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A conservation landscape for the Dry Chaco based on species habitat suitability

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ABSTRACT

The Dry Chaco (DCH) is a biodiversity-rich region that contains the largest dry forest in the world. It is seriously endangered and has one of the fastest deforestation rates. Yet, very few conservation efforts have been undertaken to protect this ecosystem, and information to develop efficient and sustainable land-use plans is scarce. This study aimed to design a conservation landscape that would maximize the conservation of the DCH's ecological integrity, endangered species, and ecological and evolutionary processes. Five focal species of high conservation value were chosen based on their ecological roles, conservation status, or endemism: white-lipped peccary *Tayassu pecari*, chacoan peccary *Catagonus wagneri*, giant anteater *Myrmecophaga tridactyla*, tapir *Tapirus terrestris*, and giant armadillo *Priodontes maximus*. We used interviews with local informants to obtain information on species presence and location. Their habitat suitability was modelled and ranked using Maxent software. A conservation landscape was designed by overlapping these spatially explicit models. A systematic conservation planning framework was followed, considering habitat connectivity using Zonation. Interviews proved to be useful for conservation planning in this region with longstanding close ethnozoological relationships. The spatial design obtained was compared with existing land-use policies and protected areas to discuss conservation strategies that could be efficient if applied in the DCH and considering land sharing vs. land sparing conservation strategies. There is a large surface of suitable habitat for the studied species, but their conservation cannot be ensured with the present conservation schemes. We consider land-sharing as a feasible conservation strategy for this region and its species, and identified areas that should be preserved and their optimal connections to increase conservation opportunities for the Dry Chaco.

Keywords: Evolutionarily Distinct and Globally Endangered (EDGE) Species; Land-use Planning; Land-sharing; Large Mammals; Landscape.

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SIGNIFICANCE STATEMENT

In this work, a Conservation Landscape for the Dry Chaco in Argentina is proposed based on five Evolutionarily Distinct and Globally Endangered (EDGE) species and existing land-use plans. This work provides evidence for a land-sharing strategy as a feasible and more effective conservation action for this region and its species.

INTRODUCTION

Habitat loss is one of the main drivers of extinction globally (Balmford et al. 2012; Pimm and Raven 2000). The equilibration of human needs and conservation is urgent in subtropical dry ecosystems, which have received little attention from conservation schemes despite agricultural expansion driving deforestation at an accelerated rate, posing a serious threat to their biodiversity (Baldi and Paruelo 2008; Clark et al. 2010). One of these ecosystems is the Dry Chaco (DCH) of South America: it is severely endangered and has the fastest deforestation rate in the world, yet very few efforts for its conservation have been undertaken (Izquierdo and Grau 2009; Vallejos et al. 2015). The DCH is a biodiversity-rich region inhabited by many endemic and threatened species; it contains the largest continuous dry forest of the world and provides essential ecosystem services (Clark et al. 2010; Gasparri et al. 2008; Graesser et al. 2015). Despite this, the DCH is one of the least protected regions in Argentina (Izquierdo and Grau 2009; Marinaro et al. 2012).

Between 2008 and 2009, Argentina created the Forests Law to protect native forests (National Law No. 26.331; Piquer-Rodríguez et al. 2015); each province created a Territorial Planning of Native Forests (OTBN) classifying its forests into three categories according to conservation value: (1) red: areas of strict conservation; (2) yellow: areas of sustainable use, and (3) green: where all uses are allowed, including deforestation. The objective of the Forests Law was to ensure permanence and sustainability of native forests, but the application of this law at provincial level lacked sufficient information and transparency and, therefore, the designed territorial planning may not ensure environmental sustainability (García Collazo et al. 2013; Piquer-Rodríguez et al. 2015). Additionally, areas for strict conservation may be scarce, disconnected, and devoid of proper buffers, potentially jeopardizing the long-term conservation of large terrestrial mammals and the ecological processes with which they are associated (Ceballos 2005; Matteucci and Camino 2012; Piquer-Rodríguez et al. 2015). Although large areas of the DCH were classified as "sectors of medium conservation value", which may be degraded but, in the judgment of the jurisdictional enforcement authority, may have a high conservation value with the implementation of restoration activities, and may be subjected to the following uses: sustainable use, tourism, collection, and scientific research. Nevertheless, the Forest Law does not clearly define sustainability. Thus, many different activities are allowed in these areas without proper monitoring schemes, e.g., logging, extensive livestock ranching, and clearing the understory for growing exotic forage (García Collazo et al. 2013; Macchi et al. 2013; Mastrangelo and Gavin 2012). Therefore, although the Forest Law provides an excellent framework to conserve natural ecosystems, depending on the implementation of each province, it may not secure the Argentinean DCH's biodiversity, processes, and integrity.

This work aimed to provide scientifically-based information for better land-use planning that would maximize the conservation of the DCH's ecological integrity, endangered species, and ecological and evolutionary processes. This study also provides novel information about the focal species' ecology and habitat preferences, which is scarce and can be used to develop more effective conservation plans and actions locally and globally.

MATERIAL AND METHODS

Study Area

The Gran Chaco region covers over a million square kilometers and sustains a rich and unique diversity of species and processes (Dinerstein et al. 1995; Loyola et al. 2009; Morello and Adámoli 1974). The study area covered 54,000 km^2 of the Semiarid sub-region of the Dry Chaco ecoregion (DCH; (Morello et al. 2012), in Chaco, Formosa and Salta provinces in Argentina. This territory is highly seasonal, with 650–900 mm of rain falling mainly during spring and summer and a dry season in winter and autumn (Morello et al. 2012). The dominant vegetation is quebracho forest (*Schinopsis* spp. and *Aspidosperma quebracho-blanco*). There are also other types of forests, open woodlands, shrublands, and grasslands (Morello et al. 2012; Prado 1993). Human density is low, and populations in the area are mainly rural, with a few villages of 20–1300 households (Figure 1) (Altrichter 2008).

The study area contains the largest continuous forest of the Argentinean DCH and other natural land-covers, e.g., shrublands or grasslands (Piquer-

Rodríguez et al. 2015; Vallejos et al. 2015). This area is seriously threatened by accelerated deforestation as a consequence of the expansion of the agricultural frontier (Izquierdo and Grau 2009; Piquer-Rodríguez et al. 2015; Vallejos et al. 2015).

Focal species

A group of species was selected to develop a spatial prioritization of the study area, following the systematic conservation planning (SCP) framework (Knight et al. 2006; Kukkala and Moilanen 2013; Moilanen 2007; Watson et al. 2011). The focus was on large terrestrial mammals that have an intrinsic conservation value because they are endangered or vulnerable to extinction, they have critical ecological roles, and information about them is scarce and needs urgently to be obtained (Table 1) (IUCN 2016; Periago et al. 2014).

Species data collection

Fieldwork was conducted between November 2010 and December 2012 to collect information on the presence of the focal species. After delimitating the study area, random points were generated using a Geographic Information System (QGIS.org 2020). Then, using Google Earth 5.0 satellite images, we identified between one and three human settlements closest to the randomly selected location. Semi-structured interviews were conducted, which means that standard questions were asked in each separate interview, allowing comparison and maintaining data quality. This type of interview allows the interviewer to ask additional questions if an interesting information arises or new lines of enquiry develop during the interview. This flexibility is important for investigations of complex issues, such as studies on habitat suitability conservation (Young et al. 2018). As interviewees, we selected one person per family that often spend more than four days a week in the forests, which resulted in 100% of the interviewees being men between 17 and 70 years old dedicated to hunting, ranching or fruit gathering. Interviews were conducted in Spanish, lasted between one and four hours, and had the oral informed consent of the interviewee. Questions focused on the observations of the focal species in the area, type of record (sighting, footprint, faeces) and location of the record. When in doubt about the correct species identification or location, we repeated the visit the next day or as soon as logistics allowed. During these visits, interviewes often provided proofs of their reports (e.g., showing skulls of killed animals), and in some cases we conducted a fieldtrip to check for the presence of signs of these species locally. Interviews were complemented with observations in houses and settlements since some people use wild species or their body parts as ornaments or pets. All ambiguous answers were removed from the analysis.

Environmental variables

To model species' suitable habitats, we used the 19 bioclimatic variables of Worldclim, with a spatial resolution of 30' (cells of approximately 1 km^2; Hijmans 2012), and variables representing the extreme aridity of the region: annual aridity index, monthly and annual potential evapotranspiration (www.csi.cgiar.org). A layer of Euclidean distance to water sources was generated based on pond information and river representation from satellite images (Google Earth 5.0). As a proxy of human impacts, a layer of the Euclidean distance to human settlements was generated. Settlements were digitalized based on Google Earth 5.0 and Landsat 5 satellite images. We used QGIS for all spatial analyses.

Habitat suitability models (HS)

To develop HS, we used the software Maxent, which is based on maximum entropy and considers the distribution that maximizes entropy subject to constraints (Merow et al. 2013; Phillips et al. 2006). First, a preliminary model was developed for each species using all variables with 100 repetitions. Then different combinations of non-correlated explanatory variables with a high contribution to the preliminary model were selected based on the Spearman correlation coefficient. The area under the curve (AUC) was used (Guisan and Zimmermann 2000; Merow et al. 2013) to measure the general performance of the final models. The Akaike Information Criteria were used to select the best model, i.e., the simplest model that best fitted the data, to avoid over-parametrization AIC was corrected by sample size (AICc) (Burnham and Anderson 2002; Merow et al. 2013). The ENMTools and Maxent software packages were used to calculate AICc and AUC (Phillips et al. 2006; Warren et al. 2010). After this selection process, a final model was developed, based on 100 repetitions dividing the presence points into two sets: 75% to train the model and 25% to validate it (Phillips et al. 2006). For each HS, a threshold value was established based on field experience. Areas with values under this threshold were considered unsuitable: between the threshold and 0.55 had low suitability, between 0.56 and 0.75 had medium suitability, and between 0.76 and 0.9 were high suitability habitats.

To meet Maxent modelling assumptions, we avoided sampling bias by collecting field data with a random design, using a constant study area with regular cell numbers. Thus, comparing the species'

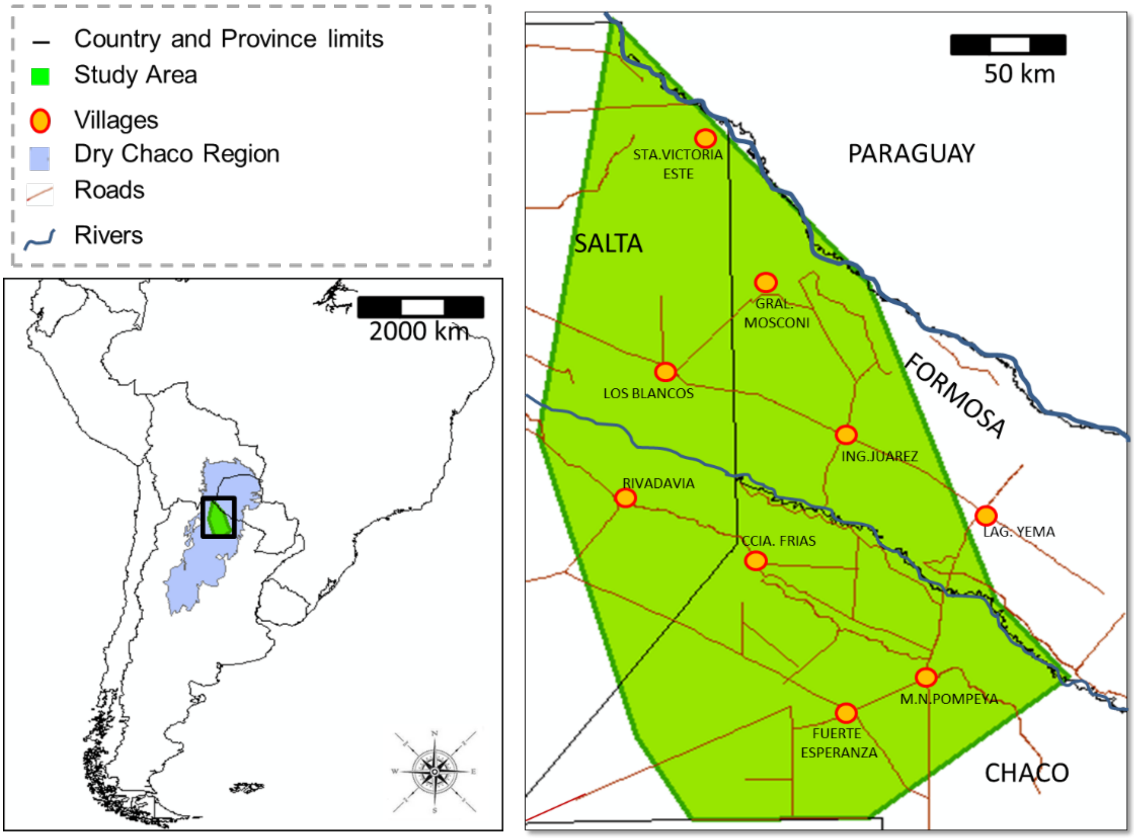

Figure 1. Study Area (54,000 km^2) in the Dry Chaco ecoregion (*sensu* Morello, 2012), in Salta, Formosa and Chaco Provinces, Argentina.

detections is always conducted against a stable background (Merow et al. 2013). The choice of logistic outputs (Merow et al. 2013) and evaluated resulting models were based on AUC (Elith et al. 2006) and also visually based on our field knowledge (Merow et al. 2013). HS of this study should not be extrapolated to the entirety of each species' geographic range.

Design of a conservation landscape (CL)

The habitat suitability maps of all five focal species were combined to identify priority conservation sites and their optimal connectivity. The software Zonation was used to frame this work in the systematic conservation planning (SCP) approach. SCP applies a series of principles to design a CL: efficiency, flexibility, persistence, and representation (Knight et al. 2006; Kukkala and Moilanen 2013; Watson et al. 2011). Efficiency refers to protecting sites that complement each other and at the lowest costs; flexibility includes transparency and measurement of the irreplaceability of sites; persistence refers to the preservation in time of the elements previously chosen to be conserved; and representation refers to the consideration of all these conservation-elements in the process of designing CLs and actions. Finally, defining objectives gives the planning approach transparency and a benchmark by which to evaluate progress towards goals, hence transparency is a clear part of flexibility (Knight et al. 2006; Kukkala and Moilanen 2013; Watson et al. 2011).

The Zonation software uses algorithms based on SCP principles (Moilanen 2007). It starts preserving the whole landscape and then hierarchically prioritizes sites (cells) by removing iteratively the least valuable remaining cell, based on the occurrence levels of the focal species while accounting for connectivity and complementarity. The Basic Core algorithm makes it possible to remove cells with occurrences of the most widespread species and to keep cells with increasingly rare species (Moilanen 2012). Therefore, areas with rare species and with the whole set of focal species are maintained in the landscape. Structural connectivity of suitable quality habitats was considered by prioritizing cell removal from the edges before cells in the middle of the study area.

Table 1. Species used to design a conservation landscape in the Argentinean Dry Chaco. EN: endangered; VU: vulnerable; EDGE: the species represents a unique evolutionary process and is endangered.

Scientific Name	Common Name	International Conservation Status (IUCN 2015)	National Conservation Status (SAREM 2019)	Importance
Tayassu pecari	White-lipped peccary	VU	EN	Ecological role, ecosystem functions: seed dispersers and predators, prey of top-predators, maintenance of water ponds (Aranda and Sánchez-Cordero 1996; Beck 2005; Beck et al. 2010). Lack of information about its populations in the DCH (Periago et al. 2014).
Catagonus wagneri	Chacoan peccary	EN	EN	Endemic and only representative of a unique evolutionary pattern – EDGE species (see EDGE 2016). Lack of information about its populations (Periago et al. 2014).
Priodontes maximus	Giant armadillo	VU	EN	Ecological role, ecosystem functions: alteration of soil characteristics and creation of new habitats (Desbiez and Kluyber 2013). Lack of information about its populations (Ojeda et al. 2012; Periago et al. 2014).
Myrmecophaga tridactyla	Giant anteater	VU	VU	Lack of information about its populations (Ojeda et al. 2012; Periago et al. 2014).
Tapirus terrestris	Tapir	VU	VU	Ecological role, ecosystem functions: seed dispersers and predators, alteration of vegetation structure (Taber et al. 2008). Lack of information about its populations (Periago et al. 2014).

Comparison between Conservation Landscape and land-use policies

The different conservation categories (red, yellow, and green) according to the OTBN of the Forest Law, protected areas, and present and projected wildlife corridors were digitalized. These layers were overlaid with the CL to identify, according to this study, conservation priority areas which are currently unprotected by normative and land-use plans and which might be threatened. The generated HSs were overlaid with the CL to determine the proportion of suitable habitat of each species that would remain protected if our CL is applied.

RESULTS AND DISCUSSION

Species conservation and habitat suitability models

A total of 1,196 interviews were conducted, and 214 were removed because they contained some ambiguous information. Interviews expressed a long lasting history of faunal use in the region and showed the importance of etnozoology in conservation (Altrichter 2005; Alves 2012). Interviews were useful for identifying species presence and location and hence for conservation planning.

The AICc of the selected models differed from the AICc of the other models for over five units except in tapirs, where two different models were equally explanatory of the data (Table 2, Figure 2). All selected models showed good general performance (AUC in Table 2).

The variables selected differed between species (Table 2), indicating their different ecological requirements. Variables associated with temperature changes, potential evapotranspiration, and precipitation of certain months were associated with suitable habitats for the focal species. These variables differed from previous research (Abba et al. 2012; Torres and Jayat 2010). However, these studies were developed in different areas, and HS with other backgrounds should not be compared (Merow et al. 2013).

The selected models and variables were used to categorize the study area from high to low suitable habitats for each species and generate the HSs. Threshold values were: 0.022 for white-lipped peccary, 0.052 for chacoan peccary, 0.015 for giant armadillo, 0.122 for giant anteater, and 0.028 for tapir (Figure 3).

All focal species are present in a large portion of the Argentinean DCH and have a large area of suitable habitat. This information is relevant because these species are endangered or vulnerable to extinction at both the local and international levels and have disappeared from a large percentage of their historical distribution (Altrichter and Boaglio 2004; Núñez-Regueiro et al. 2015; Taber et al. 2008). In 9,000 km^2 of a landscape of the DCH, dominated by an intensive productive matrix, white-lipped peccaries may be extirpated (Núñez-Regueiro et al. 2015). Also, hunting of peccaries became unsustainable in the DCH over a decade ago (Altrichter and Boaglio 2004). Therefore, the current presence of these species in the area is asseverated for the first time with this study.

Habitat suitability increases for white-lipped peccaries, giant armadillos, giant anteaters, and tapirs with increasing distances from towns and populated centers. This negative association can be expected considering the deleterious effect of hunting and habitat degradation and loss on large mammals (Ceballos 2005; Peres 1996). Humans are also negatively associated with the relative abundance of peccaries in the Argentinean DCH (Altrichter 2005; Altrichter and Boaglio 2004). The Chacoan peccary's habitat suitability did not relate to human presence. If there is a negative association between humans and this species, it probably occurs at a different scale or affects traits other than distribution (Altmoos and Henle 2010; Fa and Brown 2009; Wiens 1989). The relation between humans and chacoan peccaries may be complex; recent studies found a positive relationship between the probability of this species' occupancy and human presence in an area (Camino 2016; Saldivar-Bellasai 2014). Aridity was associated with the chacoan peccary, which is logical for a species endemic of the DCH (Wetzel et al. 1975). Suitable habitat for the white-lipped peccary did not relate to water, although the species is positively associated with it at lower scales (Bodmer 1990; Keuroghlian et al. 2009; Kiltie and Terborgh 1983; Sowls 1997).

Conservation landscape

A CL for this group of species was developed (Figure 4). Areas with intermediate or high importance for the conservation covered 30,998 km^2 (57.4%). A large area of suitable habitats for each species would remain protected according to this CL: 85% and 80% for white-lipped and chacoan peccaries, respectively; 86% of giant armadillos, 83.7% of giant anteaters, and 99.7% of tapirs.

Conserving large mammals is a considerable challenge, considering their large area requirements and current hunting pressure (Ceballos 2005; Hansen et al. 2013; Piquer-Rodríguez et al. 2015; Vallejos et al. 2015). Large areas with suitable habitats for focal species are currently unprotected, and strictly protected areas are scarce and separated by vast distances. Most protected areas are surrounded by territories where unsustainable land-uses are illegal (represented in yellow in Figure 5). Still, given the unclear definition of sustainable, the wide range of allowed activities in these areas, and the lack of proper monitoring systems and control, landscape connectivity has definitely not been secured.

Wildlife corridors planned for the area could improve the connectivity of the landscape and the conservation opportunities for these species. However, these corridors have three problems: (1) there are inconsistencies between planned corridors and present land-uses and policies in the areas, Formosa for example, where corridors are planned in areas where deforestation is allowed; (2) corridors require spatial corrections to account for the habitat requirements of these species; (3) corridors should cover such a large area that their implementation may be challenging in the territory; first, because three different provinces must agree on their implementation and control and, second, there would not be enough space for intensive agriculture.

Table 2. Information about the selected habitat suitability model for each species, N: number of sites where the species was detected, AUC: area under the curve, AICc: Akaike Information Criteria corrected by sample size. For tapir (*Tapirus terrestris*), two different models were equally explanatory of the data and had the same prediction capacity.

Species	N	Number of Variables	AUC	ΔAICc	Total models compared
White-lipped peccary (*T. pecari*)	177	5	0.95	> 15	5
Chacoan peccary (*C. wagneri*)	757	3	0.9	> 49	5
Giant armadillo (*P. maximus*)	117	6	0.98	> 68	6
Giant anteater (*M. tridactyla*)	964	8	0.92	> 28	6
Tapir 1 (*T. terrestris*)	158	5	0.97	> 2	5
Tapir 2 (*T. terrestris*)	158	6	0.97	> 6	5

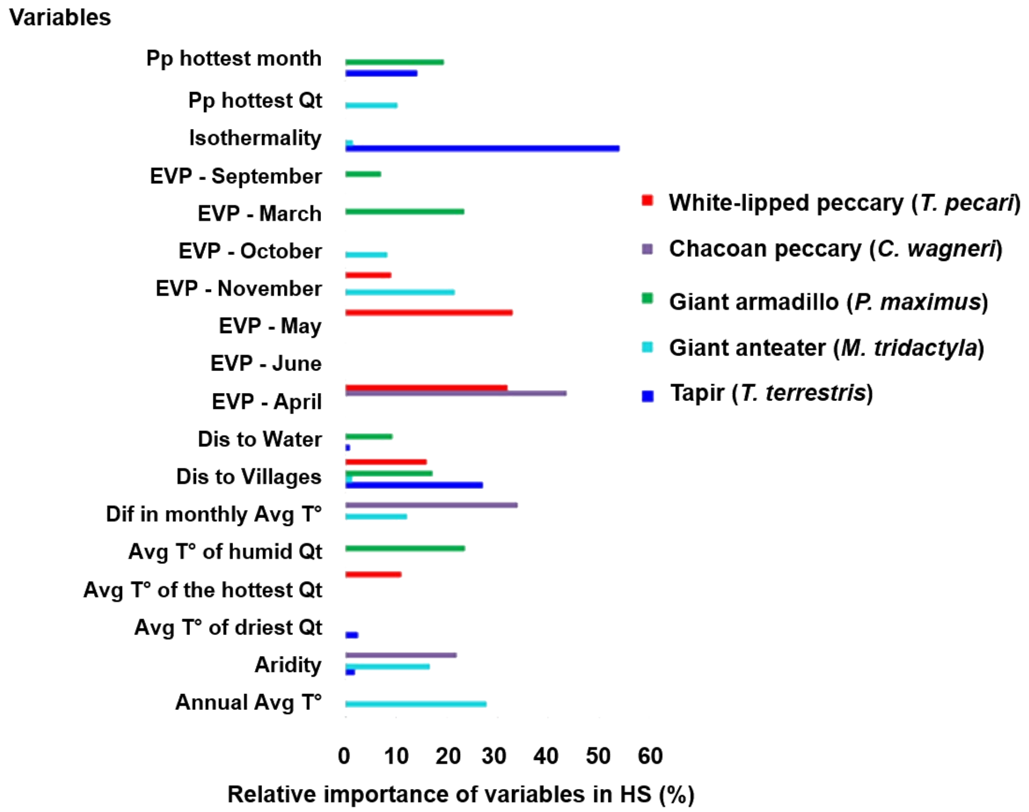

Figure 2. Relative importance of variables included in the species' habitat suitability models (HS). Pp: Precipitation; EVP: evapotranspiration; Dis: distance; Dif: difference; Avg: average; Qt: quarter of the year; pop: populated.

Existing conservation plans for the region

According to the CL proposed in this work (Figure 4) and the existing official OTBN (Figure 5), most currently existing protected areas contain areas of medium or high importance (Figure 4) and therefore we consider that they are located in a useful place for conservation. However, a total of 7,770 km^2 that was classified by the CL as medium or high conservation priorities are located in areas considered by OTBN as

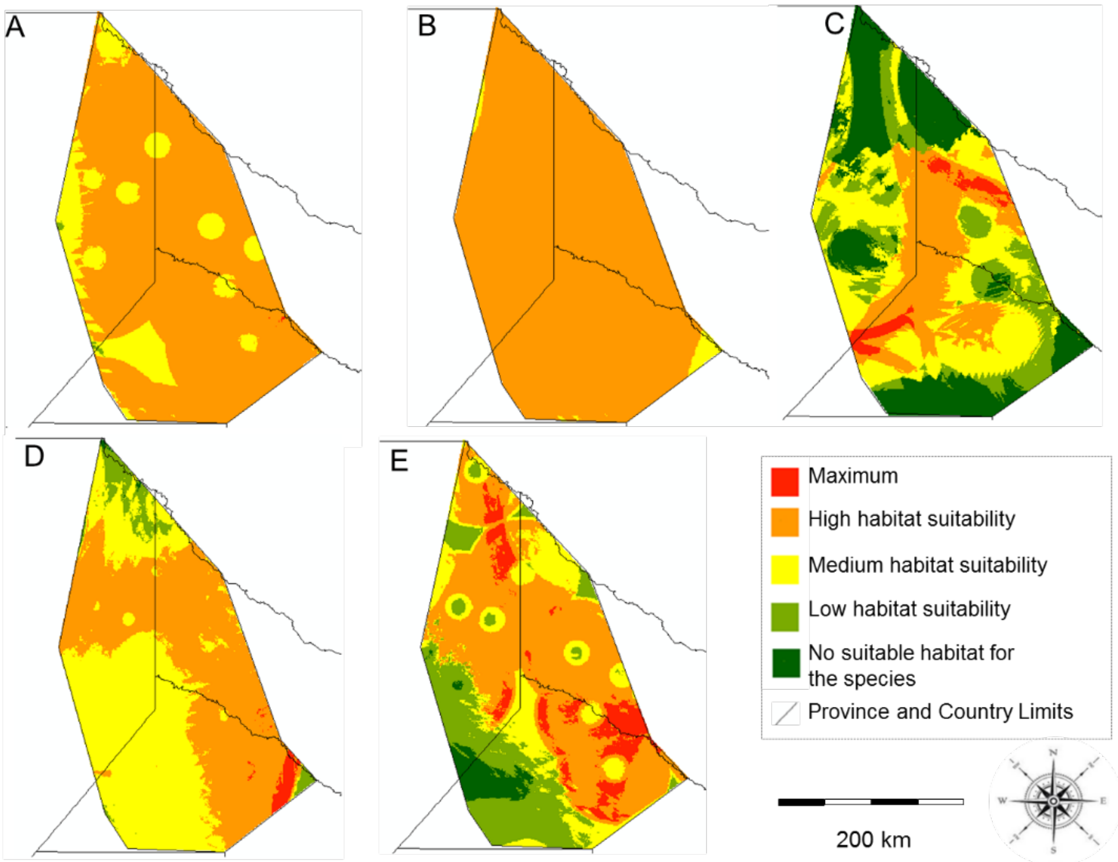

Figure 3. Habitat Suitability Models, in which habitat quality is ranked according to its suitability for (A) white-lipped peccary (*T. pecari*), (B) chacoan peccary (*C. wagneri*), (C) giant armadillo (*P. maximus*), (D) giant anteater (*M. tridactyla*) and (E) tapir (*T. terrestris*). Suitability: Maximum: 1; high: 0.76–0.9; medium: 0.75–0.55; low: 0.55–threshold value of the species.

of medium and low conservation priority, and therefore deforestation is allowed after the approval of a Land Use Change plan by the provincial authorities (represented in light-green in Figure 5). Protected areas are scarce in Formosa province and cover a larger space in Chaco and Salta provinces (Figure 5). Proposed wildlife corridors would assure the connectivity of a large portion of the CL and solve the current isolation of protected areas as suggested by the OTBN (Figure 5). The Forests Law was conceived as a way to restrict uncontrolled deforestation, and promote a social debate on the protection of native forests (Salas Barboza et al., 2019). Our data showed that federal and provincial governments were unable to properly enforce it. The discrepancies between the legal objectives (OTBN) and our results are useful to inform solutions to improve the environmental governance of the region.

Two strategies for distributing conservation and food production in the landscapes have been suggested for this region. The "Land Sparing" strategy proposes that areas dedicated to food production should produce intensively, generating the maximum amount of food in the smallest surface possible and that these areas should be separated from those dedicated to conservation, where habitats should remain as unmodified as possible (Grau and Aide 2008; Tilman et al. 2002). On the other hand, "Land Sharing" proposes that food production should be environmentally friendly, with low inputs of pesticides and fertilizers and conserving habitat elements to allow for the preservation of species and ecosystem functions (Rosenzweig 2003; Tscharntke et al. 2012).

The Land Sparing approach could be successful if it allows the conservation of enough connected land for the preservation of the species considered here and large mammals in general. Therefore, to be successful, more protected areas should be seriously considered for this region. The Land Sharing strategy may be more compatible with the maintenance of large areas of suitable habitat (Grau et al. 2005; Hansen et al. 2013; Piquer-Rodríguez et al. 2015; Vallejos et al. 2015), but imply in various social costs. The study area is one of the poorest in the country, with diffi-

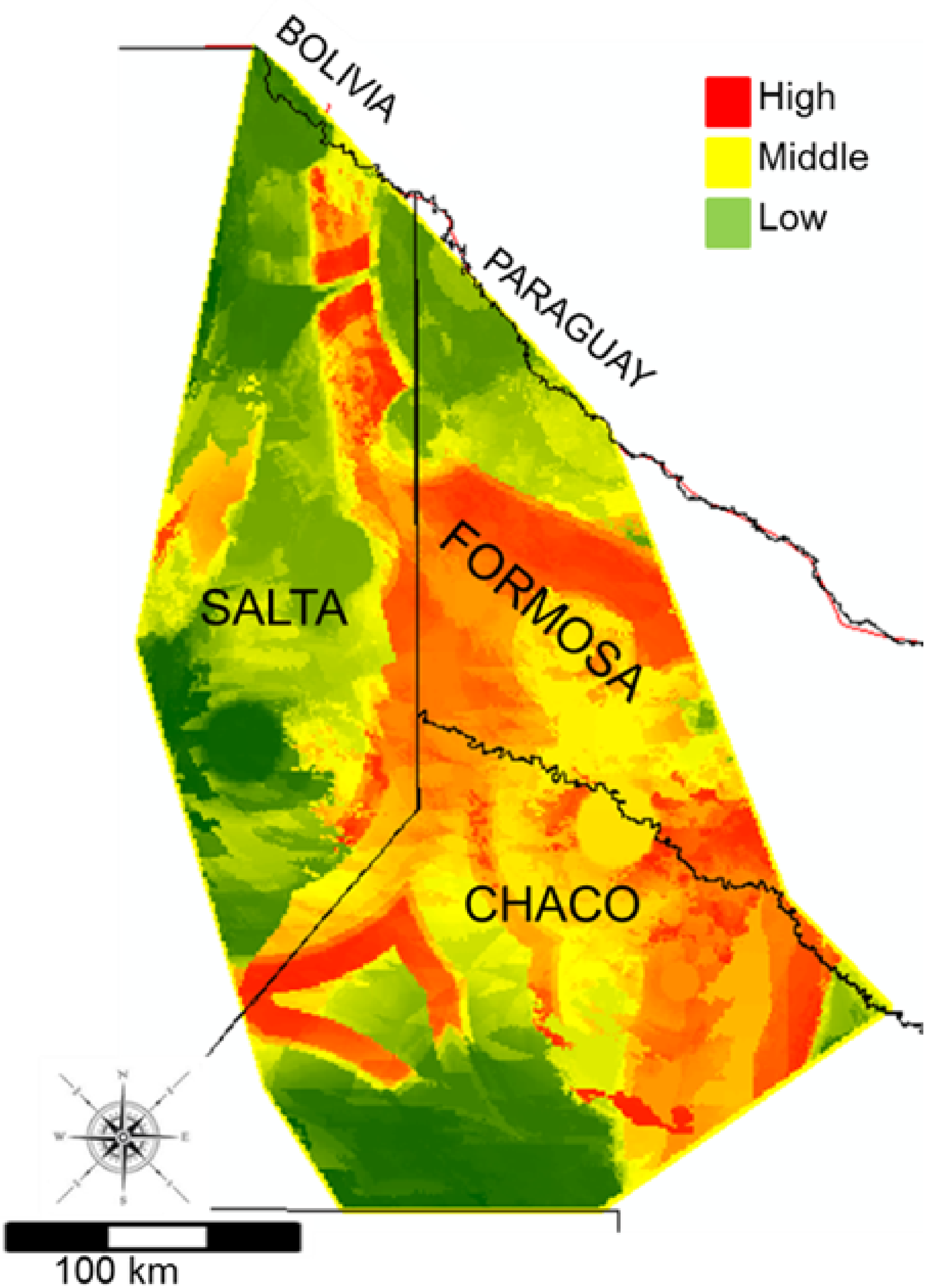

Figure 4. Priority conservation areas based on HS of five large terrestrial mammals (*T.pecari, C.wagneri, P. maximus, M. tridactyla*, and *T. terrestris*); generated following a Systematic Conservation Planning approach. Low: 0–0.45; Medium: 0.46–0.74; High: 0.75–1.

cult access to the health system, potable water and other services (Camino et al. 2017). To implement the sharing strategy, the now deficient production systems should be improved to increase food production and attain better conservation results and local people should be directly incorporated into the conservation

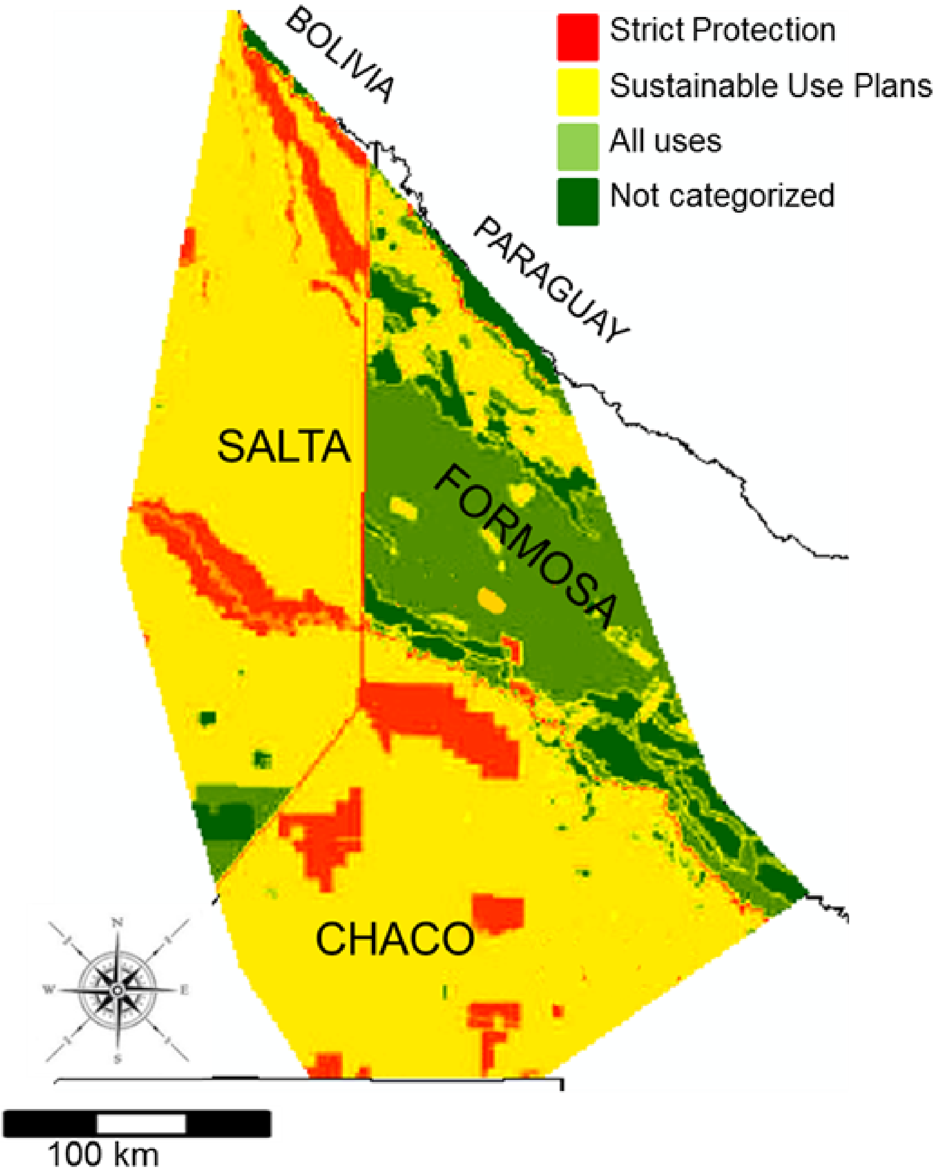

Figure 5. Land-use categorization according to existing Protected Areas and the Forests Law (National Law No. 26.331); different colors represent different land-uses allowed in the study area. Projected wildlife corridors for the area are shadowed. Sources: Ministerio de Ambiente y Desarrollo Sustentable de la Nación; Administración de Parques Nacionales (APN); Ministerio de Ambiente y Desarrollo Sustentable de la Provincia de Salta.

strategy (Camino et al. 2017; Kusnandar et al. 2019). Traditional livestock and other productive activities reduce both vegetation cover (Grau and Aide 2008; Morello et al. 2005) and wildlife (Altrichter 2005; Altrichter and Boaglio 2004), therefore, educational and awareness programs should be implemented to reverse the negative effect that human activities have on the large mammals in the DCH (Altrichter 2005; Altrichter and Boaglio 2004). Although the studied species are still present in this territory, they would not survive in totally transformed areas (Matteucci et al. 2016; Núñez-Regueiro et al. 2015). These observations indicate that the Forests Law in the Dry Chaco presents a series of challenges to improve its performance in terms of effectiveness, equity and social legitimacy. The government plays a critical role for the promotion of sustainable and resilient local agricultural practices in which all actors are fairly empowered and engaged (Brown et al. 2018).

CONCLUSION

The information provided by local informants and the use of habitat suitability models resulted in useful tools for conservation planning and strategy in a portion of the Dry Chaco. Interviews provided current information on species presence and location and systematic conservation planning allowed us to extrapolate this information to the entire study area. Suitable habitat for the species considered is still available, but their conservation cannot be ensured with the presence of conservation schemes. We recommend more and better implemented protected areas and have identified optimal areas to connect them.

A large area of the DCH is covered with forests and natural environments and sustains species with essential conservation roles, which are considered threatened with extinction. Dry tropical and subtropical ecosystems do not receive much conservation attention; this is the first CL presented for Argentina's largest remaining DCH forest. This information can join different spatially referenced data, e.g., soil productivity, and form the basis of flexible spatial conservation plans applicable within real-life constraints.

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DATA AVAILABILITY

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The author have no conflicts of interest to declare.

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