic activity. Initial characterisations should consider the entire 24-h cycle (e.g. Pérez-Granados et al. 2021). However, PAM design may be limited by costs associated with device acquisition and installation on the field and on the analysis of recordings (Wood et al. 2021). An approach is to perform the recordings around dawn as generally this time frame encompasses most bird acoustic activity (e.g. Bolaños-Sittler et al. 2021; Robert et al. 2021). However, our data indicate that the recording schedule for the Magellanic Woodpecker should encompass at least all sunlight and crepuscular hours (e.g. Singer et al. 2025). Furthermore, considering the low number of detections obtained under our sampling schedule, it is likely that increasing the number of recordings, for instance to 1 min every 5 min, would obtain a more accurate characterisation of the activity patterns.

BirdNET for recognising sounds of the Magellanic Woodpecker

Regarding the use of the BirdNET algorithm for the automated recognition of sounds produced by the Magellanic Woodpecker, our analyses indicate that the default model has an extremely low recall value (0.03 and 0.02 for vocalisation and drumming, respectively), indicating a low probability for the correct identification of the recorded sounds. However, our model trained with local recordings reached recall values equal to 0.61 and 0.39 for vocalisation and drumming, respectively. For European bird communities, Funosas et al. (2024) reported recall values between 0.300 and 0.506. The review of Pérez-Granados (2023) reported recall values for bird species from North America that range between 0.09 and 0.90. The study of Cole et al. (2022) evaluated the performance of BirdNET on 13 bird species from North America, among which for the Acorn

Woodpecker (*Melanerpes formicivorus*) and for the Nuttall's Woodpecker (*Picoides nuttalli*) the recall values were 0.14 and 0.26, respectively. Regarding the precision measures, which estimates the probability of correct classifications, for the woodpeckers reported by Cole et al. (2022) these were equal to 0.84 and 0.95, respectively. Our custom model showed a value equal to 0.82 and 1.00 for vocalisations and drumming, respectively. This outlines the importance of including an estimation of undetected sounds by the automated recogniser and shows that the BirdNET algorithm trained with local sounds can improve its performance. It is likely that further training with an ample dataset would increase the performance of the algorithm. The development and enhancement of automated recognisers of easy use would allow to instal large-scale monitoring networks to assess not only changes in behaviour but also changes in population size of sonorous species of particular interest (Kelly et al. 2023).

Limitations and potential further studies

As mentioned previously, a limitation of our study is the potential confusion of the tapping produced by the Magellanic Woodpecker with the tapping produced by the Striped Woodpecker. Although the Magellanic Woodpecker is likely to produce stronger sounds relative to the Striped Woodpecker, the amplitude of the acoustic signals decreases with distance, and as in general the distance between the ARU and the bird is unknown (at least with our sampling design), detections based on features such as signal amplitudes maybe misleading (e.g. Darras et al. 2016). Further studies should determine the attenuation and degradation patterns of the acoustic signals as well as the detection space of ARUs (e.g. Llusia et al. 2011; Penna and Moreno-Gómez 2014; Priyadarshani et al. 2018; Iglesias-Merchan et al. 2024).

In this study, we did not differentiate between types of vocalisations, however as reviewed in Chazarreta and Ojeda (2020), the vocal repertoire of the Magellanic Woodpecker includes a nasal call, a gargling call, a short toot call, a cackling call, whines and sharp cries, and these are produced in different social contexts such as when pairs move or when foraging, under predation risk or when the offspring begs for food. A further study should generate a large dataset of the different vocalisation types to properly train the BirdNET algorithm to recognise each type, this will allow to evaluate potential different temporal patterns of types of vocalisations and therefore add information to the understanding of their function.

A limitation of our recording schedule relates to the temporal extension of the sampling performed, i.e. 3 months, starting on December, a moment that may correspond to the nestling period (reviewed in Saavedra et al. 2011). A further study carried out over the entire year would encompass reproductive and non-reproductive stages. As reviewed in Saavedra et al. (2011) nest excavation occurs intensely 2–4 months prior to egg laying, which starts in October–November, while excavation of roost cavities may last extended periods of time. Therefore, information obtained through PAM could be used to evaluate potential variations in the temporal patterns of the different acoustic signals throughout all the different stages of the reproductive process. Furthermore, effects of tree senescence and forest canopy continuity on pairing, retention of the young and group size have been reported in the literature (e.g. Vergara et al. 2016; Soto et al. 2017; Alaniz et al. 2021), and therefore future studies could evaluate how differences in habitat quality affects the acoustic activity patterns, contributing to strengthen the status of the Magellanic Woodpecker as an indicator of forest condition. Moreover, as the Magellanic Woodpecker has a significant role on the wood dynamics of old-growth forests as well as on the structure of community assemblies (e.g. Schlatter and Vergara 2005; Altamirano et al. 2017; Alaniz et al. 2024; Wynia et al. 2025), future studies may evaluate the use of PAM as a proxy to quantify the ecosystem functions that the Magellanic Woodpecker provides.

Conclusion

In conclusion, our study underpins the importance of manual analyses of acoustic recordings for a first characterisation of activity patterns of the acoustic signals of species that have low rate of detection. This allowed to establish a behavioural baseline needed for the assessment of future monitoring trends. In addition, this manual procedure allowed an evaluation of the BirdNET algorithm, a widely used automated recogniser. Our analyses indicate that training the BirdNET recogniser with local data enhances its recognition performance. The Magellanic Woodpecker is a known species indicator of forest condition that also acts as an ecosystem engineer; therefore, we expect that this study contributes to the development and implementation of ecoacoustic tools aiming to monitor sonorous species and their ecosystems.

Acknowledgements

The authors acknowledge CONAF for support during fieldwork and two anonymous reviewers for comments that contributed to the manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

FNMG was supported by Vicerrectoría de Investigación y Postgrado, Universidad Católica del Maule, [UCM-IN-21208]. This report was completed during the award of Fondo Nacional de Desarrollo Científico y Tecnológico Grant [1201197] to MP.

Data availability statement

Data will be available on request to the corresponding author.

ORCID

Felipe N. Moreno-Gómez http://orcid.org/0000-0001-5715-309X
Javiera Carrasco-Rojas http://orcid.org/0009-0002-5280-4046
José Bartheld http://orcid.org/0000-0002-6306-7945
Rodrigo Gutiérrez http://orcid.org/0000-0002-1119-9989
Mario Penna http://orcid.org/0000-0001-9476-5095

References

Alaniz AJ et al. 2021. Remote-sensing estimates of forest structure and dynamics as indicators of habitat quality for Magellanic woodpeckers. Ecol Indic. 126:107634.

Alaniz AJ et al. 2024. Unravelling the cavity-nesting network at large spatial scales: the biogeographic role of woodpeckers as ecosystem engineers. J Biogeogr. 51(4):710–724. https://doi.org/10.1111/jbi.14786

Altamirano TA, Ibarra JT, Martin K, Bonacic C. 2017. The conservation value of tree decay processes as a key driver structuring tree cavity nest webs in South American temperate rainforests. Biodivers Conserv. 26(10):2453–2472. https://doi.org/10.1007/s10531-017-1369-x

Araya-Salas M, Smith-Vidaurre G. 2017. warbleR: an r package to streamline analysis of animal acoustic signals. Methods Ecol Evol. 8(2):184–191. https://doi.org/10.1111/2041-210X.12624

Bartheld J, Moreno-Gómez FN, Soto-Gamboa M, Silva-Escobar AA, Suazo CG. 2011. Monitoreo Acústico de Aves y Anfibios en el Bosque Costero Valdiviano. Valdivia, Chile; p. 78.

Bolaños-Sittler P, Aubin T, Padilla A, Sueur J. 2021. Acoustic competition within a tropical bird community: the case of the Resplendent Quetzal *Pharomachrus mocinno* in Guatemala. J Trop Ecol. 37(6):291–301. https://doi.org/10.1017/S0266467421000420

Bolker B, R Development Core Team. 2023. _bbmle: tools for general maximum likelihood estimation_. R package Version 1.0.25.1. https://CRAN.R-project.org/package=bbmle

Bradbury JW, Vehrencamp SL. 2011. Principles of animal communication. 2nd ed. Sinauer Associates.

Buckland M, Gey F. 1994. The relationship between recall and precision. J Am Soc Inf Sci. 45 (1):12–19. https://doi.org/10.1002/(SICI)1097-4571(199401)45:1<12::AID-ASI2>3.0.CO;2-L

Chazarreta ML, Ojeda V. 2020. Magellanic Woodpecker (Campephilus magellanicus), Version 1.0. In: Schulenberg TS, editor. Birds of the world. Cornell Lab of Ornithology. https://doi.org/10.2173/bow.magwoo1.01

Cole JS, Michel NL, Emerson SA, Siegel RB. 2022. Automated bird sound classifications of long-duration recordings produce occupancy model outputs similar to manually annotated data. Ornithol Appl. 124(2):duac003. https://doi.org/10.1093/ornithapp/duac003

Cretois B et al. 2024. Snowmobile noise alters bird vocalization patterns during winter and pre-breeding season. J Retailing Appl Ecol. 61(2):340–350.

Darras K, Pütz P, Rembold K, Tscharntke T. 2016. Measuring sound detection spaces for acoustic animal sampling and monitoring. Biol Conserv. 201:29–37.

Ducrettet M et al. 2020. Monitoring canopy bird activity in disturbed landscapes with automatic recorders: a case study in the tropics. Biol Conserv. 245:108574.

Folliot A, Haupert S, Ducrettet M, Sèbe F, Sueur J. 2022. Using acoustics and artificial intelligence to monitor pollination by insects and tree use by woodpeckers. Sci Total Environ. 838:155883. https://doi.org/10.1016/j.scitotenv.2022.155883

Funosas D et al. 2024. Assessing the potential of BirdNET to infer European bird communities from large-scale ecoacoustic data. Ecol Indic. 164:112146. https://doi.org/10.1016/j.ecolind.2024.112146

Gaylord M, Duarte A, McComb B, Ratliff J. 2023. Passive acoustic recorders increase White-headed Woodpecker detectability in the Blue Mountains. J Field Ornithol. 94(4):1–11. https://doi.org/10.5751/JFO-00330-940401

Gil D, Llusia D. 2020. The bird dawn chorus revisited. In: Aubin T, Mathevon N, editors. Coding strategies vertebr acoustic communication. 7th ed. Cham: Springer; p. 45–90.

Gilbert NA, Dominoni DM. 2025. Robust analysis of diel activity patterns. J Anim Ecol. 94 (2):172–174. https://doi.org/10.1111/1365-2656.14235

Hammond RL, Theimer TC. 2020. A review of tree-scale foraging ecology of insectivorous bark-foraging woodpeckers in North America. For Ecol Manage. 478:118516. https://doi.org/10.1016/j.foreco.2020.118516

Hardin FO et al. 2021. Secondhand homes: the multilayered influence of woodpeckers as ecosystem engineers. Ecol Evol. 11(16):11425–11439. https://doi.org/10.1002/ece3.7932

Iannarilli F, Gerber BD, Erb J, Fieberg JR. 2024. A ‘how-to’ guide for estimating animal diel activity using hierarchical models. J Anim Ecol. 94(2):182–194. https://doi.org/10.1111/1365-2656.14213

Iglesias-Merchan C, Llusia D, Márquez R. 2024. Importance of the receiver’s height for transmission studies in acoustic ecology. J Acoustical Soc Am. 155(3):2065–2074. https://doi.org/10.1121/10.0025286

IUCN. 2024. The IUCN red list of threatened species. Version 2024-2. [accessed 2024 Oct 28]. www.iucnredlist.org

Kahl S, Wood CM, Eibl M, Klinck H. 2021. Bird NET: a deep learning solution for avian diversity monitoring. Ecol Inf. 61:101236. https://doi.org/10.1016/j.ecoinf.2021.101236

Kelly KG et al. 2023. Estimating population size for California spotted owls and barred owls across the Sierra Nevada ecosystem with bioacoustics. Ecol Indic. 154:110851.

Lewis RN, Williams LJ, Gilman RT. 2021. The uses and implications of avian vocalizations for conservation planning. Conserv Biol. 35(1):50–63. https://doi.org/10.1111/cobi.13465

Llusia D, Márquez R, Bowker R. 2011. Terrestrial sound monitoring systems, a methodology for quantitative calibration. Bioacoustics. 20(3):277–286. https://doi.org/10.1080/09524622.2011.9753651

Mariton L, Le Viol I, Bas Y, Kerbiriou C. 2023. Characterising diel activity patterns to design conservation measures: case study of European bat species. Biol Conserv. 277:109852. https://doi.org/10.1016/j.biocon.2022.109852

Marler PR, Slabbekoorn H. 2004. Nature’s music: the science of birdsong. Elsevier.

Menon T, Shahabuddin G. 2021. Assessing woodpeckers as indicators of bird diversity and habitat structure in managed forests. Biodivers Conserv. 30(6):1689–1704. https://doi.org/10.1007/s10531-021-02164-0

Morales G et al. 2022. Method for passive acoustic monitoring of bird communities using umap and a deep neural network. Ecol Inf. 72:101909. https://doi.org/10.1016/j.ecoinf.2022.101909

Moreno-Gómez FN, Bartheld J, Briones R, Márquez R, Penna M. 2024. Summer calling activity patterns of a bird assemblage in a Valdivian temperate rainforest biodiversity hotspot. Bioacoustics. 33(1):41–57. https://doi.org/10.1080/09524622.2023.2280533

Morton ES. 1975. Ecological sources of selection on avian sounds. Am Natura list. 109(965):17–34. https://doi.org/10.1086/282971

Oestreich WK, Oliver RY, Chapman MS, Go M, McKenna MF. 2024. Listening to animal behavior to understand changing ecosystems. Trends Ecol Evol. 39(10):961–973. https://doi.org/10.1016/j.tree.2024.06.007

Ojeda V. 2004. Breeding biology and social behaviour of Magellanic woodpeckers (*Campephilus magellanicus*) in Argentine Patagonia. Eur J Wildl Res. 50(1):18–24. https://doi.org/10.1007/s10344-003-0029-5

Ojeda V, Chazarreta M, Pozzi C. 2011. El carpintero gigante: especie clave del bosque andino patagónico. Desde la Patagonia, difundiendo saberes. 8(11):8–17.

Penna M, Moreno-Gómez FN. 2014. Ample active acoustic space of a frog from the South American temperate forest. J Comp Physiol A. 200(3):171–181. https://doi.org/10.1007/s00359-013-0875-x

Pérez-Granados C. 2023. BirdNET: applications, performance, pitfalls and future opportunities. Ibis. 165(3):1068–1075. https://doi.org/10.1111/ibi.13193

Pérez-Granados C, Schuchmann KL. 2021. Passive acoustic monitoring of Chaco Chachalaca (*Ortalis canicollis*) over a year: vocal activity pattern monitoring recommendations. Trop Conserv Sci. 14:19400829211058295. https://doi.org/10.1177/19400829211058295

Pérez-Granados C, Schuchmann KL, Marques MI. 2021. Passive acoustic monitoring of the Ferruginous Pygmy-Owl (*Glaucidium brasilianum*) over a complete annual cycle: seasonality and monitoring recommendations. Stud Neotrop Fauna Environ. 58(2):213–220. https://doi.org/10.1080/01650521.2021.1933699

Podos J, Webster MS. 2022. Ecology and evolution of bird sounds. Curr Biol. 32(20):R1100–R1104. https://doi.org/10.1016/j.cub.2022.07.073

Priyadarshani N, Castro I, Marsland S. 2018. The impact of environmental factors in birdsong acquisition using automated recorders. Ecol Evol. 8(10):5016–5033. https://doi.org/10.1002/ece3.3889

Robert A et al. 2021. Patterns of bird song evolution on islands support the character release hypothesis in tropical but not in temperate latitudes. J Evol Biol. 34(10):1580–1591. https://doi.org/10.1111/jeb.13928

Saavedra M, Ojeda V, Soto I, Galaz JL. 2011. Plan Nacional de conservación del carpintero negro (*Campephilus magellanicus*) King, 1828) en Chile. Dpto. Áreas Silvestres Protegidas, IX Región de la Araucanía.

Schlatter RP, Vergara P. 2005. Magellanic Woodpecker (Campephilus magellanicus) sap feeding and its role in the Tierra del Fuego forest bird assemblage. J Ornithol. 146(2):188–190. https://doi.org/10.1007/s10336-004-0069-y

Servicio Agrícola y Ganadero. 2015. La ley de caza y su reglamento. Servicio Agrícola y Ganadero (SAG).

Sethi SS et al. 2024. Large-scale avian vocalization detection delivers reliable global biodiversity insights. Proc Natl Acad Sci USA. 121(33):e2315933121. https://doi.org/10.1073/pnas.2315933121

Short LL. 1970. The habits and relationships of the Magellanic Woodpecker. Wilson Bull. 82:115–129.

Short LL, Sandstrom GF. 1982. Woodpeckers of the world.

Singer D, Kamp J, Hondong H, Schuldt A, Hagge J. 2025. Diel and seasonal vocal activity patterns revealed by passive acoustic monitoring suggest expert recommendations for breeding bird surveys need adjustment. J Ornithol. 1–16.

Soto GE et al. 2016. Lethal agonistic behavior between two male Magellanic Woodpeckers Campephilus magellanicus observed in the Cape Horn area. Wilson J Ornithol. 128(1):180–184. https://doi.org/10.1676/1559-4491-128.1.180

Soto GE, Pérez-Hernández CG, Hahn IJ, Rodewald AD, Vergara PM. 2017. Tree senescence as a direct measure of habitat quality: linking red-edge vegetation indices to space use by magellanic woodpeckers. Remote Sens of Environ. 193:1–10.

Stachura-Skierczyńska K, Kosiński Z. 2016. Do factors describing forest naturalness predict the occurrence and abundance of middle spotted woodpecker in different forest landscapes? Ecol Indic. 60:832–844. https://doi.org/10.1016/j.ecolind.2015.08.020

Stark RD, Dodenhoff DJ, Johnson EV. 1998. A quantitative analysis of woodpecker drumming. Condor. 100(2):350–356. https://doi.org/10.2307/1370276

Stotz DF. 1996. Neotropical birds: ecology and conservation. University of Chicago Press.

Stowell D. 2022. Computational bioacoustics with deep learning: a review and roadmap. PeerJ. 10:e13152. https://doi.org/10.7717/peerj.13152

Sueur J, Farina A. 2015. Ecoacoustics: the ecological investigation and interpretation of environmental sound. Biosemiotics. 8(3):493–502. https://doi.org/10.1007/s12304-015-9248-x

Sullivan BL et al. 2009. eBird: a citizen-based bird observation network in the biological sciences. Biol Conserv. 142(10):2282–2292. https://doi.org/10.1016/j.biocon.2009.05.006

Symes L et al. 2024. Acoustic analysis with BirdNET and (almost) no coding: practical instructions. https://doi.org/10.5281/zenodo.8357176

Thieurmel B, Elmarhraoui A. 2022. _suncalc: compute sun position, sunlight phases, moon position and lunar phase_. R package Version 0.5.1. https://CRAN.R-project.org/package=suncalc

Tremain SB, Swiston KA, Mennill DJ. 2008. Seasonal variation in acoustic signals of Pileated Woodpeckers. Wilson J Ornithol. 120(3):499–504. https://doi.org/10.1676/07-137.1

Trzcinski MK et al. 2022. Woodpeckers and other excavators maintain the diversity of cavity-nesting vertebrates. J Anim Ecol. 91(6):1251–1265. https://doi.org/10.1111/1365-2656.13626

Vergara P et al. 2017. Magellanic woodpeckers in three national parks of central-southern Chile: habitat effects and population variation over the last two decades. Avian Conserv Ecol. 12(2). https://doi.org/10.5751/ACE-01106-120215

Vergara PM et al. 2016. Foraging behaviour in Magellanic woodpeckers is consistent with a multi-scale assessment of tree quality. PLOS ONE. 11(7):e0159096. https://doi.org/10.1371/journal.pone.0159096

Vergara PM, Soto GE, Rodewald AD, Quiroz M. 2019. Behavioral switching in Magellanic woodpeckers reveals perception of habitat quality at different spatial scales. Landscape Ecol. 34(1):79–92. https://doi.org/10.1007/s10980-018-0746-5

Virkkala R. 2006. Why study woodpeckers? The significance of woodpeckers in forest ecosystems. Annales Zoologici Fennici. 43:82–85.

Walsh ES, Vierling KT, Strand E, Bartowitz K, Hudiburg TW. 2019. Climate change, woodpeckers, and forests: current trends and future modeling needs. Ecol Evol. 9(4):2305–2319. https://doi.org/10.1002/ece3.4876

Wickham H. 2016. ggplot2: elegant graphics for data analysis. Springer-Verlag.

Wood CM et al. 2021. Survey coverage, recording duration and community composition affect observed species richness in passive acoustic surveys. Methods Ecol Evol. 12(5):885–896. https://doi.org/10.1111/2041-210X.13571

Wood SN. 2017. Generalized additive models: an introduction with R. 2nd ed. Chapman and Hall/CRC.

Wrege PH, Bambi FBD, Malonga PJF, Samba OJ, Brncic T. 2024. Early detection of human impacts using acoustic monitoring: an example with forest elephants. PLOS ONE. 19(7): e0306932. https://doi.org/10.1371/journal.pone.0306932

Wynia AL, Rozzi R, Jiménez JE. 2025. The Magellanic woodpecker's role in its assemblage: a case study of cavity provisioning and habitat selection in the world's southernmost forests. Avian Conserv Ecol. 20(1):3. https://doi.org/10.5751/ACE-02786-200103

Xie J et al. 2022. A review of automatic recognition technology for bird vocalizations in the deep learning era. Ecol Inf. 101927:101927. https://doi.org/10.1016/j.ecoinf.2022.101927

Zeller AC, Bayne EM, Mahon CL. 2024. An ecological perspective on the temporal variation in Pileated Woodpecker (*Dryocopus pileatus*) drumming behavior in Alberta, Canada. Avian Conserv Ecol. 19(2). https://doi.org/10.5751/ACE-02724-190211