Predicting the current distribution of the Chacoan peccary (*Catagonus wagneri*) in the Gran Chaco

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Abstract

The Chacoan peccary (*Catagonus wagneri*), or Tagua, an endemic species living in the Chaco eco-region, is endangered by highly increasing deforestation rates across the region, particularly in the last decade. This situation highlights the need to better understand the current distribution of the species, as well as how environmental conditions affect habitat suitability. This study predicts the distribution of the Chacoan peccary and evaluates the current environmental conditions in the Chaco for this species. Using six environmental variables and 177 confirmed occurrence records (from 2000 to 2015) provided by researchers, we developed a Species Distribution Model (SDM) applying the Maxent algorithm. The final model was highly accurate and significant ($p < 0.001$; AUC 0.860 ± 0.0268; omission error 1.82 %; post-hoc validation of omission error using independent presence-only records 1.33 %), predicting that 46.24 % of the Chaco is suitable habitat for the Chacoan peccary, with the most important areas concentrated in

the middle of Paraguay and northern Argentina. Land cover, isothermality and elevation were the variables that better explained the habitat suitability for the Chacoan peccary. Despite some portions of suitable areas occurring inside protected areas, the borders and the central portions of suitable areas have recently suffered from intensive deforestation and development, and most of the highly suitable areas for the species are not under protection. The results provide fundamental insights for the establishment of priority Chacoan peccary conservation areas within its range.

Introduction

The Chacoan peccary (*Catagonus wagneri*) is an endemic species living in the Chaco eco-region (Mayer and Wetzel, 1986; Redford and Eisenberg, 1992; Taber, 1993). Evolutionary speaking, the species represents a very distinctive and unique pattern (Gasparini et al., 2011). Due to a serious decline in numbers and range size of Chacoan peccary, it is considered "Endangered" by the IUCN Red List (Altrichter et al., 2015). The species' geographical range has been reduced in the three countries it occupies: Argentina, Bolivia and Paraguay (Altrichter, 2006; Neris et al., 2002). Due to their behavior and their low reproductive rate, Chacoan peccaries are vulnerable to human disturbance (Taber et al., 1993; Altrichter and Boaglio, 2004). The presence of the species is associated to native forests (Taber et al., 1993; Altrichter and Boaglio, 2004; Saldivar-Ballesai, 2015; Camino, 2016) and therefore Chacoan peccaries may be seriously threatened by the increasing deforestation rates in the Gran Chaco (Cardozo et al., 2014; Vallejos et al., 2014). This threatening situation attracted the attention of conservation scientists in an attempt to protect the Gran Chaco, and develop a current strategy to prevent the peccary's extinction. One of our most urgent goals was to re-assess the current distribution of the species, as well as understand how habitat conditions and characteristics (e.g. land cover, climate and topographic variables) affect the suitability of the habitat for implementing proper conservation measures.

Species Distribution Models (SDMs) are an important tool often used to assess the relationship between a species, its distribution, and the environmental conditions. They integrate species occurrence records and environmental variables to develop environmental suitability maps for a species in space and time (Peterson, 2006; Pearson, 2007; Elith and Leathwick, 2009). SDMs have been used not only to describe the environmental requirements of a species, but also to be applied for: identifying sites for translocation and reintroduction of species (Peterson, 2006; Jiménez-Valverde et al., 2008), identifying priority areas for conservation (Morato et al., 2014), managing invasive species (Ficetola et al., 2007), assessing species distribution in human-modified landscapes (Ferraz et al., 2010; Angelieri et al., 2016) and finally predicting biodiversity response to both climate change (Adams-Hosking et al., 2012; Freeman et al., 2013; Lemes and Loyola, 2013) and land use change (Ficetola, 2010; Angelieri et al., 2016). In summary, SDMs also provide important elements for future conservation planning and management (Araújo and New, 2006).

With the goal of determining priority conservation areas and generating information for appropriate conservation strategies, we used a SDM with occurrence records provided by researchers, and then corroborated by the attendants to the Chacoan peccary conservation planning workshop held in Asuncion, Paraguay. The objectives of this study were: (1) to predict the Chacoan peccary distribution, and (2) to evaluate the current environmental conditions of the

Chaco for the species occurrence. The SDM developed was evaluated for accuracy by the specialists considering the current known distribution of the species.

Materials and Methods

Study area

Predictive models for the Chacoan peccary were generated for the full extent of the Gran Chaco region (1,076,035 km^2 in the central South American, Fig 1). The Chaco ecoregion (Olson, 2000) includes territories of western and central Paraguay, southeastern Bolivia, northwestern Argentina, and a small part of Brazil. The predominant habitats in the Gran Chaco include a seasonal, open to semi-open palm savanna and grassland (Wet or Humid Chaco), and a low, closed-canopy seasonal or semi-arid deciduous thorn forests (Dry Chaco); many areas incorporate a gradient between this two environments. The Dry Chaco is dominated by thorny bushes, shrubs, and cacti, with dense, closed canopy trees up to 13 m high called “Quebracho woodland” (Short, 1975). Some of this impenetrable primary thorn forest still remains in the region, and its isolation led to the discovery of new species of endemic vertebrates, including the Chacoan peccary, as recently as the 1970’s (Wetzel et al., 1975). Since then however, this region has become more developed and deforestation has increased rapidly in the last few years; total deforestation in the Chaco account for 265.169 ha in 2010, 336.445 ha in 2011, 539.233 ha in 2012, and 502.308 ha in 2013 (Cardozo et al., 2014).

Data collection

Through expert consultation we gathered 177 Chacoan peccary presence records (e.g. sightings, camera trapping, capture, feces, tracks, interviews, etc.) occurring between 2000 and 2015 (Fig 2a). All presence points used for modeling and validation represented accurate records with exact

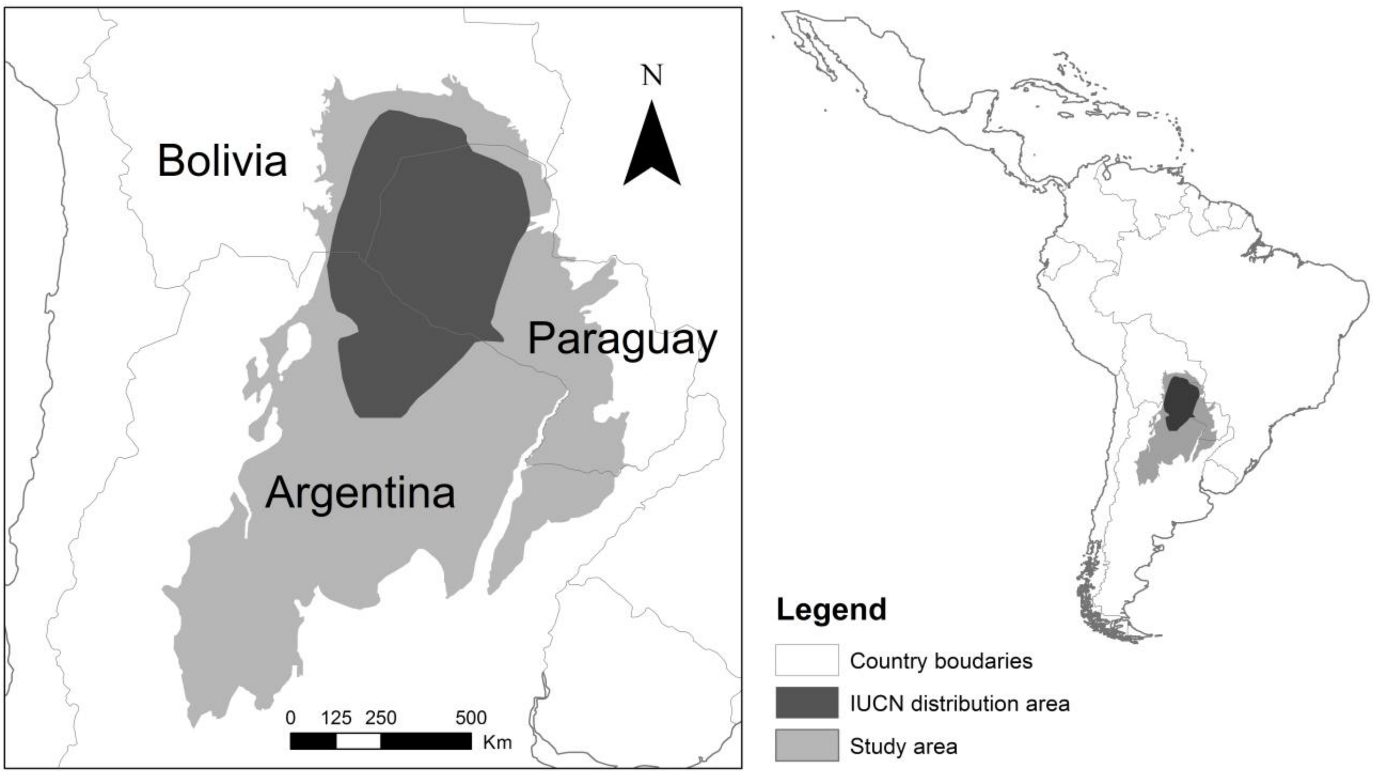

Fig 1. Map of the study area for the Chacoan peccary distribution model.

locations. In order to reduce spatial autocorrelation and to compensate biases in data that usually occur when some areas in a landscape are sampled more intensively than others (Elith et al., 2011), we used the spatially rarefied occurrence data to produce SDMs via the SDM Toolbox v1.1b (Brown, 2014), which resulted in 87 spatially independent presence points used for the modeling process (Fig 2a). The predictive ability of the average SDM was tested by plotting a new, independent dataset (not used for modeling, N = 990), against species presence records sampled after 2000 (Fig 2b).

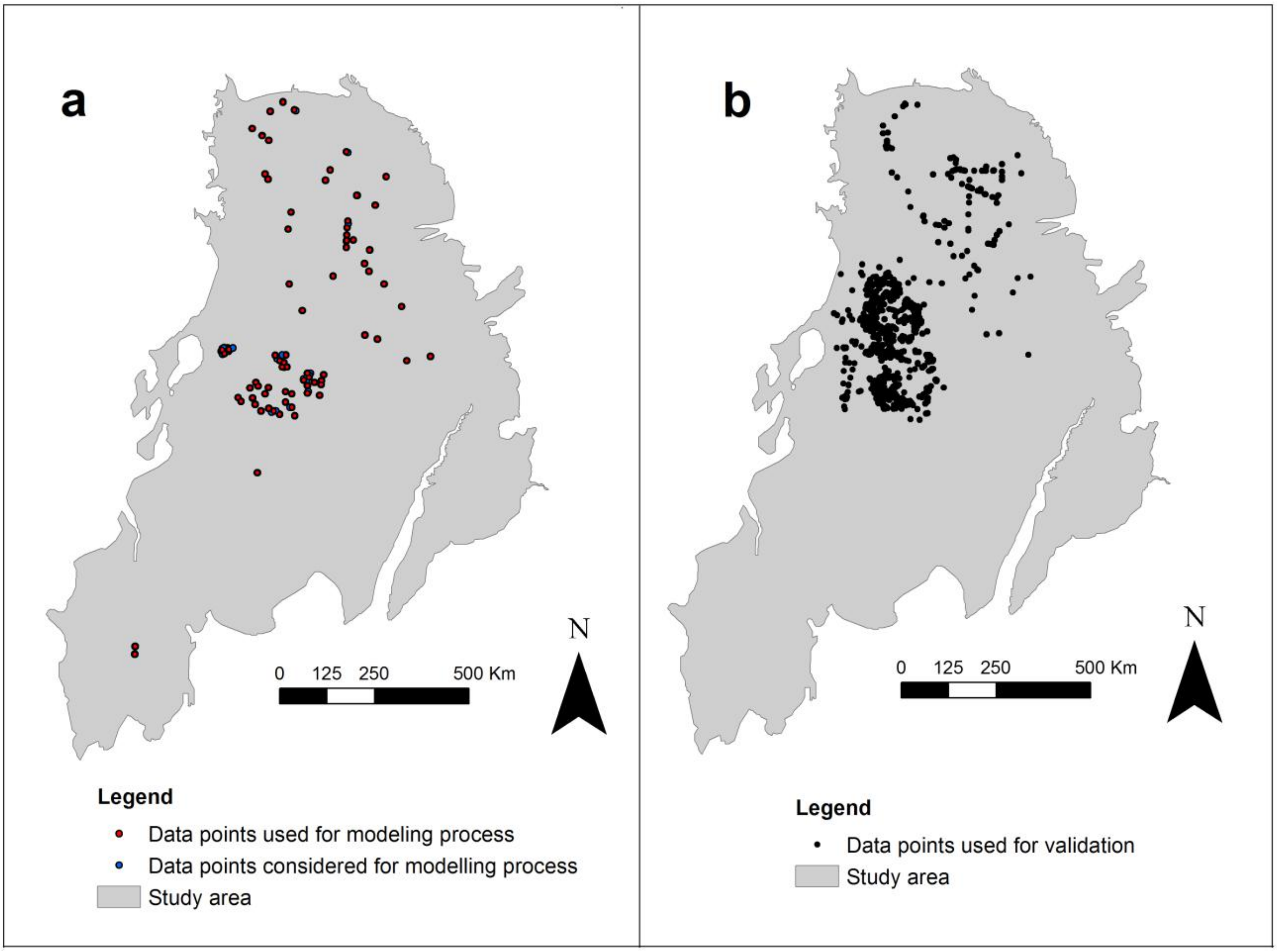

Fig 2. Chacoan peccary presence records considered (N=177) and used (N=87) for modeling (a) and presence points used for model validation (N=990) (b).

Environmental variables

We initially selected 21 environmental variables (i.e., 19 bioclimatic variables plus elevation and land cover) to examine for inclusion in our SDM's. After analyzing autocorrelation among variables, 15 were discarded (correlations > 0.7), leaving only six environmental variables to be used as model predictors (Table 1; Figure 3) at a spatial resolution of 0.0083 decimal degrees (~1 km^2).

Tab. 1. Environmental variables used for predictive models.

Variable	Description	Year	Source
Elevation	Map of elevation	2004	NASA Shuttle Radar Topography Mission
Globcover with deforestation	Map of land cover classes, with deforestation included	2009	Globcover map from ESA GlobCover 2009 Project Deforestation map from Guyra Paraguay
Bioclimatic variables	Bio 1 = Annual mean temperature Bio 2 = Mean diurnal range Bio 3 = Isothermality* Bio 12 = Annual precipitation		Data layers from Worldclim global climate variables

Isothermality = Mean diurnal range (Mean of monthly (max temp - min temp))/Temperature annual range) (100)

Modeling procedures

Species Distribution Models (SDMs) were generated using a maximum entropy algorithm via the program Maxent, version 3.3.3.k (Phillips et al., 2006; Phillips and Dudik, 2008). Maximum entropy is a widely accepted and used algorithm for modeling species distribution, generally performing better than alternative approaches (Elith et al., 2006; Elith and Graham, 2009). In particular, Maxent proposes a target probability distribution for a species by estimating the distribution of maximum entropy (i.e., the distribution that is closest to uniform, or most “spread out”) as it is constrained by missing information about that target distribution (Phillips et al., 2006).

SDMs were generated using bootstrapping methods with 10 random partitions with replacement using 70 % of the full dataset for training models and 30% for testing (Pearson, 2007). Parameters set for all runs were based on a convergence threshold of 10-5 with 500 iterations, and with 10,000 background points. The average model was cut off by the

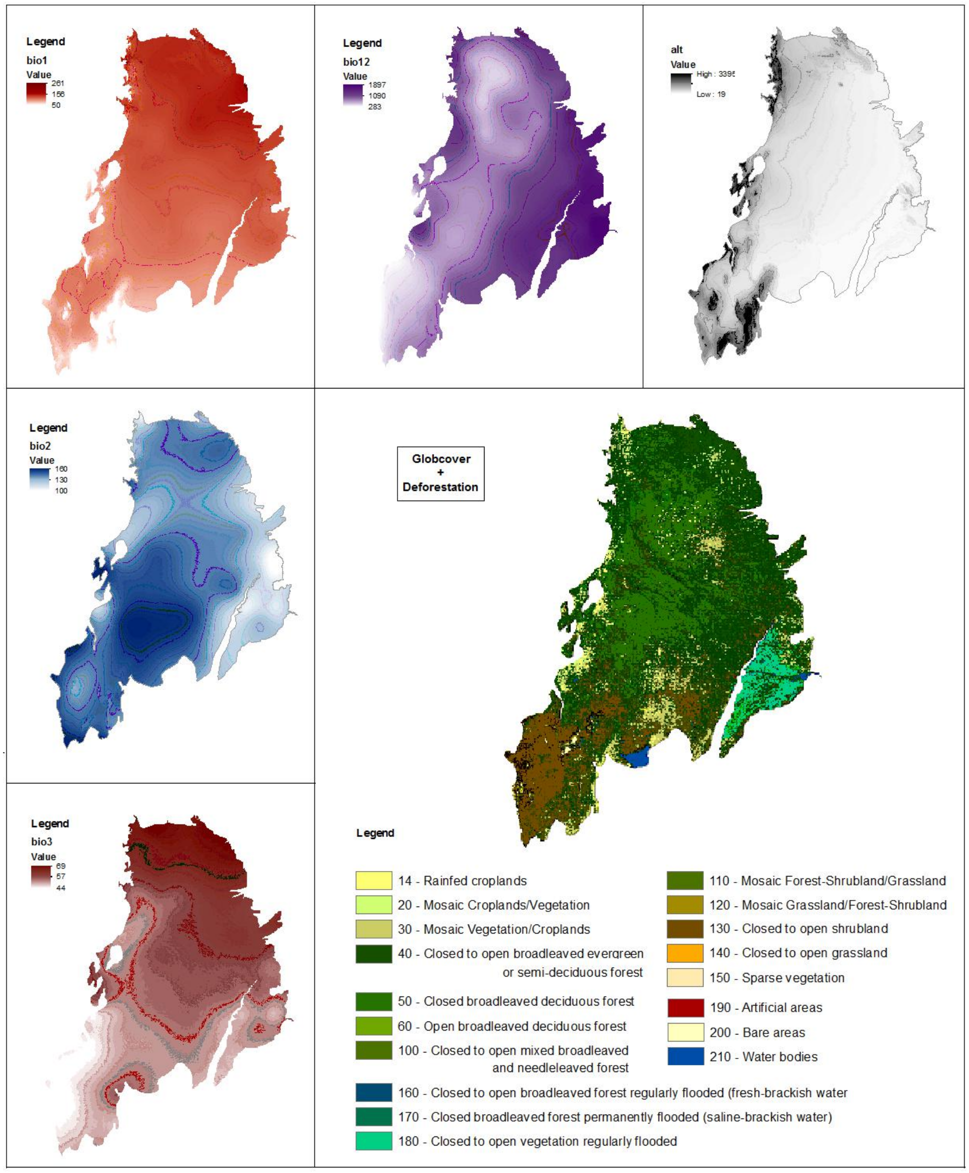

Fig 3. Environmental variables used in the Chacoan peccary model.

minimum training presence logistic threshold (0.0975), which resulted in a binary map (0 = unsuitable, 1 = suitable). When multiplied by the average model, this binary map yielded the final model describing the probability of the species occurrence in the biome. The final model was evaluated by AUC value, binomial probability and omission error (Pearson, 2007).

Maxent's average distribution model was also categorized into three habitat suitability classes: low suitability (values from 0.0975 ≤ 0.25), medium suitability (0.25 ≤ values ≤ 0.50) and high suitability (0.50 ≤ values ≤ 1) with the manual classification method using the reclassify tool in ArcGIS 10.1 Spatial Analyst. A shapefile of areas of varying protection levels was provided by the IUCN PSG [Peccary Specialist Group], 2016, which and converted into a raster dataset to create the current protected areas file. ArcGIS 10.1 Spatial Analyst Zonal tool was then applied to cross-tabulated areas between the suitability area classes and the protected areas zone.

Results and Discussion

Predictive distribution model for the Chacoan peccary (0.860 ± 0.0268) was highly significant (p < 0.001) with low omission error (1.82 %) (Fig 4a). The post-hoc validation using the independent presence-only records confirmed that the model was highly accurate, with only 1.33 % of omission error. The model predicted that 46.24% (~497,577.34 Km2) of the Gran Chaco is suitable for the Chacoan peccary (Fig 4b). Suitable areas are concentrated in the Paraguayan department of Presidente Hayes, Boqueron and Alto Paraguay, and in northern Argentina, especially near the borders of Formosa, Chaco, Salta and Santiago del Estero Provinces, as well as in the north-central portions of the Bolivian Chaco. The limits of the current distribution area have suffered intensive habitat loss due to recent land cover conversion, especially in Paraguay (Caldas et al., 2013; Cardozo et al., 2014), suggesting that the Chacoan peccary distribution range is probably retracting rapidly.

Deforestation rates in Chaco were among the highest of the world between 2000 and 2010 (Aide et al., 2013; Hansen et al., 2013) and potentially affecting the distribution of Chacoan peccaries. In Bolivia, deforestation remains low, however, in both Argentina and Paraguay deforestation is associated to intensive agriculture and cattle production (Caldas et al., 2013; Piquer-Rodriguez et al., 2015). Moreover, there is an expanding urban area (i.g.

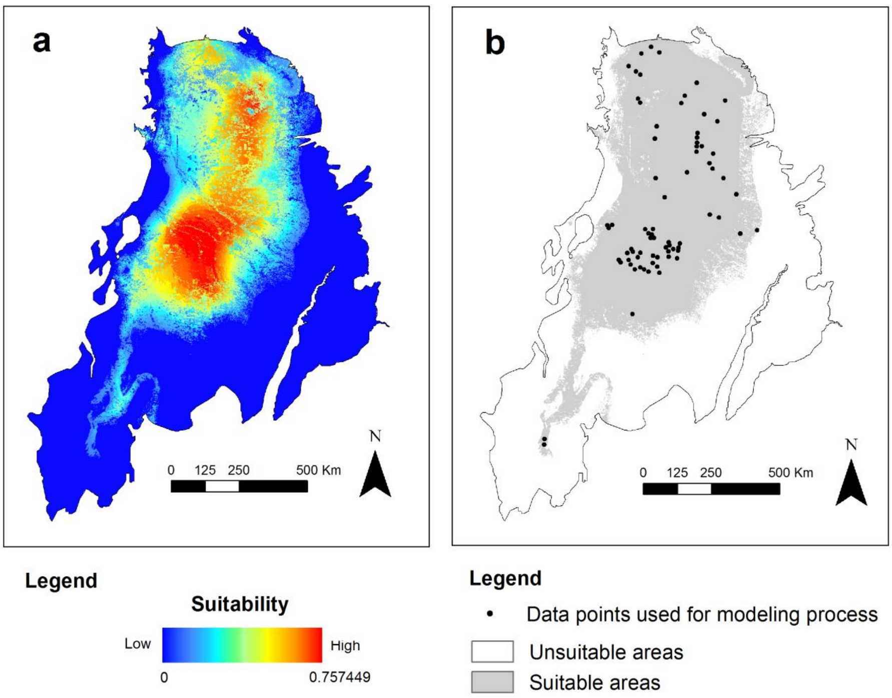

Fig 4. Predictive distribution model of Chacoan peccary. (a) Maxent average model shows the continuous suitability of the Chaco for the species. (b) Categorical suitable and unsuitable areas.

the city of Filadelfia) in the center of the high suitability area in Central Paraguay and the species is one of the most hunted animals in the Dry Paraguayan Chaco (Neris et al., 2010).

The three variables that better explained the predictive distribution model were land cover (31.57 %) (Fig 5a), isothermality (22.52%) (Fig 5b) and elevation (21.60%) (Fig 5c). Suitable areas for Chacoan peccary were characterized by closed broadleaf deciduous forest so called Chaco-Quebracho (Paraguay) and Chiquitano (Bolivia) woodlands (57.93 %), closed to open broadleaf forest/shrubland (21.86 %) and by mosaic vegetation/cropland (13.67 %). The association between suitable habitat and forest cover is probably positive, as found in previous studies (Taber et al., 1993; Altrichter and Boaglio, 2004; Camino, 2016). However, this is the first published study that shows that the species' habitat is composed of closed and semi-deciduous forests, and forests with shrublands. As far as we know, no other study differentiated the type of forests used by this species.

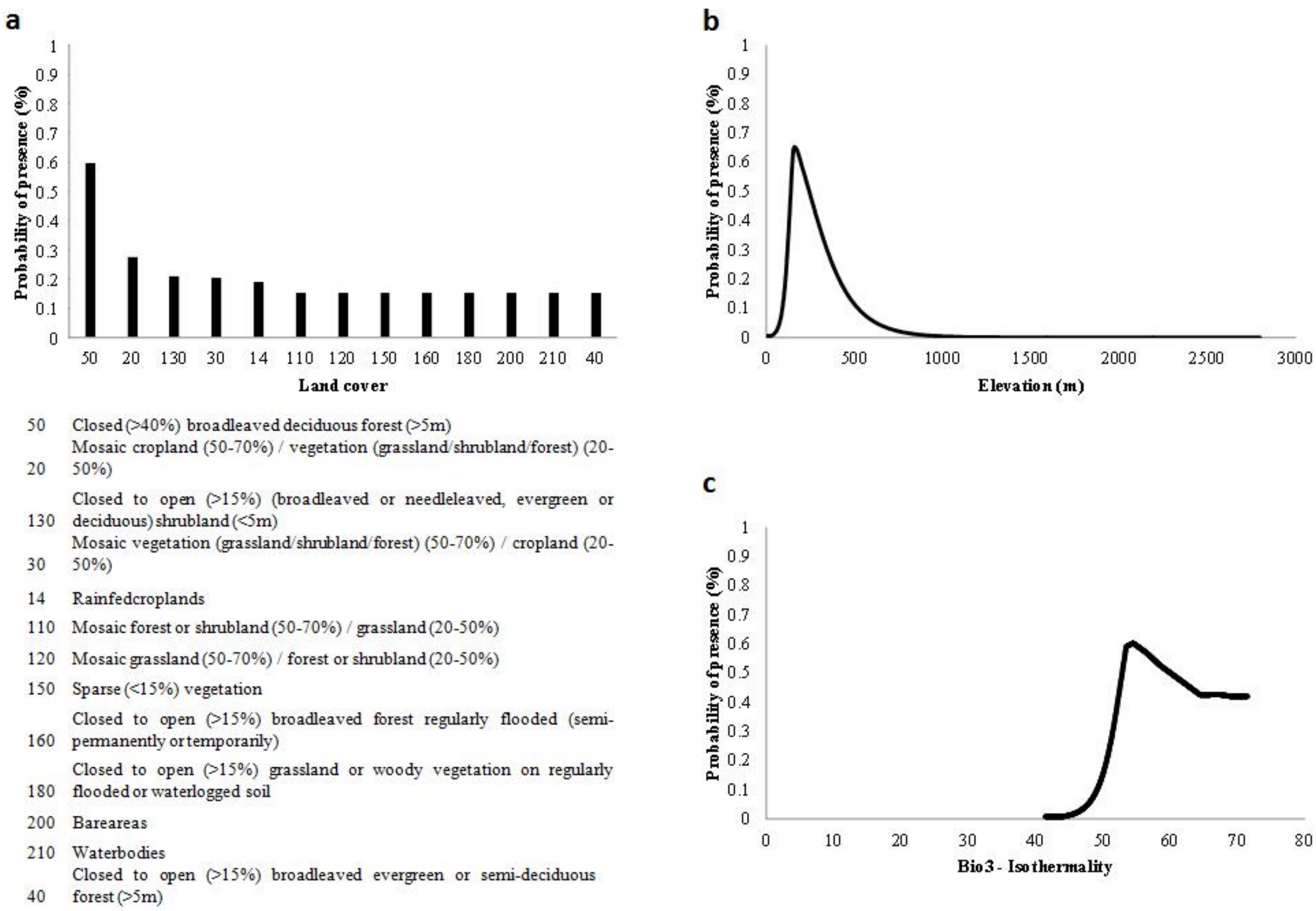

Fig 5. Response curves of probability of presence (%) according to Land Cover (a), Elevation (b) and Bio 3 – Isothermality (c).

Despite that some portions of suitable areas are legally protected, most parts of highly suitable areas for the species are not included in an official protection system. Less than 17 % of the areas under some type of protection occur in areas suitable for the Chacoan peccary (Figure 6b), and only 12 % of high suitability areas for Chacoan peccary are protected in the Chaco (Table 2). Furthermore, when analyzing suitable areas by country, only 7 % of the high suitability areas in

Argentina, and 13% in Paraguay, are currently under some kind of protection. Therefore, the existent protected areas are not effective at protecting suitable areas for the Chacoan peccary. In Bolivia, almost 79% of the high suitability areas for the species are already under protection in the Kaa-Iya del Gran Chaco National Park; however, we believe that the suitability inside this inaccessible area may be underestimated due to a lack of presence records.

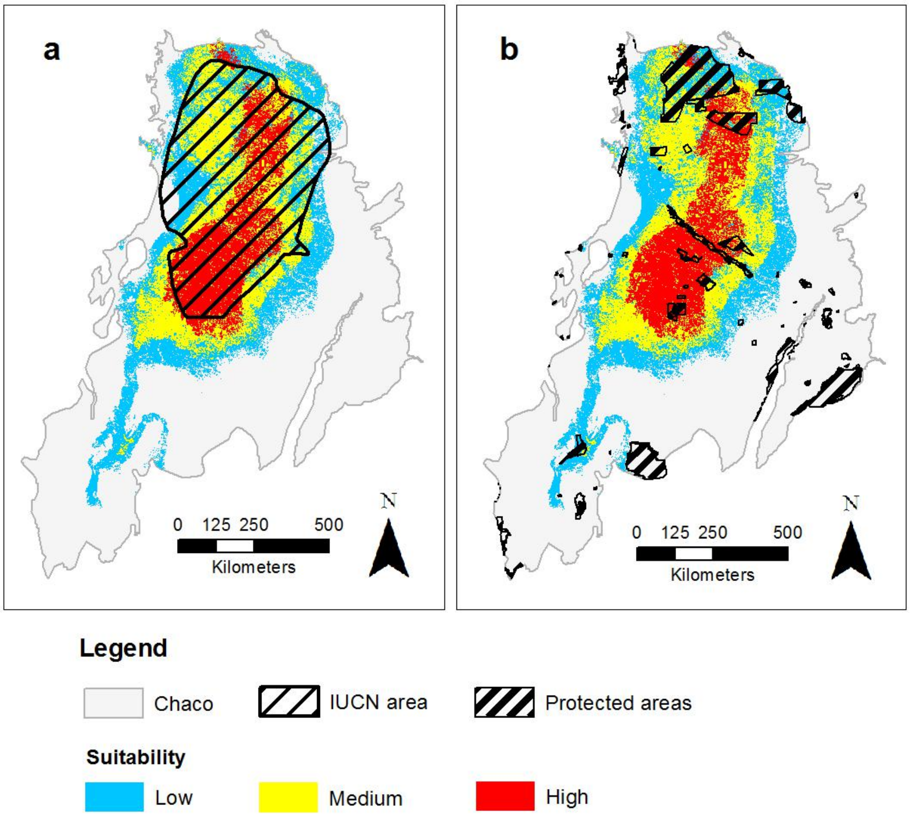

Fig 6. Suitable areas for the Chacoan peccary showing low suitability in blue (probability of presence from 0.0975 to 0.25), medium suitability in yellow (probability of presence from 0.25 to 0.50) and high suitability in red (probability of presence from 0.50 to 0.76), overlain with IUCN distribution area (a) and protected areas (b).

Finally, high suitability areas for the Chacoan peccary showed here must be considered as key localities for conservation efforts aiming to protect the species and its habitat, and to avoid human conflicts (e.g., hunting pressure), particularly if these areas are not protected by law. Such areas might also guide the establishment of new protected areas and their connectivity should be considered in land-use planning. A key factor for the successful conservation of the species will be to involve the indigenous people and the local pheasants, that historically occupied some of these areas (Camino et al., 2016). Regardless of which combination of approaches

	Argentina			Bolivia		
Suitability	Total area (km^2)	Protected (km^2)	%	Total area (km^2)	Protected (km^2)	%
Low	93,637.81	2,462.29	2.63	49,192.99	17,674.56	35.93
Medium	66,336.67	2,779.66	4.19	37,218.70	16,638.37	44.70
High	68,124.66	5,021.85	7.37	4,137.34	3,265.19	78.92

	Paraguay	All countries				
Suitability	Total area (km^2)	Protected (km^2)	%	Total area (km^2)	Protected (km^2)	%
Low	50,978.50	2,128.43	4.18	193,809.30	22,265.28	11.49
Medium	80,849.08	4,620.40	5.71	184,404.46	24,038.42	13.04
High	46,940.08	6,163.55	13.13	119,202.07	14,450.58	12.12

Tab 2. Suitable areas for Chacoan peccary (i.e. low, medium and high suitability) protected by country and in total across all countries.

are employed, urgent measures are needed to stop deforestation across the Gran Chaco, one of the most threatened ecological regions in South America today.

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