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Following the trail of the grey brocket deer (*Mazama gouazoubira*) in Argentina: new locality records, activity patterns and habitat use

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The brown brocket deer (*Mazama gouazoubira*) is a species of neotropical ungulate that inhabits several countries in South America. In Argentina, it is distributed in the northern portion of the country, while historical records do not mention it in the province of Mendoza. However, in the Categorization of Mammals of Argentina (2019), the NE of Mendoza is proposed as a potential distribution area of the species. In this work we confirm the presence of the brown brocket deer in the province of Mendoza (locality of Desaguadero - RAMSAR Site), and we also evaluate its activity patterns and habitat preferences. We established 1 km^2 grids in three environments: salt flats, shrublands, and forests. A camera trap (n = 38) was placed in each grid, active for 55 days between October 2022 and April 2023 for fauna survey. In addition, NDVI values (Normalized Difference Vegetation Index) were calculated from LANDSAT-8 images as an estimator of vegetation cover for each grid. We obtained 25 independent records of 11 individuals (5 males and 6 females) from a sampling effort of 51,072 hours of camera operation (2,090 night/trap = 55 night * 38 camera). The males were individually identified based on the presence of antlers, their size, dimension and texture, while the females by their body size and gestation condition. In terms of activity patterns, we observed that these animals are most active in the afternoon (16 to 19 hs) and morning (8 to 9 hs), avoiding the moments of greatest solar radiation (Rayleigh-test $r = 0.99$, $p < 0.001$). NDVI was significantly different among the three environments (*Chisq* = 32.98; $p < 0.001$), with the forest having the highest vegetation cover. Finally, generalized linear models with binomial distribution were used to evaluate the effect of vegetation on the presence of brown brocket deer. We found that the higher the NDVI value, the higher the probability of presence of the deer ($z = 2.27$; $p < 0.05$). These results expand the distribution of the species and increase the diversity of mammals for Mendoza province, which generates added value to the planning of the proposed protected area for Desaguadero in the RAMSAR site Lagunas de Guanacache, Desaguadero y del Bebedero.

La corzuela parda (*Mazama gouazoubira*) es una especie de ungulado neotropical que habita varios países de Sudamérica. En Argentina se distribuye en la porción norte del país, mientras que los registros históricos no la mencionan en la provincia de Mendoza. Sin embargo, en la Categorización de Mamíferos de Argentina (2019) se propone el NE de Mendoza como un área de distribución potencial de la especie. En este trabajo confirmamos la presencia de la corzuela parda en la provincia de Mendoza (localidad de Desaguadero - Sitio RAMSAR), y evaluamos también sus patrones de actividad y las preferencias de hábitat en dicha provincia. Para los relevamientos de fauna se establecieron cuadrículas de 1 km^2 en 3 ambientes: salares, arbustales y bosques. En cada cuadrícula se colocó una cámara trampa (n = 38) activa durante 55 días entre octubre 2022 y abril 2023. Además, para cada una de las cuadrículas se calcularon valores de NDVI (Normalized Difference Vegetation Index) a partir de imágenes LANDSAT-8 como un estimador de la cobertura vegetal. De un esfuerzo de muestreo de 51,072 horas de operación de cámara (2,090 noches/trampa = 55 noches * 38 cámaras), obtuvimos 25 registros independientes de 11 individuos (5 machos y 6 hembras). Los machos fueron identificados a nivel individual a partir de la presencia de astas, tamaño, dimensión y textura de las mismas, mientras que las hembras por su contextura, tamaño corporal y condición gestacional. En cuanto a los patrones de actividad, observamos que estos animales presentan mayor actividad durante la tarde (16 a 19 hs) y la mañana (8 a 9 hs), evitando los momentos de mayor radiación solar (Rayleigh-test $r = 0.99$, $p < 0.001$). En los tres ambientes estudiados, el NDVI fue significativamente diferente (*Chisq* = 32.98; $p < 0.001$), siendo el bosque el de mayor cobertura vegetal. Finalmente, se utilizaron modelos lineales generalizados con distribución binomial para evaluar el efecto de la vegetación en la presencia de corzuela parda. Encontramos que cuanto mayor fue el valor de NDVI, mayor fue la probabilidad de presencia de la corzuela ($z = 2.27$; $p < 0.05$). Estos resultados amplían la distribución de la especie e incrementan la diversidad de mamíferos para la provincia de Mendoza, lo cual genera valor agregado a la planificación del área protegida propuesta para Desaguadero en el sitio RAMSAR Lagunas de Guanacache, Desaguadero y del Bebedero.

Keywords: Activity patterns; brown brocket deer; forest; habitat use; Mendoza.

Introduction

The brown brocket deer (*Mazama gouazoubira*), also known as the "corzuela parda", is a neotropical ungulate species that inhabits various countries of South America, such as Brazil, Bolivia, Paraguay, Uruguay, and Argentina (Silva-Caballero and Ortega 2022; Figure 1). This species occupies a great variety of habitats and ecoregions, such as the Chaco, Pantanal, Cerrado, Espinal, Bosque Atlántico, Pampas, and Caatinga (Silva-Caballero and Ortega 2022; and references in there). Due to its wide distribution and ecological importance, the "corzuela parda" has attracted considerable attention from researchers aiming to understand its biology, behavior, and conservation status. In recent years, the "corzuela parda" had been categorized as Least Concern, both internationally (IUCN; Black-Décima and Vogliotti 2016), and locally in Argentina (CMA; Juliá *et al.* 2019), Brazil (Duarte *et al.* 2012), Paraguay (Asociación Paraguaya de Mastozoología y Secretaría del Ambiente 2017), and Bolivia (Aguirre *et al.* 2009).

The "corzuela parda" is one of the largest herbivores in native forests of South America; it feeds on a wide variety of species, being mostly a browser but with several pulses of frugivory (Serbent *et al.* 2011; Silva-Caballero and Ortega 2022), thus becoming an important seed disperser agent. It exhibits a predominantly solitary behavior although some authors suggest the presence of complex social interactions, including territoriality and mating systems (Juliá 2002; Black-Décima *et al.* 2010). Its lifestyle is mainly crepuscular, with individuals primarily active during dawn and dusk (Leeuwenberg *et al.* 1999; Rivero *et al.* 2005). The species' adaptability to different environments has allowed it to thrive across a diverse range of ecosystems, including forested habitats, tropical and subtropical forests, as well as grasslands and savannas. This species tends to occupy areas in good conservation status (Periago *et al.* 2015), or areas providing some cover, such as riverine forests (Silva-Caballero and Ortega 2022) becoming an important indicator species for assessing ecosystem health. However, "corzuela parda" also uses modified habitats like agricultural patches-lots or fragmented forests (Juliá *et al.* 2019; Silva-Caballero and Ortega 2022). Despite its ecological significance, the brown brocket deer has faced numerous challenges, including habitat loss, fragmentation, and hunting pressure, which have led to population declines in certain regions (Juliá 2002; Juliá *et al.* 2019).

In Argentina, the "corzuela parda" had been recorded in five biogeographic regions: Chaqueña, Espinal, Paranaense, Monte, and Yungas (Chebez and Johnson 1985; Romero and Chatellenaz 2013; Cirignolli *et al.* 2011), but most research on life history had been done in the Yungas (Tucumán province; Black-Décima 2000; Juliá 2002; Black-Décima *et al.* 2010) and the Chaco regions (Córdoba province; Periago and Lyenaud 2009a,b; Serbent *et al.* 2011; Periago *et al.* 2012; 2015). Barquez et al (1991) mentioned its presence in Mendoza province, but there were not accurate records that prove its presence further west of the Desaguadero River (Juliá *et al.* 2019). According to Roig (1988; 1989) the "corzuela parda" does not appear in historical records of naturalists who visited Mendoza, nor in regional archaeological records from the specialized literature. Recent studies conducted in the Central-Eastern part of the province have not yielded any records of this species, even using camera traps or in interviews with forest inhabitants (Moreno 2023). Recently, Juliá *et al.* (2019) published a distribution map of the "corzuela parda" for Argentina, including a little portion of the east limit of Mendoza province, which neighbors with San Luis province. Nevertheless, in their description they mentioned as doubtful the presence in Mendoza because of the previous data.

In this paper, we confirm the presence of a new population of the brown brocket deer in the Eastern portion of Mendoza province (Desaguadero locality), thereby increasing the number of native species for the province and adding a new taxonomic group to its previous biodiversity records. We also provide information about the population inhabiting this new locality, their activity patterns and habitat preferences. With this information we aim to underscore the importance of evaluating effective conservation actions and management strategies to ensure the long-term survival and sustainable coexistence of the "corzuela parda" with its changing environment in Argentina.

Materials and methods

Study site. This research is part of the project "Aportes científico – técnicos al proceso de creación y gestión de la Reserva Natural Municipal Lagunas del Desaguadero, La Paz, Mendoza – ImpaCT.Ar Desafío N° 40" granted by Ministerio de Ciencia, Tecnología e Innovación of Argentina. The project focuses on the creation of a protected area around the Desaguadero River, through scientific-technical research which links natural and socio-cultural assets of the area.

The study site is located in the Monte biogeographic region, specifically in the Central-East of Mendoza province, Argentina (Figure 1). The climate in this area is semi-arid to arid, characterized by pronounced seasonality and a wide daily temperature range. The average annual temperature is approximately 17 °C. Precipitation is concentrated in the summer and decreases from East to West. The mean annual rainfall is around 300 mm (Labraga and Villalba 2009). Within this region, there are multiple streams of the Tunuyán River that flow from West to East, forming an alluvial fan. The runoff is collected by the Desaguadero River (Figure 1). The study area includes 2 dams or "azudes" constructed in 2014 on the Desaguadero River to temporarily retain water.

A closed gallery forest, conformed mainly by *Neltuma flexuosa* (Hughes *et al.* 2022; "algarrobo dulce", ex *Prosopis*) trees, occupied the banks of the streams. The floodplain is covered by different plant communities, such as open *Neltuma* forests of lower density and coverage, as well as shrublands, and salt flats (Suplementary material 1). Typical species of Monte region, such as *Larrea* spp., *Condalia*

microphylla, Licium spp., among others, are present in the area (Villagra *et al.* 2010; Del Olmo 2012). The study site is adjacent to the Chaco Seco ecoregion, separated by the Desaguadero river, and as a result, some species of plants form the Chaco, such as *Celtis tala* (tala), *Aspidosperma quebracho-blanco* (quebracho blanco) and *Acacia caven* (espinillo), can also be found in the study site (Villagra *et al.* 2010).

Sampling design. Grids of 1 km^2 were established to survey mammal assemblage in 3 main plant communities, classified a priori according to their physiognomy as: salt flats, shrublands and forests. Salt flats are open areas with low cover of halophyte shrubs, such as *Allenrolfea vaginata* or *Suaeda divaricata*. Shrubland community has a patchy cover of shrubs, mainly composed by *Larrea* spp., *Condalia microphylla and Lycium* spp. Forest includes open forest and gallery forest where *N. flexuosa* is the main species, accompanied by *Neltuma nigra*, *Geoffroea decorticans*, *Capparis atamisquea* and *Larrea* spp., among others. In the gallery forest, species incoming from the Chaco ecoregion are also present, such as *Celtis tala*, *Schinus fasciculatus,* and the exotic *Tamarix* spp.

Camera traps stations were placed in each grid according to logistic possibilities: 11 in shrublands, 15 in Salt flats and 12 in forests (n = 38 stations) (Figure 2). Each station contains 1 camera trap. Camera traps sampling was conducted in the period of highest population abundance of the animal species, coincident with the wet season: ends of spring 2022 and early summer 2023. Cameras were active during a total of 55 consecutive days on each station, over a 24 hs, period (2,090 night/trap = 55 night * 38 camera). Camera traps (Browning Patriot) were mounted on a 0.50 m high backing and vegetation surrounding the detection zone was cleaned to allow animal identification. The cameras took 3 consecutive pictures whenever animal movement was detected, with a 1 second delay between shoots. Individuals were identified from photos based on presence of antlers (size and texture), fur color, tail and body length and other species specific physical traits (Silva-Caballero and Ortega 2022).

Data Analysis. To shape the new distributional southern limit of the species within Mendoza province, we used not only records of camera trap but also opportunistic records by colleagues of brown brocket deer next to the main road

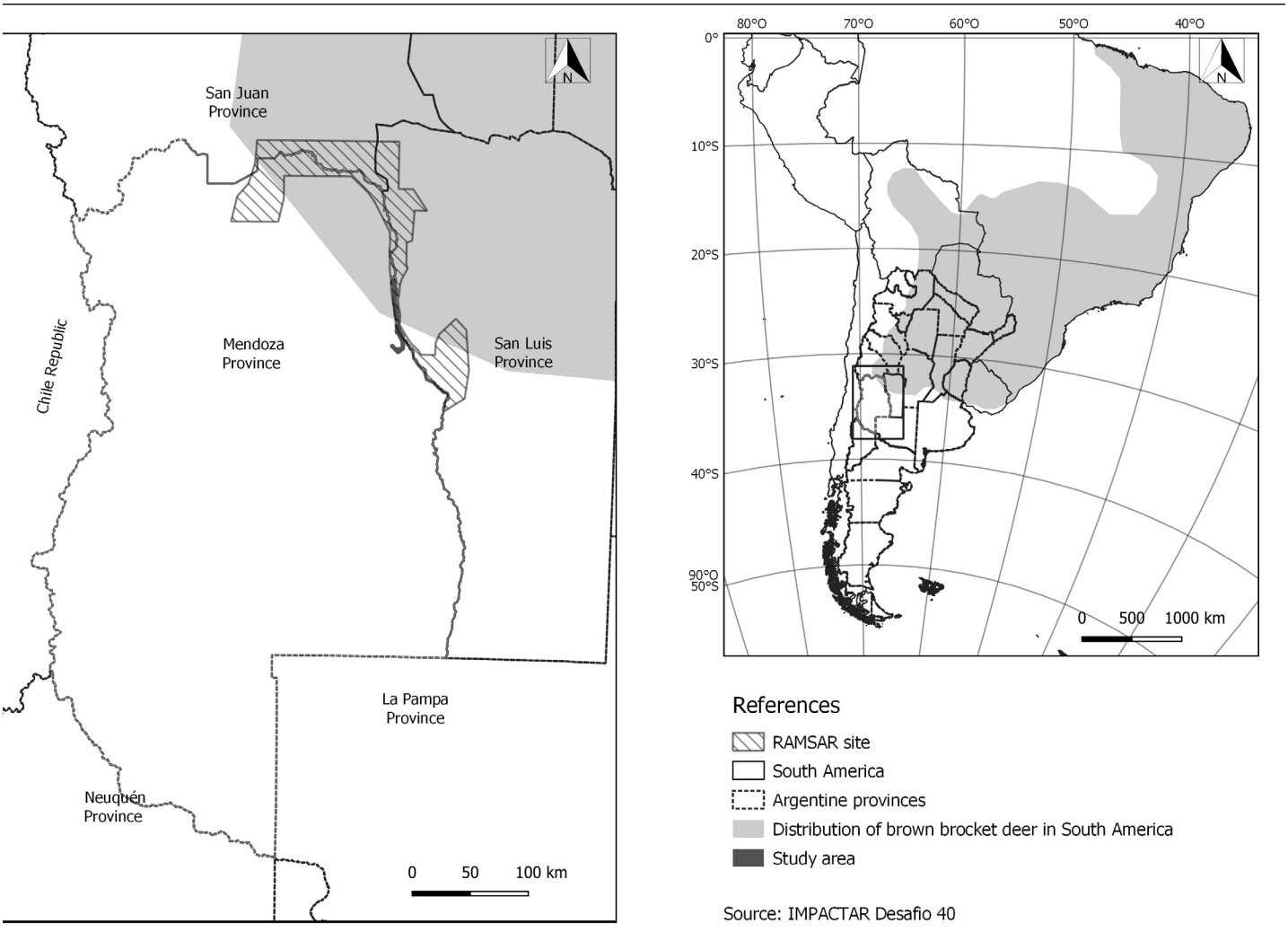

Figure 1. "Corzuela parda" distribution in South America by Silva-Caballero and Ortega 2022. The square indicates the south-west actual distributional limit and the rectangle indicates the study site in Mendoza Province were new records of "corzuela parda" are located.

and i-Naturalist records published online. To evaluate daily activity patterns, we defined independent events (or activity records) as camera trap photographs in which the delay between two consecutive images of an individual exceeded 2 hours. With this information, circular statistic was used to unveil the daily activity patterns of the "corzuela parda". The analyses were performed using R v.3.2.5 environment and language (R Core Team 2023). The daily wind rose diagram, which convert data into a circular object, was performed with the "circular" package (Lund *et al.* 2022). To test for significant differences in the circular distribution among hours, we used the Rayleigh test (Zar 2010). Here, the null hypothesis assumes a uniform circular distribution across 24 hours, indicating the absence of preferred activity hours for the "corzuela parda". We used the "CirStats" package (Agostinelli and Agostinelli 2018) to perform the Rayleigh test.

To evaluate habitat use, NDVI index (Normalized Difference Vegetation Index) was estimated for each of the 38 cells of the grid. This index identifies the presence of green vegetation on the surface and characterizes its spatial distribution. NDVI values were obtained from a LANDSAT-8 image, OLI Sensor, from December 2022 with a pixel size of 30 m by 30 m. Because each index is estimated over a surface of 10 m^2, an average of all the cells included in the grid was estimated as the NDVI of each sampling site. Differences in the NDVI between plant communities were assessed using the Kruskal-Wallis test. When significant differences were observed, *post-hoc* comparisons were conducted using a Dunn test (Zar 2010). Subsequently, generalized linear models with a binomial distribution were used to evaluate the effect of vegetation (as measured by NDVI) on the presence of "corzuela parda". All records, including those obtained from this study and external sources, were used in the model. R^2 coefficient was calculated to assess the goodness of fit. Graphic methods were used to test assumptions of normality and homogeneity of residuals. All analyses were performed using R v.3.2.5 environment and language (R Core Team 2023). Kruskal-Wallis test was performed with "agricolae" package (Mendiburu 2020). GLM was fitted with "stats" (R Core Team 2023), "DHARMa" (Hartig 2020) and "visreg" (Breheny and Burchett 2017) packages.

Results

New records. In this paper, we report 4 new site records from camera traps, 1 new record from personal observation of a CONICET colleague and include 3 iNaturalist reports added last spring (Table 1). These new records, located on the Central-East part of La Paz department, not only confirm the presence of the species on Mendoza province as previously mentioned by naturalists, but also rearrange the map proposed by Juliá *et al.* 2019 (Figure 2).

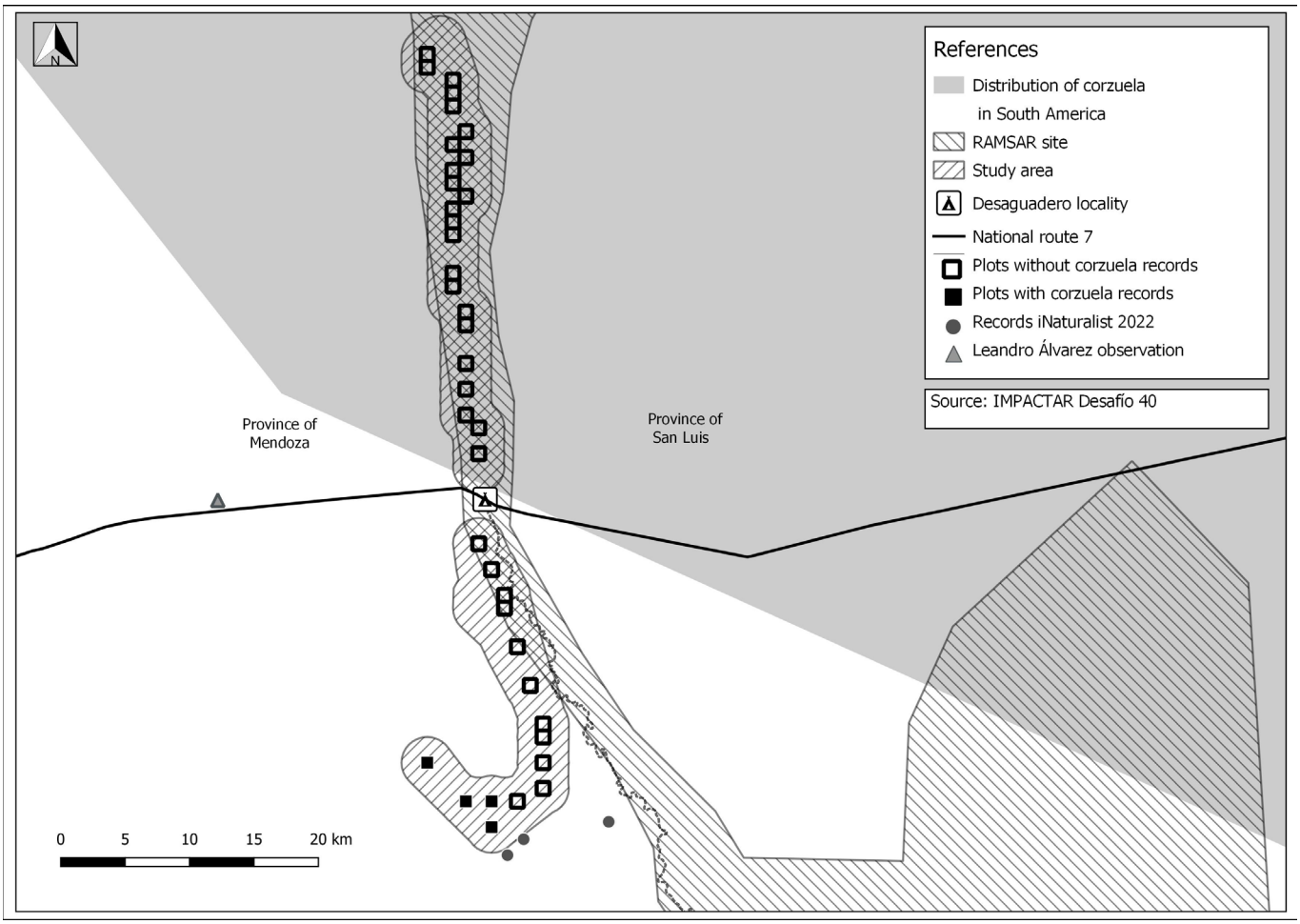

Figure 2. Location of camera traps stations in the study site.

Table 1. List of records of *Mazama gouazoubira* in Mendoza Province.

Latitude	Longitude	Source	Date
33° 37′ 58″ S	67° 8′ 57″ W	This study-B05	Summer 2023
33° 36′ 55″ S	67° 8′ 54″ W	This study-B03	Summer 2023
33° 35′ 26″ S	67° 12′ 1″ W	This study-B01	Summer 2023
33° 37′ 4″ S	67° 10′ 4″ W	This study-B02	Summer 2023
33° 24′ 38″ S	67° 22′ 39″ W	Leandro Alvarez observation	Autumn 2023
33° 38′ 24 ″ S	67° 7′ 4″ W	iNaturalist-Quentin Vandem	Spring 2022
33° 37′ 36 ″ S	67° 2′ 48″ W	iNaturalist-Damian Gamine	Spring 2022
33° 39′ 4″ S	67° 7′ 51″ W	iNaturalist-Damian Gamine	Spring 2022

Population. From a total sampling effort of 50,160 hours operation camera, we obtained 25 independent records of *M. gouazoubira*: three records in B01, two in B02, 11 in B03, and nine in B05. Eleven individuals of *M. gouazoubira* were identified, with five of them being adult males and six adult females. The males were primarily distinguished from the females by the presence of antlers, and among themselves, by their size, dimension and texture (Figure 3b, c). One male stood out for having a cut on the left ear and was photographed in the company of a female (Figure 3c, e). For the distinction among the females, their body size was taken into account (Figure 3a, d), with one female being identified as highly probably pregnant (Figure 3a). One individual from camera B01 could not be identified as it was camouflaged among the bushes. All individuals recorded in the camera trap photos exhibited a good overall physical condition.

Figure 3. Photos of "corzuela parda" in Mendoza province, Argentina, captured by the camera trap during the sampling period: a- Pregnant female, b-Adult male, c-Adult male with a cut on the left ear, d-Adult female, e-Male with a cut ear with an adult female.

Activity patterns. The 25 independent camera trap events are represented on a wind rose based on their time record. The brocket deer has higher activity between 8 and 9 am in the morning and then between 16 and 19 pm hours (Figure 4), avoiding the peak radiation hours (12 to 16 hours) during the summer season of 2023. Rayleigh test confirmed that these time preferences were statistically significant (r = 0.99, $p = 3.6062^{e-10}$).

Habitat use. The plant communities exhibited significantly different NDVI values among them, being the NDVI of the forest twice as high as that of the salt flat (*Chisq* = 32.98; $p < 0.00001$) (Figure 5). The higher the NDVI of the vegetation, the higher the probability of presence of the "corzuela parda" ($z = 2.27$; $p < 0.05$) (Figure 6). The NDVI explained about 36 % of the variance in the probability of presence.

Discussion

In this paper we report a new locality of "corzuela parda" in Argentina, particularly in Mendoza province, extending the distribution of the species to the South-West of its previous range. We also report the habitat use and activity patterns of "corzuela parda" in the new locality, suggesting a preference for habitats with higher complexity and NDVI, and being mostly active during the dawn and dusk time. Our results not only support the previous hypothesis of Juliá *et al.* (2019), who suggests the possible presence of "corzuela parda" in Mendoza, but also confirm that there is a stable and reproductive population in this new province.

By revising the distribution maps of the "corzuela parda", we found three different distributions according to different authors (Black-Décima 2010; Juliá *et al.* 2019; Silva-Caballero and Ortega 2022). However, none of them include our study site as part of the species' distribution

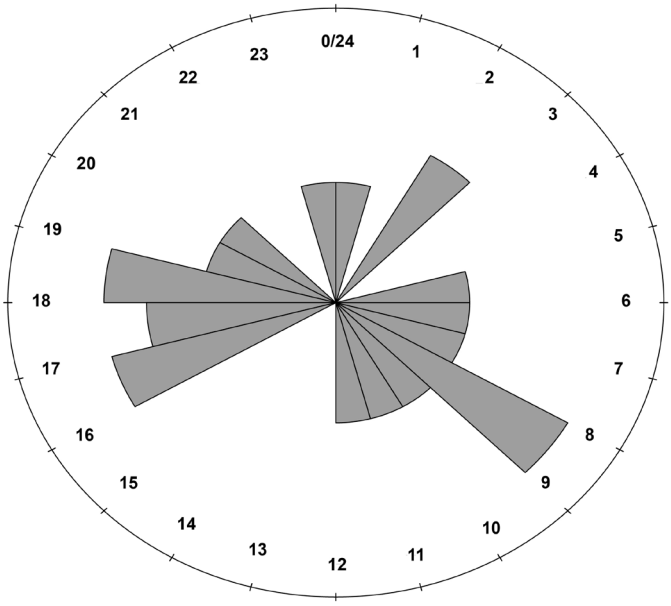

Figure 4. Wind rose recording daily activity pattern of the "corzuela parda" in Mendoza Province, Argentina. Numbers indicate daily hours. Longer arms indicate a higher number of independent records of corzuela captured on camera traps.

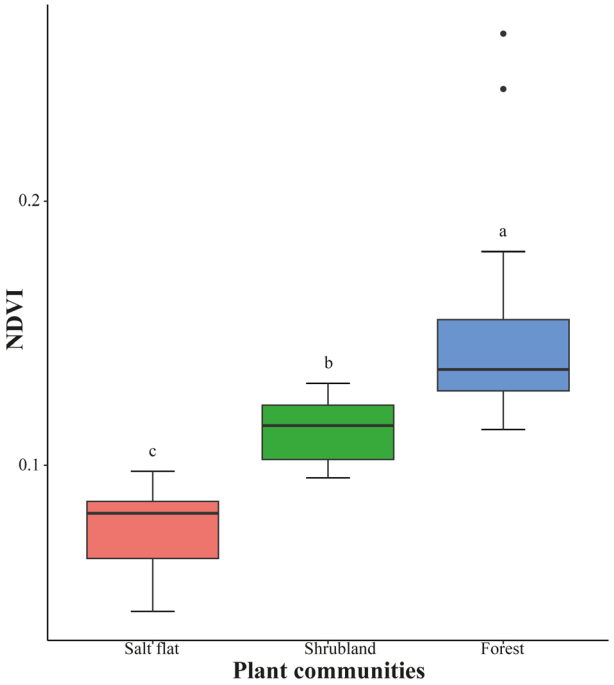

Figure 5. Box-plot of NDVI for different plant communities: salt flat, shrubland and forest. Different letters indicate significant differences among plant communities.

area. Considering the one proposed by Silva-Caballero and Ortega (2022), our records increase the South-West limit of "corzuela parda" of about 25 km, and confirm its presence in the province. While this work was being writing, the Mendoza government reported a new record of "corzuela parda" in the Central-West portion of Mendoza province (https://www.mendoza.gov.ar/prensa/fue-registrada-una-nueva-especie-de-la-fauna-silvestre-protegida-en-la-provincia/). Particularly, the sighting was at the Southern limit of the Ñacuñan protected area, about 90 km apart from our study site in the South-West direction. The precise record had not been provided in newspaper notices, so we could not include it here. Also, it is important to mention that recent studies carried out in the area, that included sampling with camera traps and surveys of residents, did not find records of this cervid (Moreno 2023). Future research that focuses on this species in Mendoza province will allow us to confirm or deny new records of populations presence, and probably the distribution area will change within a short time.

According to the ecology of the species, previous studies report that adult males mostly do not overlap their home range (Silva-Caballero and Ortega 2022). Nevertheless, some pairs of animals had been reported, mother and fawn or male and female or adult male and young male (Black-Décima 2000; Chebez and Johnson 1984; Juliá 2002). In our study, we found not only solitary individuals in all camera sites but also the presence of three different males (male #1,# 2 and #3) and two females (female #1 and #2) in a single sampling site (W03). Although there are no records of two or three males sharing the habitat at the same time, we found that presence records have a range of five and 17 days between different males. Moreover, the record of the three males and the two females was sequential, which means that during the first 20 days, only male #1 and female #1 used the area. After that period, and during the next month, male #2 and female #2 were recorded sharing the site. Finally, male #3 was recorded at the end of the sampling period only once. Therefore, this population could share its home range in space, but not in time. This pattern had not been previously reported in literature and became a new behavior for this species.

Records of activity patterns were consistent with literature, which mentions changes in the feeding behaviour of "corzuela parda" according to seasonality. During the spring and summer seasons, the "corzuela parda" is mainly found during the twilight periods, with individuals primarily active during dawn and dusk (Leeuwenberg *et al.* 1999; Rivero *et al.* 2005; Pautasso *et al.* 2008; Barrientos and Maffei 2000; Noss *et al.* 2003; Ferreguetti *et al.* 2015; Oliveira *et al.* 2016; Grotta-Neto *et al.* 2019). Although particular hours vary according to the biogeographic region of the sampling sites and seasonality (Bolivia, Brazil, Argentina), all studies reported two main activity peaks, one in the early hours of the morning, and the other in the latest hours of the day. This behavior avoids the exposition to the highest temperatures during the snap time, which can reach up to 45 °C in the summer time in our study site (Morello *et al.* 2018). During autumn and winter, "corzuela parda" would use all daily hours for foraging, besides dawn and dusk, something reported previously in other small ruminants (Putman 1988). This behavioral strategy, which prioritizes quality over quantity, would be responsible for the rhythm of activity previously described, in which "corzuela parda" invests a lot of time in food selection (Richard and Juliá 2004).

Habitat use of "corzuela parda" is one of the best known characteristics of this species across their entire range of

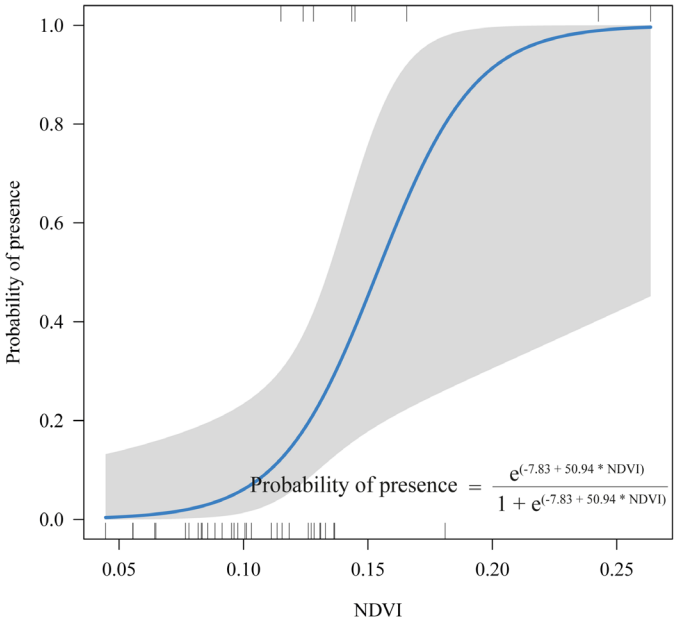

Figure 6. Probability of presence of "corzuela parda" in relation to the NDVI in Mendoza Province, Argentina. The solid blue line indicates the estimated parameter and the gray area represents the confidence intervals.

distribution. Non-anthropic terrestrial environments are optimal for the species, such as jungles, forests, shrublands, and grasslands, while anthropic environments such as agricultural crops, forest plantations, and cattle pastures are considered suboptimal (Juliá *et al.* 2019). In humid habitats, like the Brazilian savannah (Cerrado ecorregion), the "corzuela parda" mostly used forest habitats or bushy grasslands (Leeuwenberg *et al.* 1999; Grotta-Neto *et al.* 2019) and disturbed or agricultural habitats like Eucalyptus plantations (Rodrigues *et al.* 2014, 2017). In Argentina, the secondary forests of Parque Nacional El Rey are more frequently used than the mature forests of tropical forest habitat (Yungas), the difference being greater in the dry season compared to the wet season (Lepera *et al.* 2005). In North-East portion of Argentina, (Santa Fe and Misiones provinces), "corzuela parda" was recorded on gallery and Espinal forests, savannah and shrublands (Pautasso *et al.* 2008; Cirignoli *et al.* 2011). In Misiones jungle, a population growth was observed, favored by the fragmentation of the landscape and the increase in pine plantations (Juliá *et al.* 2019). In more arid habitats, such as the Chaco ecorregion in Argentina, "corzuela parda" is mostly present in habitats with a greater tree and bare soil cover and a less shrub cover (Periago *et al.* 2012). Our results show a higher presence probability on higher NDVI areas, supporting the hypothesis of the need of arboreal cover as a main habitat requirement of this species (Caraballo 2009; Desbiez *et al.* 2009). Because of our study site is next to the Chaco Seco ecorregion, the intrusion of elements of the Chaco into our study area could creates a propitious environment for the presence of the "corzuela parda". Particularly, riparian forests like the one present in our study site, could act as a corridor not only for "corzuela parda" individuals, but also their associated vegetation.

Finally, it is important to highlight that this portion of Mendoza Province has an ecological condition that allows the development of a *M. gouazoubira* population. Moreover, the political limit between Mendoza and San Luis provinces is also a biogeographic limit between Monte and Chaco Seco, so the Desaguadero river, and particularly the intersection between it and the Tunuyan River, could be acting as a biological corridor for the expansion of this species. The creation of the new protected area around Desaguadero and Tunuyan rivers, joint with the new record of "corzuela parda" in the nearby of Ñacuñan protected area, emphasize not only the importance of keep protecting these protected areas, but also the protection of surrounding habitats which was the potential of being used by "corzuela parda" to travel between patches.

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Appendix 1

Main plant communities in the study site: a) Salt flat, b) Shrubland, and c) Forest.

Supplementary material

Residuals of the Presence probability model

https://www.revistas-conacyt.unam.mx/therya/index.php/THERYA/article/view/5158/5158_Supplementary%20material