Unravelling the drivers of maned wolf presence patterns along an elevational gradient in the Atlantic Forest, south-eastern Brazil

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Abstract

The maned wolf is the largest canid in South America, and considered to be in decline in Brazil. This species was originally distributed in areas with open natural vegetation in the Cerrado biome, Chaco and Pampas regions. However, in recent years the distribution of the species has expanded, in line with the conversion of Atlantic Forest areas into open anthropogenic environments. Although the maned wolf's overall distribution is well documented, little is known about smaller-scale landscape use within the species current expansion areas. Here, we used favourability distribution models to relate local landscape use by maned wolves in the Serra da Mantiqueira, in the core of the species overall distribution, to environmental drivers. Our results showed that favourability of territories for maned wolves increases with altitude, with the proportion of coverage of upper montane vegetation refuges, and of open habitats such as agricultural fields. This corroborates quantitatively that, at least in part, substitution of Atlantic Forest vegetation with open environments facilitates maned wolf expansion, and that topography is also important in determining local-scale landscape use in these populations. Increased contact with humans may however be problematic for this species, as we also identified retaliation events targeting the wolf in the surroundings of the studied protected areas. Overall, our results support the importance of maintaining the integrity of high-altitude grasslands for the conservation of maned wolf habitat.

Keywords: *Chrysocyon brachyurus*; favourable home range movements; high-altitude grasslands; human activities; Serra da Mantiqueira

Introduction

The maned wolf (*Chrysocyon brachyurus* Illiger, 1815) is the largest canid in South America, and is anatomically adapted to move in open areas (Dietz, 1984; Coelho et al., 2008; Massara et al., 2012). Maned wolf body shape, with long and slender legs, facilitates locomotion and prey capture in environments with tall grasses, such as savannahs, being a species more adapted to these open environments (Childs-Sanford, 2005; Coelho et al., 2008; Massara et al., 2012). In Brazil, the species was originally distributed in areas of native open vegetation, reaching high population densities in the Brazilian savannah, i.e., Cerrado biome (Queirolo et al., 2011). However, due to habitat loss, roadkill, diseases and retaliation for predation of domestic animals (Curi et al., 2010; Freitas et al., 2015; Massara et al., 2015), the maned wolf is now considered vulnerable in Brazil (MMA, 2014), with a projected population reduction of 30% expected in the next 20 years (Paula et al., 2013). This decline is mostly linked to the current and forecasted devastation of approximately 50% of the Brazilian savannah due to agricultural expansion (Queirolo et al., 2011). Nevertheless, some marginal populations of the maned wolf show an inverse pattern. The replacement of Atlantic Forest by anthropogenic fields (mainly pastures), has led to the expansion of the maned wolf's distribution into the Atlantic Forest biome of south-eastern Brazil, where the species was previously absent or rare (Queirolo et al., 2011). Numbers of maned wolf records in the Atlantic Forest have increased in recent years, mostly in altered pasture fields (Queirolo et al., 2011; Eckhardt, 2016; Beca et al., 2017; Bereta et al., 2017; Xavier et al., 2017). However, there have been occasional records in the high-altitude natural grasslands of the Atlantic forest (Avila-Pires and Gouvea, 1977; Geise et al., 2004).

One of the most representative areas of the Atlantic Forest is the Serra da Mantiqueira, a mountainous region ranging from 500m a.s.l. to 2,798m a.s.l. (Simas et al., 2005; Barreto et al., 2013), located in the most populated states in Brazil, i.e. São Paulo, Minas Gerais and Rio de Janeiro (IBGE, 2016). The Serra da Mantiqueira is considered an irreplaceable region of high biodiversity value and, thus, a conservation priority area (Myers et al., 2000; Le Saout et al., 2013). The first record of maned wolves in the Serra da Mantiqueira was in the state of Rio de Janeiro in 1954. Specifically, the species was observed in native high-altitude grasslands at 2,400m a.s.l. in the Itatiaia National Park (Avila-Pires and Gouvea, 1977). However, since that time, evidence of the presence of the species in the region has only been registered more recently, and in just a few mammal surveys carried out in higher areas of the region, such as in the high-altitude fields (Geise et al., 2004; Aximoff et al., 2015).

In the state of Minas Gerais, the maned wolf had only been recorded in Cerrado areas (e.g. Aragona and Setz, 2001; Queirolo and Motta-Junior, 2007), until its diet was recently described in forested areas of the Serra da Mantiqueira (Rosa et al., 2015). Indeed, the Serra da Mantiqueira was recently identified as an area of high favourability for the species globally, being comparable to the Cerrado Biome as the centre of the species range in terms of high environmental favourability for this canid (Coelho et al., 2018). Such high favourability, together with its location near to the species core distribution (Queirolo et al., 2011), may indicate that the Serra da Mantiqueira could act as one of the source cores for maned wolf populations. This highlights the importance of assessing the local drivers shaping the species home range movements in the Serra da Mantiqueira, to better understand its spatial role for the survival of this canid in a changing world.

Although the maned wolf's wide distribution is now well documented (see Queirolo et al., 2011), as well as the environmental drivers that determine it (Coelho et al., 2018), there is a scarcity of information regarding the local spatial behaviour of the species within its current expansion area (Queirolo et al., 2011), or regarding spatial configuration along an elevational gradient, which may be an import factor to consider as gradient characteristics can determine local adaptations in resource use (e.g., Myslajek et al., 2012; Carvalho et al., 2019). Species distribution models have been used successfully to establish the relationship between a species and its environment (Guisan and Zimmermann, 2000; Guisan et al., 2013; Romero et al., 2016; Coelho et al., 2018), and even to predict the presence of species in localities not previously known to be occupied (Real et al., 2017). Here we apply the favourability function in order to improve our understanding of local landscape use by the maned wolf in the Serra da Mantiqueira, a protected territory in the core of the maned wolf global distribution. Our specific objectives were to: (i) identify the most favourable territories for maned wolves in the Serra da Mantiqueira; (ii) estimate the effect of environmental factors on the occupancy patterns; and (iii) obtain relevant information for conservation management for the maned wolf in a key part of its global range.

Material and method

Study area

The study was carried out in two protected areas within the Serra da Mantiqueira: Itatiaia National Park and Serra do Papagaio State Park (hereinafter INP and SPSP respectively; Fig. 1). The INP encompasses the counties of Itatiaia and Resende, in the state of Rio de Janeiro, and the counties of Itamonte and Bocaina de Minas, in the state of Minas Gerais. The INP covers an area of 28,084ha ranging from

540m a.s.l. to 2,798m a.s.l. The SPSP is located in the counties of Aiuruoca, Alagoa, Baependi, Itamonte and Pouso Alto in the state of Minas Gerais, and covers an area of 22,917ha ranging from 1,000m a.s.l. to 2,314m a.s.l. These protected areas make up part of a large corridor of protected areas along the Serra da Mantiqueira Mountains, including the Pedra Selada State Park, Serra da Mantiqueira Environmental Protection Area, the Passa Quatro National Forest and numerous Private Nature Reserves (Carvalho et al., 2015). The INP and SPSP are covered by four different types of vegetation which vary as elevation increases: lower montane forest (between 50 and 500m a.s.l.), montane forest (from 500 to 1,500m a.s.l.), upper montane forest (between 1,500 and 2,000m a.s.l.) and high-altitude fields (above 2,000m a.s.l.) (Segadas-Vianna and Dau, 1965). The forests are dominated by a mixture of seasonal semi-deciduous and ombrophilous dense forest, including sites with the critically endangered Brazilian pine *Araucaria angustifolia*-Kuntze, 1898 (Oliveira-Filho and Fontes, 2000). The rural areas surrounding the protected areas are covered by remnants of secondary forest, degraded grasslands, federal and a network of state highways and unpaved roads embedded in a matrix of agricultural lands. The most north – north-western portion of the Serra da Mantiqueira (state of Minas Gerais), is considered to be a transition zone between the Atlantic forest and the Cerrado biomes (Ururahy et al., 1983; IBGE, 2004). The region's climate is mesothermal (Koeppen, 1948), with mean annual temperature and precipitation of 11.5°C and 2,150mm, respectively (IEF, 2008; Barreto et al., 2013). The study area encompasses ca. 535km^2 representing more or less seven times the average home range-size described for this species in Brazil (ca. 70km^2; Coelho et al., 2008). As such, the monitored area was large enough to cover several animals' home-ranges. We generated a grid of 1km x 1km spatial resolution within the study area for the modelling procedure (Fig. 2). This resolution allows the identification of areas of high-quality habitat appropriate as a management unit for maned wolf conservation (Barbosa et al., 2010). Finally, to assess the potential for human-wildlife conflicts, we carried out interviews in the rural areas located close to INP.

Records of maned wolf presence

We sampled maned wolf presence from October 2010 to September 2014 in the two protected areas (INP and SPSP). In INP, monthly censuses were carried out between October 2010 and September 2012, and in SPSP, 30-day campaigns were carried out in each season between January 2010 and December 2014. In both locations, the censuses covered all types of land cover considered in the present study. The study area was sampled at least twice (once in the dry season and once in the rainy season), totalling 1,500km of effort. The censuses covered an area with a wide elevational range, varying from 400 to 2,500m a.s.l.

Both direct observations and tracks or faeces were considered as signs of presence of maned wolves (Becker and Dalponte, 1991; Reis et al., 2010), and used to define the area with maned wolf activity (54 records of presence in Fig. 2a). The rest of the study area was considered as lacking maned wolf activity, and therefore to be an unoccupied area. Then, for the modelling procedure we generated a buffer with a radius of 1.5 km around each of the 54 presence points (see Silveira et al., 2009 for more details), which was considered to be the territory used by each maned wolf detected. All the 1km x 1km grid squares totally or partially contained in the buffer area were considered part of the area with activity of the species (Fig. 2b). So, a total of 203 grids with maned wolf activity were the number of grids from which was built the model. In this way, we used grids instead of geographical locations in the models, so solve a large part of the spatial autocorrelation derived from observation spatial clustering or sampling bias (Romero et al., 2019).

Finally, in order to register possible human-maned wolf conflicts, a total of 70 local people, including residents and park staff, were interviewed in the surroundings and within the area of the INP. Specifically, the interview consisted of the following questions: 1) when and where was the last time that you saw a maned wolf in the region?; 2) Do you know of any predation of domestic animals by maned wolves?; 3) Have you witnessed any maned wolf deaths as a result of retaliation for predation damages, or a road collision?

Environmental characterization

To characterize the environment in the study area we used different environmental predictors: topography, land use category, human activities and vegetation types (Table 1). We assigned a value or category to each 1km x 1km grid cell depending on the type of environmental predictor considered. The mean elevation per gird was obtained from the Insituto Nacional de Pesquisas Espaciais (INPE, 2019). So, the topography was represented by the mean elevation, slope and North-South predominant orientation. The land use category was defined as the type of landscape use (see Table 1), being classified according to the vegetation map for the Atlantic Forest (IBGE, 2004). The vegetation type was also defined according to the vegetation classification of the Atlantic Forest (Segadas-Vianna and Dau, 1965), and as all locations were above 500 m a.s.l. the types were: montane forest (from 500 to 1,500m a.s.l.), upper montane forest (between 1,500 and 2,000m a.s.l.) and high-altitude fields (above 2,000m a.s.l.). The population density in the study area according to the Data

Center in NASA's Earth Observing System Data and Information System (EOSDIS) was used as a proxy for the intensity of human activities (details in Table 1).

Analysis of the favourability of the landscape for maned wolf activity

We used a logistic regression approach to evaluate which environmental factors might be influencing maned wolf presence patterns (Hosmer et al., 2013). Based on the grids with activity of the species (Fig. 2B), and the set of environmental predictors generated, we applied the favourability function (FF) to predict the location of areas where maned wolf home range activities may occur (Real et al., 2006; Coelho et al., 2018). This function consists of a multifactorial logistic regression, with a model selection based on a forward-backward stepwise procedure and on Akaike Information Criteria or AIC (Burnham and Anderson, 2002). Model building and selection was implemented using the *fuzzySim* package (Barbosa, 2016) for R (R Core Team, 2017). The probability of maned wolf presence for each grid cell was used to calculate the favourability values (F) according to the following equation:

$$F=[P/(1-P)]/[(n1/n0)+(P/[1-P])],$$

where P is the probability value obtained from the multifactorial logistic regression, and n1 and n0 are grid numbers corresponding to presences or pseudo-absences, respectively. We applied the FF to identify the areas that contain favourable conditions regardless of the presence/pseudo-absence ratio (Real et al., 2006), and therefore suitable conditions for the species to be present. The FF reflects the degree (between 0 and 1) to which the probability values obtained in the model differ from that expected according to the species' prevalence, where 0.5 indicates no difference between both probability values. Probability depends both on the response of the species to the predictors and on the overall prevalence of the species (Cramer, 1999), whereas favourability values only reflect the response of the species to the predictors (Acevedo and Real, 2012). Favourability values were categorized into high (areas with favourability values higher than 0.8), intermediate (with favourability values between 0.21 and 0.80), and low (with favourability values less than 0.2) favourability. This categorization is equivalent to defining a prediction with odds higher than 4:1 as favourable and lower than 1:4 as unfavourable (Muñoz and Real, 2006).

Prior to the modelling procedure, we standardized all predictors to avoid bias in the modelling results associated with the difference in scale of the continuous variables. To avoid excessive multicollinearity in the model, we checked pair-wise variable correlations (Pearson's test) applied the "corSelect" function from fuzzySim package and checked the Variance Inflation Factor or VIF (Zuur et al., 2009; Zar, 2010).

We evaluated the discrimination and classification capacity of the models with the *modEvA* R package (Barbosa et al., 2016). Specifically, we calculated the discrimination ability of the models using the AUC (Lobo et al., 2008), and the classification capacity by assessing sensitivity, specificity, Kappa and Correct Classification Rate (CCR) values (taking the value of F= 0.5 as the classification threshold). Finally, we checked the relative weight of the variables in the model using a Wald's test (Wald, 1943) through the *survey* package (Lumley, 2004; 2018). Responses to interview questions were expressed as percentage of interviewees mentioning the focal issue.

Results

Model assessment

Correlations between predictor variables used in the model procedure were always below 0.7 (p> 0.05) (Table 1 and Appendix A, Table A.1), and inflation values were lower than 1.5 (VIF values up to 10 are acceptable according to Montgomery and Peck, 1992), and commonly accepted as the cut-off value to consider variables as non-collinear (Zuur et al., 2009). As such, all predictor variables were used in subsequent modelling procedures. The favourability model obtained acceptable scores according to the evaluation indices used to estimate discrimination and classification capacities. Discrimination capacity measured by the index AUC was 0.724 or “excellent” according to Hosmer and Lemheshow (2000). In general, the classification indices indicated that the model correctly classified registered presences of maned wolves (CCR> 0.70). Specifically, the model was slightly better at classifying territories as being of low favourability for maned wolf activity (specificity= 0.743), than at classifying territories as being favourable (sensibility= 0.621) (Table 2).

Territory with maned wolf activity

We detected 54 locations with maned wolf presence: 36 confirmed by faeces, 11 by footprints and 7 by visual observation. The maned wolf presence records defined two main populations in the study area: one at the far north in the SPSP, and another at the southern end in the INP, with smaller populations scattered in between (Fig. 2). All these populations were located in areas with the highest concentrations of high-altitude fields above 2,000m a.s.l (Appendix A, Fig. A.1). These include two small populations, one in the north and another on the edge of the SPSP, that are located in areas where part of the natural fields have been converted to pastures, mainly signal grass (*Brachiaria decumbens*) and molasses grass (*Melinis minutiflora*).

All the regions within the Serra da Mantiqueira Mountains study area were classified as being of at least intermediate favourability for maned wolves ($F \geq 0.2$). A core regional nucleus of high favourability ($F \geq 0.8$) for maned wolves was identified in the south of the study area in the INP, and three small highly favourable core areas more to the north in the SPSP. Furthermore, 92% of the grid cells classified as being highly favourable for maned wolf presence were in high-altitude fields, above 2,000m a.s.l (Fig. 3).

Environmental drivers of favourability for maned wolves

Only five of the eighteen candidate environmental predictors explained the activity patterns of maned wolves in the study area: high-altitude fields, slope; high coverage of upper montane vegetation refuges; high coverage of agriculture fields; and dense-mixed ombrophilous forest, ordered in decreasing relative importance according to a Wald's test (Wald, 1943) (Table 3).

With respect to human activity in the study area and surroundings, we observed domestic animals (horses and cattle) and evidence of grazing, even in natural fields in the SPSP. Beyond this, more than half the local people interviewed mentioned that they had seen maned wolves in areas surrounding the INP (n = 37; 52.8%); and half of them stated that these records have increased in the last five years (n = 35; 50%), especially in rural areas of Resende county (Appendix A, Fig. A.2 photo A). Moreover, the team of environmental managers from the municipalities of Itatiaia and Resende reported maned wolf presence in industrial areas of both cities (Appendix A, Fig. A.2 photos E-G). In terms of detecting human conflicts in the surroundings of the study area, on the one hand, only eighteen percent of the interviewed local people reported maned wolf attacks on small domestic animals (n = 13; 18.5%), such as chickens. On the other hand, ten percent reported maned wolf killing as a retaliation measure (n = 7; 10%), and only four reported deaths as a result of road collisions (n = 4; 5.7%).

Informal interviews with park rangers also confirmed the use of anthropogenic areas by maned wolves. However, there were no reported conservation conflicts (death by retaliation) within the INP. Rangers reported one adult and one juvenile maned wolf consuming rubbish in a dump and exploring camping areas of the INP. The use of such anthropogenic areas was confirmed by scat analysis, as we detected plastic material in maned wolf faeces (Appendix A, Fig. A.2 photo C).

Discussion

Maned wolf activity and drivers in the Serra da Mantiqueira

The Serra da Mantiqueira has been described as a central part of the maned wolf's distributional range, based both on high population density and on high favourability compared with other parts of its range (Queirolo et al., 2011; Coelho et al., 2018). However, our results show that there is a gradient of favourability of areas for the maned wolf within the Serra da Mantiqueira when examined at the local scale. Indeed, we found the areas with the most favourable conditions for maned wolf activity are concentrated at the far north of the SPSP and in the southern part of the study area, on the border between SPSP and INP.

In common with other authors (Dietz, 1984; Queirolo et al., 2011; Coelho et al., 2018), we found that areas of high altitude (above 2000m a.s.l.) with low cover of upper montane forest, and with open habitats such as high-altitude fields or even agricultural fields, are more favourable for maned wolves. Areas of upper montane forest likely appear favourable as a result of the abrupt classification of the vegetation (Segadas-Vianna and Dau, 1965), when in reality there is a relative transition between the different types of vegetation, forming a mosaic (Appendix A, Fig. A.1). For example, in the SPSP area up to 2,314 m a.s.l., there are large areas of high-altitude fields that form a matrix containing natural patches of upper montane forest of different sizes (see Ribeiro et al., 2018). The model indicated a positive relationship between the coverage of agricultural areas and the regions with higher favourability for maned wolf activity, which probably reflects the relative ease with which maned wolves can move through and use these open areas, compared with the Atlantic forest vegetation they have replaced (Dietz, 1984; Queirolo et al., 2011; Coelho et al., 2018). In fact, the agricultural areas in our study region are concentrated mainly in the north of the SPSP, as well as in the surrounding areas further south where the model indicated intermediate and high favourability.

Maned wolf activity in high-altitude fields in the Atlantic forest mountains

Modelling showed that the high-altitude natural open fields of the Serra da Mantiqueira are more favourable for activity of maned wolves. This is perhaps unsurprising given that these areas show similar structural characteristics to the grasslands of the Brazilian savannah, where the maned wolf evolved (Coelho et al., 2008; Jácomo et al., 2009; Queirolo et al., 2011). This ecosystem is restricted to higher elevations of the Atlantic forest in south-eastern and southern Brazil, and has many endemic and endangered plant and animal species (Martinelli, 1996; Safford, 1999; Aximoff, 2011; Carvalho et al., 2015; Ortiz et al., 2017; Aximoff et al., 2018). Although Rosa et al. (2015) detected maned wolf faeces in semi-deciduous forests in the county of Itamonte, our model indicated it is common for species to avoid the forested areas, especially those with a dense understory which makes movement more difficult for maned wolves (Childs-Sanford, 2005; Coelho et al., 2008; Massara et al., 2012).

The higher favourability of high-altitude grasslands for maned wolves may also be related to their feeding habits. *Solanum lycocarpum* (Solanaceae) is one of the main food sources for maned wolves in the Serra da Mantiqueira (Rosa et al., 2015). This plant occurs in both Brazilian savannahs and the Atlantic Forest, being more common in open habitats (Mentz and Oliveira, 2004; Stehmann et al., 2014). Moreover, *Solanum* is a genus that exhibits higher species richness and abundance with increasing elevation along the mountain ranges of South America. The occurrence of *Solanum* sp. in several regions, and mainly in higher areas in mountain ranges in the Atlantic Forest (Knapp, 2002), may also be contributing to the spread of the maned wolf into those areas (Bueno and Motta-Junior, 2009). Indeed, given that records of maned wolf in the high-altitude grasslands have been made in the region for several decades, registered for the first time in 1954 by Avila-Pires and Gouvea (1977), we suspect that the occurrence of maned wolves in these areas is probably natural and not the result of the current colonization of recently cleared forest, as detected in other regions (Bueno and Motta-Junior, 2009; Queirolo et al., 2011).

Human-maned wolf conflicts

Human-wildlife conflict is one of the main threats identified for maned wolves, especially in rural areas (Paula et al., 2013), which are the dominant landscapes in the vicinity of the two Protected Areas studied. Despite detecting maned wolf activity in the vicinity of urban and peri-urban environments (see photos in Appendix A, Fig. A.2), the modelling procedure did not identify human influence within protected areas as a direct driver of maned wolf activity. Indeed, although domestic grazers such as horses and cattle were observed in the SPSP, the number of animals per unit area is very low and the SPSP management team has on-going programs to eliminate livestock grazing within the park (Carvalho et al., 2015; Mendonça, 2017). This result shows that the two protected areas have been effective in the conservation of this near endangered canid. On the other hand, the surveys surrounding the Serra da Mantiqueira mountains (in the buffer zone) highlighted the existence of some human-maned wolf conflicts related with incidences of attacks on poultry, with subsequent persecution and retaliatory killing of maned wolves. So, we would recommend management and awareness plans in the towns near these points. Furthermore, as we have documented (see Appendix A, Fig. A2 photo C), consumption of waste by maned wolves has been increasing in urban areas, but also in protected areas, with unknown consequences for maned wolf populations (Aragona and Setz, 2001; Massara et al., 2012; Silva and Talamoni, 2003). Such increases, typical of more generalist species, should be monitored to identify the tipping point, from which the negative impact on maned wolfs starts to be greater than the possible advantages of exploring easy to access and easy to use resources close to humans. In addition, educational programs on the correct disposal of rubbish, with more effective enforcement (perhaps with fines), should be carried out with tourists, researchers and employees of both Protected Areas.

Maned wolf conservation in the Serra da Mantiqueira mountains

The Serra da Mantiqueira mountains are considered a conservation priority site within the Atlantic Forest, owing to large forest remnants and threatened high-altitude natural grassland fields that host biodiversity-rich communities of animals and plants (Le Saout et al., 2013; Martinelli, 2007; Ribeiro et al., 2009). It should be noted that the threats that currently impact the region include real estate speculation, construction of hydroelectric dams and opening of fields for mining (Carvalho et al., 2015; Ferreira et al., 2014). Thus, conservation measures aiming to maintain the integrity of high-altitude grasslands are crucial to ensure that maned wolf habitat requirements are met, thus avoiding population decline as required in its management plan (see Paula et al., 2008). The species has large home range requirements, and as such conservation programs for maned wolves must help to guarantee the preservation of large areas of land (Caro, 2010), including the buffer zones of protected areas, which are also very important for the local fauna (Paolino et al., 2016; Xavier et al., 2018).

Beyond this, here we have applied a novel methodology (the favourability function) to determine the range of activity movement of a species, allowing us to identify favourable territories for maned wolf home ranges within the Serra da Mantiqueira. Thus, the identification of favourable areas in a specific geographic space within a region of high favourability, allows the detection of regions more likely to be used during daily movements. Here we highlight that in the INP and SPSP there is a structure-oriented habitat preference, with a clear preference for grasslands or other open environments such as agricultural fields, despite their differing from the Cerrado habitats where the species historical presence was previously known. This may indicate that maned wolf conservation actions in the Serra da Mantiqueira should be adapted to the specific characteristics of the favourable areas for home range activities, and such a territorial management approach for maned wolf conservation has already been highlighted as a solution by other authors (Massara et al., 2012; Moraes et al., 2015; Rodrigues and Oliveira, 2006).

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Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interest

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Tables

Table 1: Variables and factors used to model the maned wolf activity patterns. In bold the variables used in the modeling procedure by overcoming multicollinearity and correlation filters.

Abbreviation	Variable/Factor	Sources
	Topography	
ME	**Mean elevation (m)**	Obtained from Instituto Nacional de Pesquisas Espaciais (INPE, 2019). http://www.dsr.inpe.br/topodata/
S	**Slope**	Calculated from elevation.
$O_{N/S}$	**Orientation N/S**	Calculated from slope.
	Land use	
AGR	**Agriculture (%)**	
DOF/MOF	**Dense Ombrophilous Forest / Mixed Ombrophilous Forest (%)**	
UMDOF	**Upper Montane Dense Ombrophilous Forest (%)**	
LIV	Livestock (%)	
SF/MOF	Seasonal Forest/Mixed Ombrophilous Forest (%)	Extracted from the Brazilian Institute of Geography and Statistics – IBGE (2004).
SSMF	Seasonal Semideciduous Montane Forest (%)	
UMVR	Upper Montane Vegetational Refuges (%)	
FS	Forested Savannah (%)	
GWS	**Gramineous-Woody Savannah (%)**	
SVI	Secondary Vegetation Initial (%)	
	Human activities	
PobDen	Population density (inhabitants'	Gridded Population of the World (GPW-v4).

	number×$[km^2]^{-1}$)	Socioeconomic Data and Applications Center (SEDAC). Hosted by CIESIN at the Columbia University. 2010. https://sedac.ciesin.columbia.edu/data/collection/gpw-v4/
	Vegetation Bands	
HAF	**High-Altitude Fields (%) (above 2,000 a.s.l.)**	
UMF	**Upper Montane Forest (%) (ca. 1,501 to 2,000 m. a.s.l.)**	Based on the classification described by Segadas-Vianna and Dau (1965).
MF	Montane Forest (%) (ca. 501 to 1,500 m. a.s.l.),	

Table 2: Evaluation of the maned wolf favourability model, showing the discrimination and classification indices values, AUC = area under the ROC (receiving operating characteristic) curve; CCR = correct classification rate; UPR = under prediction range; OPR = over prediction range.

Evaluation Indexes		**Favourability model**
		Maned wolf
Discrimination	AUC	0.723
Classification (thresholds of 0.5)	Sensitivity	0.507
	Specificity	0.823
	CCR	0.742
	UPR	0.172
	OPR	0.5

Table 3: Predictor variables included in the maned wolf favourability model. Signs in brackets show the positive or negative relationship between favourability and the variables in the models. The Wald parameter indicates the relative weight of every variable in the Maned Wolf model.

Variable	*Sign*	Wald
High-Altitude Fields	(+)	27.953
Slope	(+)	7.072
Upper Montane Vegetation Refuges (%)	(+)	5.566
Agriculture (%)	(+)	4.776
Dense Ombrophilous Forest (%)	(+)	4.093

Figure captions

Fig. 1 (A) South America highlighting in the box the location of the Serra da Mantiqueira in Brazil; and (B), the protected areas where the study was carried out, along the elevational gradient of the Mantiqueira Range: INP – Itatiaia National Park and SPSP – Serra do Papagaio State Park.

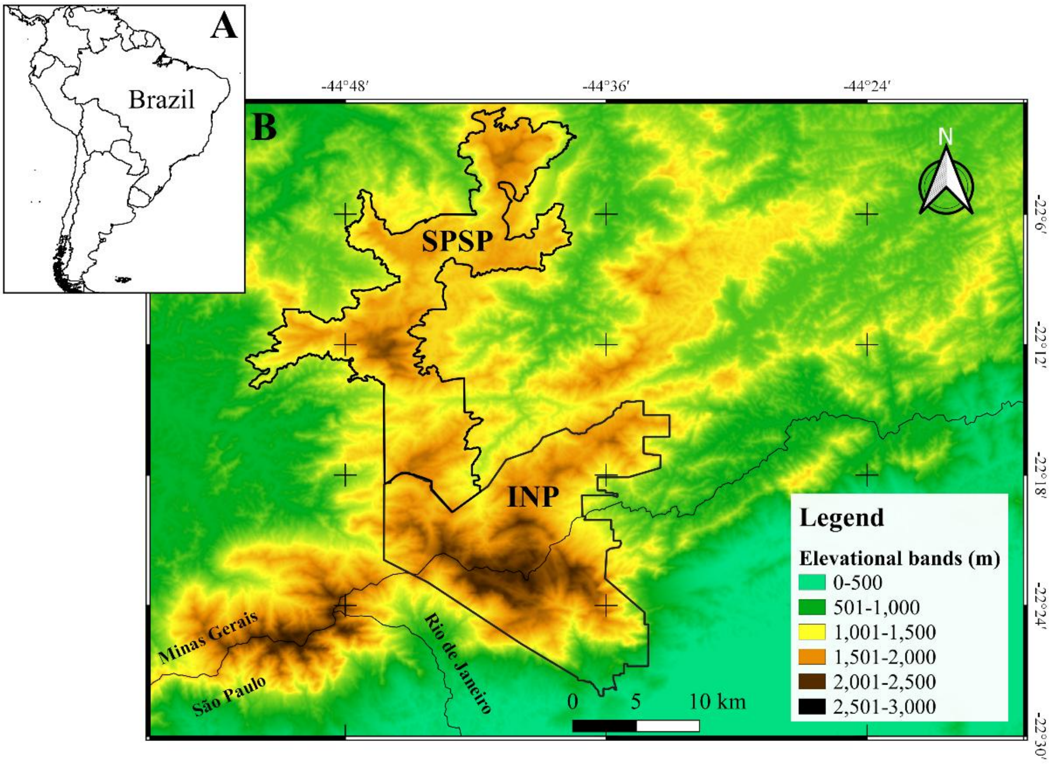

Fig. 2 Maned wolf presence records and buffer of activity (shown in grey) in the Serra da Mantiqueira in Brazil; and (B), the area with maned wolf activity in black and with no activity in white. INP – Itatiaia National Park (INP); SPSP – Serra do Papagaio State Park (SPSP).

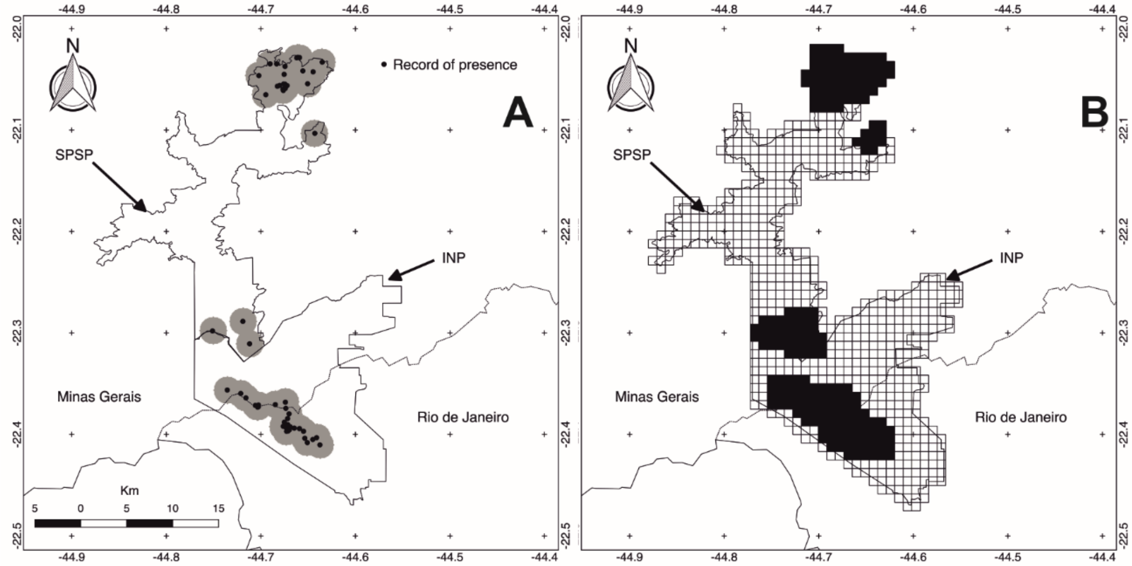

Fig. 3 Maned wolf favourability map, showing the favourable areas for maned wolves in the Itatiaia National Park (INP) and the Serra do Papagaio State Park (SPSP). Favourability values are shown in grayscale; from 0 to 1, where 0 indicates unfavourable areas and 1 the most favourable areas according to the environmental conditions analysed. No grid obtained unfavourable values (f<0.2).