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Research Article

Combining road surveys and aerial counts for abundance and density estimates of the last known Pampas deer population in Brazilian Pampas

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Abstract

Pampas deer *(Ozotoceros bezoarticus)* inhabit the major open habitats of South America, running from the Brazilian Cerrado to the subtropical grasslands of Uruguay and Argentina. In Brazil, the major population of this species is found in the Pantanal region, with several fragmented populations from the central to the southern regions. However, no information is available, regarding the abundance of Pampas deer in southern Brazilian Pampas or their connectivity with Pampas deer populations in other occurrence areas. Therefore, the Pampas deer population of Brazilian Pampas has not been included in the assessments made by the International Union for the Conservation of Nature thus far. In this study, we aimed to estimate the population density and abundance of the last known population of Pampas deer in Brazilian Pampas combining data from road surveys and aerial counts. Transect line estimates indicated a density of 1.50 individuals/km^2 (95 % CI = 1.05–2.15). The average aerial count was 1.55 individuals/km^2. Based on these density estimates, we further estimated that 243 Pampas deer (95 % CI = [170–348]) inhabit the area effectively occupied by the spotted individuals. Our study shows that drones can be used to survey the Pampas deer population in Brazilian Pampas and presents the first population data for this species in southern Brazil. The findings of this study highlight the importance of conserving this population of *O. bezoarticus* along the southern border of Brazil.

Introduction

Pampas deer (*Ozotoceros bezoarticus*) is a medium-sized Neotropical cervid weighing 20–40 kg (Mantellatto et al., 2017). Typically inhabiting the open areas of Bolivia, Paraguay, middle north Argentina, Uruguay, and Brazil, it is an abundant species in most areas of its distribution (González et al., 2016; Duarte et al., 2012; Mähler Jr. and Schneider, 2003). However, the number of this species decreased from millions of individuals to 20,000 to 80,0000 living in fragmented populations (González et al., 1998).

Pampas deer is currently classified as "Near Threatened" by the International Union for Conservation of Nature (IUCN) (González et al., 2016). In Argentina, it is listed as "Endangered" (SAyDS-SAREM, 2019), while in Brazil it is considered "Vulnerable" (Duarte et al., 2012), despite the good number of individuals living in the Pantanal region. In southern Brazil, particularly in Rio Grande do Sul and São Paulo, the species is classified as "Critically Endangered" (Rio Grande do Sul, 2014; São Paulo, 2010), primarily due to population declines driven by illegal hunting and habitat loss (Becker and Dalponte, 2013). In the southern region of the country, most populations of this species inhabit the grasslands of the Atlantic Highlands (a region associated with the Atlantic Forest formation) in the northeastern part of Rio Grande do Sul State (Duarte and Cerveira, 2013). However, there is another population of this species in the western part of this region, in the Brazilian Pampas, near the Argentinean border (Duarte and Cerveira, 2013; Mähler Jr. and Schneider, 2003). Both populations seem to be remnants of a more extensive and widespread population; however, information regarding their connectivity with other populations and abundance estimates, is lacking. Probably because of this lack of relevant information, the population of the western region was not included in the IUCN assessment for the conservation of this species (González et al., 2016).

Similar to several other landscapes, the Pampas region has been rapidly and constantly modified by the loss and conversion of natural areas. In this context, monitoring wild animal populations, particularly endangered populations, may be crucial for planning effective conservation and management actions. One of the most important variables for monitoring animal populations are their abundance and population size (Brack, 2022). Multiple techniques, including camera traps, track and scat counts have been used to estimate the relative abundance of mammals (Camargo, 2021; García-Aguilar, 2012; Kasper et al., 2012, 2007; Pardini et al., 2006). Although these are non-invasive methods (do not involve captures), they are limited in their ability to generate accurate population density estimates (Chiarello, 2008; Wilson and Delahay, 2001). Transect lines are the standard method for obtaining density estimates of animals (Cullen Jr. and Rudran, 2003; Buckland et al., 1993) and has been used successfully for determining the population density of various terrestrial and aquatic mammals (Fettermann et al., 2022; Evans and Hammond, 2004). Specifically, it has been used to obtain the population density estimates of large herbivores, such as *Blastocerus dichotomus* (marsh deer) (Andriolo et al., 2005), *O. bezoarticus* (Pampas deer) (Bilenca et al., 2017), *Odocoileus virginianus* (white-tailed deer) (Preston et al., 2021), and *Loxodonta africana* (African

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bush elephant) (Vermeulen et al., 2013). Transect line surveys enable the generation of punctual estimates associated with confidence intervals, leading to a great acceptance of this method (Marshall et al., 2008; Davenport et al., 2007; Pardini et al., 2006; Cullen Jr. and Rudran, 2003). In some cases, terrestrial transects are made along available roads, as road surveys (Kasper et al., 2012).

Large herbivores can be either sampled on the ground (on foot or by car) or using aircraft (Dunham, 2012; Kruger et al., 2008; Andriolo et al., 2005; Mourão et al., 2000). Aerial counts have been made using unmanned aerial vehicles (UAVs), also known as drones (Brack, 2022; Pereira et al., 2022; Hodgson et al., 2018). This equipment allows the sampling of large areas in a relatively short time (Hodgson et al., 2018), emerging as a powerful tool for density estimates because of its low cost and safety compared with the use of conventional aircraft (Brack, 2022; Pereira et al., 2022; Hodgson et al., 2018; Christie et al., 2016). Despite their popularity, doubts remain regarding the detectability of some species, as reported by Barasona et al. (2014) and Zamboni et al. (2015), particularly in highly heterogeneous habitats. It is known that the accuracy of data obtained from aerial images is lower than that obtained from ground-based surveys (Schlossberg et al., 2016; Jachmann, 2002). However, larger surveys covered by the drone can offset this lower data accuracy.

In this context, we aimed to estimate the density and abundance of the last known population of Pampas deer in the Brazilian Pampas combining two sampling methods: road surveys and aerial counts. This comparison will reveal if aerial counts allow for efficient population monitoring and can be used for surveying this species in other areas of the Pampas biome.

Materials and methods

Study area

The study was conducted in the São Borja region, southern Brazil, near the border with Argentina (central coordinates 28.689 S, 55.957 W) (Fig. 1). With a mean elevation of 99 m above sea level, the area consists of forest formations in the Brazilian Pampas (sensu IBGE 1993), part of the Uruguayan savanna (Dinerstein et al., 1995), and the southern temperate grasslands of the Pampas (Olson et al., 2001). This environment is dominated by open grasslands, with patches of forests associated with rivers and rugged terrain. The climate of this region is classified as humid subtropical *Cfa* with hot summers based on the Köppen climate classification (Alvares et al., 2013). The mean annual rainfall is 1.625 mm (Robaina et al., 2007), with no notable differences in precipitation between seasons. However, a water deficit occurs in summer because of low soil depths (Hasenack et al., 2023) and high evaporation rates.

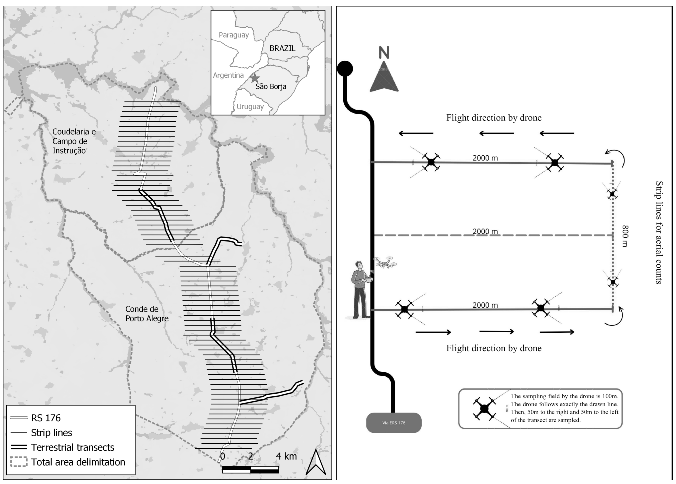

Figure 1 – Left: Sampling plan of aerial counts in the study area highlighting the flying routes and the road surveys in two environments (Conde and Coudelaria) in Brazilian Pampas. Right: A schematic of flight orientation, covering two sampling strips.

The study area can be divided into two major categories based on land uses: one highly anthropized by agriculture (Fig. S1) and the other relatively more preserved and consisting of native grass vegetation (Fig. S2). The anthropized area, known as Conde de Porto Alegre (hereafter referred to as Conde), covers 264 km^2 and is used for the plantations of soybean (*Glycine max*), wheat (*Triticum* spp.), corn (*Zea mays*), radish (*Raphanus sativus* L.), and rapeseed (*Brassica napus* L.) in small proportions. The low-lying regions contain rice (*Oryza sativa*) plantations. This area includes grasslands with a mix of native and commercial grass species used for cattle and ovine and equid livestock. Small scattered patches of exotic trees, such as pine (*Pinus* sp.) and eucalyptus (*Eucalyptus* sp.), are present in this area. The well preserved area is a military property of 153 km^2 known as "Coudelaria e Campo de Instrução de Rincão" (hereafter referred to as Coudelaria) (Coudelaria e Campo de Instrução de Rincão, 2022). The vegetation in this area is mainly composed of tussock-forming grasses (growing in clumps) with small heights (Boldrini et al., 2010). These grasslands occur in smooth relief with an abundance of species such as *Bromus auleticus*, *Jarava plumosa*, and *Nassella neesiana*. The lower stratum in this area is continuous and composed of a high diversity of the grasses of the genus *Paspalum* and forage legumes, such as *Adesmia bicolor* and *Arachis burkartii* (Hasenack et al., 2023).

In addition to cattle, these areas have records of the gray brocket deer (*Subulo gouazoubira*), a native species with solitary and elusive behavior; the introduced chital deer (*Axis axis*), a gregarious species that can forage throughout the day but reduces its activity during hot hours, seeking shade under trees; and the wild boar (*Sus scrofa*), an invasive exotic species of wild pig. Wild boars are more frequently sighted, causing damage to agricultural areas according to the local people. The chital deer seems associated to the grassland areas near the Icamaquã River, as suggested by Smith-Jones (2023), who highlights the relationship between shade and water availability and the presence of this species.

Data collection

The survey of Pampas deer populations in the study area was conducted monthly from December 2022 to January 2024 (except for June 2023) in 12 campaigns. We surveyed Pampas deer using two methods: 1) road surveys and 2) aerial counts.

1) Road Surveys. We established four terrestrial transects of 4–6 km in length (Cullen Jr. and Rudran, 2003; Buckland et al., 1993), three of which were in Conde and one in Coudelaria (once access to military property was restricted) (Fig. 1). The transects were fixed along secondary roads, the only roads accessible by truck. Sampling was conducted in the morning (between 0700– and 1200) and afternoon (between 1500 and 1900). The surveys were conducted using a pickup truck traveling at a maximum speed of 25 km/h, with a single observer looking for Pampas deer from the truck bed. Upon sighting a Pampas deer, the truck was stopped at a position perpendicular to the initial point of observation to record the distance on the transect, the perpendicular distance from the transect, the number of individuals (if in a group), and time (Cullen Jr. and Rudran, 2003). The perpendicular distance was measured using the first individual sighted in each group of deer. These distances were measured with the maximum possible precision using a laser rangefinder (Bushnell Trophy Cam 4×20) with centimeter precision. The records were analyzed using the Distance 7.5 software, which calculates detectability functions to estimate species abundance and population density in a sampled area (Buckland et al., 1993). We disregarded 5 % of the most distant records using the resource-truncation zone, as suggested by Buckland et al. (1993). The detection functions used for density estimates were adjusted based on different models, such as "Uniform key/ Cosine adjustment" or "Half-normal/ Hermite," selected based on the lowest value of Akaike's Information Criterion (AIC). These adjustments provided better Goodness of Fit values, representing the best adjustment of the detection functions and, consequently, relatively more accurate density estimations (Cullen Jr. and Rudran, 2003).

Table 1 – Estimates of the expected value of the density of clusters (DS), the expected value of cluster size [E(S)], the density of animals (D) individuals/km², and effective strip width (ESW) in m, considering the "Half-normal" adjustment of the recorded data regarding Pampas deer population in the Brazilian Pampas.

Parameter	Point estimate	Standard error	Coefficient of variation (%)	95% Confidence interval
DS (density of clusters)	0.79	0.13	17.1	0.56–1.10
E(S) (expected value of cluster size)	1.90	0.12	6.6	1.66–2.16
D (density of animals)	1.50	0.27	18.3	1.04–2.15
ESW (effective strip width)	287.3	22.5	7.8	246.0–335.5

2) Aerial Counts. The aerial counts were made using images recorded by a UAV–drone–model, "DJI Mavic 2 Zoom." This drone traveled predefined routes programmed by the "Litchi App" (https://flylitchi.com). The routes, called missions, were executed in an automated manner without interference from a controller, even in the absence of contact between the drone and the operational base (Meller, 2022). The flight was conducted at an altitude of 90 m above ground at a speed of 22 km/h to avoid collisions with trees or power lines, recording continuous videos of 4K quality with a 2X zoom. The camera was positioned to record the frontal view of the flight at an angle of −45, covering a strip of 100 m (50 m to each side of the programmed displacement axis). Each flight sampled two strips, with each strip of 2.000 m in length, covering 200.000 m^2 (20 ha or 0.2 km^2) each. The two strips were 800 m apart (Fig. 1).

The study area was sectioned into 140 numbered flight lines of 2.000 m each, oriented perpendicular to the main road that crossed the study area (Fig. 1). The flight lines are 400 m apart. All flights began on the main road and ended on the same road. The experiment started by sampling a strip of 2.000 m, then moved 800 m to the north and returned to the road to sample another strip of 2.000 m. This design maximized the use of the flight capacity (30 min of autonomy) of the drone. Each flight sampled the strips for approximately 20 min (to save reserve energy for headwinds). The decision regarding not sampling the neighboring lines was taken to reduce the possibility of recording the same animals in two consecutive samples (strip lines).

For each monthly campaign, we randomly selected 12 initial lines for flights using a random number generator on the Internet. The only rule was that the 12 numbers would not be sequential (e.g., lines 84 and 85). When this occurred, we reran the selection until non-sequential numbers were obtained. Based on these 12 initial flight lines, we sampled 24 strips (each flight covered two strips). The flights were performed sequentially (from lines 1 to 140) on 2 days. Aerial counts were considered independent in each (monthly) survey; therefore, the sampled lines were not excluded from subsequent campaigns.

The recorded files were analyzed in a laboratory using a 74-inch television (TV) with 4K playback capability (Samsung Smart TV). The number of individuals spotted, along with the time and location coordinates, were recorded each time a Pampas deer was observed.

Area estimates

To estimate the area occupied by this Pampas deer population, we adopted two approaches: 1) based on the exact location of individual sightings (Approach A), and 2) based on the local characteristics of the environment (Approach B). These area estimates, combined with density estimates, allowed us to calculate the population size in the study area.

For Approach A, a conservative scenario, we plotted all available records for the Conde and Coudelaria localities, including those obtained from the survey of road surveys, aerial counts, and occasional encounters while traveling and exploring the study area. Based on the external points of the point cloud, we defined a minimum convex polygon (MCP) to which we added a buffer zone equivalent to the radius of the home range of Pampas deer, as described by Vila et al. (2008), representing the minimal area occupied by this species in the region, referred to as the central area.

For approach B, the entire locality of Conde and Coudelaria was considered the occupancy area of this species. In this case, we extended the area of occurrence to the small "landscape barriers", such as small rivers and riparian forests, associated with these localities. No considerable difference (in our view) was observed in the vegetation structure or the land use between the central area (approach A) and the surrounding area. However, these records were found to be concentrated in the central area. Therefore, we considered that this approach represented an optimistic scenario.

Based on these two approaches, we calculated the population size of Pampas deer using the road surveys estimates, due the robustness of these estimates. Aerial counts were considered to obtain new points of occurrence of the species and to validate their use in new surveys of Pampas deer in the Pampas environment.

Results

Road Surveys

We obtained 114 records of Pampas deer along 240 km of the road surveys. Up to 10 individuals were found per sighting, with a mean perpendicular distance of 202.4 m (14.2 to 634 m) from the road. A total of 109 records were used for density estimates using the truncation zone resource, with perpendicular distances varying from 14 to 524 m, resulting in an effective strip width of 287 m (Table 1).

We obtained a satisfactory encounter rate (n/L), with 0.45 encounters/km (varying from 0.33 to 0.61, with a 95 % confidence interval) and a coefficient of variation of 15.15 %. Based on these values, the population density of this species was estimated at 1.50 individuals/km^2 (varying from 1.05 to 2.15 individuals/km^2, with a 95 % confidence interval).

Aerial counts

We sampled 276 strip transects, accounting for 55.2 km^2 recorded in 2.760 minutes (46 hours) of video takes. A total of 86 individuals were spotted during these flights, of which 78 were spotted in Conde and eight in Coudelaria. This count results in a population density estimate of 1.55 individuals/km^2.

Area and abundance estimates

Based on the records of the locations where Pampas deer were spotted, a MCP of 82.5 km^2 was assigned as the smallest area considered for this population. We estimated a minimum occupancy area of 161.9 km^2 by including a buffer zone equivalent to the radius of the mean home range (Fig. S3). Based on this value, we estimated a minimum population of 243 individuals (95 % CI = $[170, 348]$).

In the optimistic scenario, we considered the entire available area of 417.6 km^2 (equivalent to the combined localities of Conde and Coudelaria). In this scenario, we projected a maximum population of 626 individuals (95 % CI = $[438, 898]$). Table 2 presents the two estimates (conservative and optimistic scenarios).

Discussion

Our data show that the use of UAVs (drones) for performing aerial counts or surveys of Pampas deer in Pampas grasslands is suitable. The number of animals recorded using this method (1.55 individuals/km^2) was similar to the estimate based on road surveys (1.50 individuals/km^2) and within the confidence interval of this estimate (1.05 to 2.15 individuals/km^2). Notably, we do not suggest that the use of aerial counts can replace the population density estimates based on the survey of transect lines, which is a standard and ro-

Table 2 – Estimates of the occupancy area, population density (based on road surveys), and abundance of a Pampas deer population in the Brazilian Pampas, with a 95% confidence interval.

Scenario	Occupancy area	Population density	Abundance (95% confidence interval)
Conservative	161.9 km^2	1.50 (95 % CI = [1,04–2,15])	243 individuals (170 to 348)
Optimistic	417.6 km^2		626 individuals (438 to 898)

bust method for obtaining population density estimates (Zamboni et al., 2015; Kasper et al., 2012; Chiarello, 2008; Marshall et al., 2008; Kasper et al., 2007). Instead, we suggest that aerial surveys using drones can complement the exploratory studies or surveys of this species in areas where the establishment of road or transect lines are difficult or impractical (Finch et al., 2021; McRoberts et al., 2011).

Despite the apparent differences in the abundance of Pampas deer observed between the agricultural environment of Conde and the native grasslands of Coudelaria, we obtained a general estimate of the population density. Differences in the abundance of this species between these two localities (Conde versus Coudelaria) are suggested by aerial counts, which record almost 10 times more individuals in the agricultural area. These differences may be associated with a decrease in the detectability of Pampas deer in relatively more heterogeneous environments, as suggested by Zamboni et al. (2015). Considering this possibility, the differences can arise from a bias in estimates because of the greater difficulty in locating individuals or a higher abundance of this species in agricultural areas than in native grasslands. It is important to point that the abundance of some deer species are underestimated when the estimates are based only in road surveys, because they can avoid the road borders (Green et al., 2022; Preston et al., 2021). The same authors show that the use of Drones with thermal cameras improve the results, especially for the withe-tailed deer (*Odocoileus virginianus*), in more forested areas.

Difficulties related to finding the individuals of this species in heterogeneous vegetation have been addressed by Barasona et al. (2014), who argued that the detectability of focal species in a habitat must be considered in abundance estimates made based on aerial counts. In our study, the identification of Pampas deer in the native grasslands of Coudelaria was harder than that in the uniform and cleaner habitats of Conde, however, not impractical. The records in 4K videos (along with pictures) and their analyses in high-resolution TVs enabled the detection of animals based on their silhouette, color, and movement in the vegetation. A similar explanation was provided by Hodgson et al. (2018), who reported no differences in the number of individuals based on high-resolution images captured during flight from a height of up to 90 m. Furthermore, the size of Pampas deer and their diurnal activities and use of open environments (Duarte et al., 2012) make this species ideal for this type of counting. In addition, we identified other species, such as great rhea (*Rhea americana*) and wild boar (*Sus scrofa*), in this heterogeneous habitat. Therefore, we believe that our data reflect the local reality of a lower abundance of Pampas deer in native grasslands than in agricultural environments. We did not properly assess the reasons for this difference; however, it could be linked to the nutritional properties of cultivars in agricultural areas, as discussed below.

Our results align with those reported by Braga (2004), who found a higher abundance of Pampas deer in agricultural environments than in native environments, suggesting a differential use of the two environments by this species. Similarly, we found relatively more individuals of this species in agricultural environments than in native grasslands. In our surveys, the sightings of individuals or herds of this species foraging in soybean plantations (spring/ summer) and wheat plantations (autumn/ winter) were common. Merino et al. (2009) argued that Pampas deer present a broad alimentary habit along their distribution range, including a high diversity of grasses and dicotyledons, preferentially consuming sprouts, which are soft and nutritious. They added that the major reason for the selection of cultivated areas, such as soybean plantations, could be the high crude protein content of plants compared with that in many native pastures. Braga (2004) suggested that soybean consumption is beneficial during the lactation phase of female Pampas deer. González et al. (2010) pointed out that their reproduction period is associated with food availability, with births occurring throughout the year, peaking from September to November in Uruguay and Argentina, which coincides with the planting period and initial development of soybeans in this region. In southern Brazil, their reproductive period appears to coincide with the winter season (personal communication V. Facin) or the period from winter to early summer (Mähler Jr. and Schneider, 2003).

The population density estimated for the Brazilian Pampas was congruent with previous studies (Table 3), most of which estimated approximately one individual per square kilometer. Certain regions, such as the Pantanal (Tomás et al., 2001) and parts of the Pampas grasslands in Uruguay (Cosse and González, 2013), exhibit a hyperabundance of Pampas deer. This may be due to the presence of highly suitable habitats, favorable historical conditions, or a combination of both factors that support increased deer populations.

Table 3 – Population density estimates of Pampas deer in its distribution range and the most conservative estimate for the Brazilian Pampas region based on the results obtained in the present study.

Locality	Density estimate (individuals/km^2)	Studied area (sampled) (km^2)	Abundance (*n* of individuals)	Total area of the locality (km^2)
Brazil				
Pantanal[a]	9.81	84	465	400
Emas National Park[b] (Cerrado)	1.00	1,318	1,000–1300	1,318.68
Paraná State[c] (Atlantic Highlands)	1.19	60	71	60
Brazilian Pampa (present study)	**1.50**	**161.9**	**170–348**	**417.6**
Argentina				
Corrientes[d]	1.17	1,278	>1,000	1,278
San Luis[e]	0.43–0.83	1,311–2,848	500–1,200	1,450
Uruguay				
Los Ajos[f]	3.46	33.97	117	80
El Tapado[g]	16.00		1,000	

References mentioned in Table 3: [a] Tomás et al. (2001), [b] Rodrigues and Monteiro-Filho (2000), [c] Braga and Kuniyoshi (2010), [d] Zamboni et al. (2015), [e] Dellafiore et al. (2003), [f] Cosse and González (2013), and [g] González et al. (2010)

Our conservative estimates of the area effectively used by the studied population in the Brazilian Pampas are safe and can be considered the minimal area occupied by this population. The procedure involving the addition of a buffer equivalent to the radius of the home range species to an MCP of sighting locations in the records is commonly used for the estimates of area occupied by individuals and effective area covered by the grids of traps (Reis et al., 2010; Mangini and Nicola, 2006) and camera traps (Kasper et al., 2015; Tomás and Miranda, 2003). This method enabled us to estimate a minimal population of 243 individuals (170–348). We believe that the actual population is bigger than the estimated minimal population because the entire area covering the sighting locations (Conde and Coudelaria) is 417.6 km^2, which could support a population of 626 individuals. However, this seems to be an optimistic approach because it does not consider an apparent difference in the abundance of this species in the two localities.

Conclusion

In conclusion, we showed that drones can be useful for aerial counts or surveys of Pampas deer and report a small population of at least 243 individuals of the species. Also, relictual populations are significant when added to the main population of Pantanal, with 20–40 thousand individuals (González et al., 2010), adding variability to the habitat adaptations of this species. Despite their apparent limited distribution and small number of individuals, this population of Pampas deer in the Brazilian Pampas is the largest known population in southern Brazil. Further studies on Pampas deer in the Brazilian Pampas are necessary to evaluate the distribution range of this population and the decrease in its abundance when moving away from the core (central) area. We believe that the data presented here highlight the importance of putting this population of Pampas deer on a map for conservation strategies.

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Supplemental information

Additional Supplemental Information may be found in the online version of this article:

Figure S1 Mosaic with images collected by the author during visits to Conde.

Figure S2 Mosaic with images collected by the author during visits to Coudelaria.

Figure S3 Map depicting the central location of a population of Pampas deer in Brazilian Pampas based on a minimum convex polygon (MCP).