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Dinâmica de cobertura da terra e a conservação de aves endêmicas no Chaco paraguaio

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"… What is the purpose of our life in this world? Why are we here? What is the goal of our work and all our efforts? What need does the earth have of us? It is no longer enough, then, simply to state that we should be concerned for future generations. We need to see that what is a stake is our own dignity".

Pope Francis

Pies, para que los quiero si tengo alas para volar.

Frida Kahlo

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Ao Deus por ter me tornado uma fortaleza, mantido-me persistente nesses meses, por ter permanecido ao meu lado.

À minha família, por estar todos os dias presentes, mesmo à distância, dizendo que eu poderia voltar qualquer dia, que eles me esperariam.

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Sumario

Resumo geral

O Gran Chaco é uma região biogeográfica que forma, juntamente com o Cerrado e a Caatinga, a Diagonal seca sulamericana (Prado & Gibbs, 1993). Tal faixa abrange o Paraguai, Argentina, Bolívia e o Brasil, e caracteriza-se por ser uma das regiões com uma das maiores taxas de supressão de floresta seca no continente. O Chaco paraguaio destaca-se dentre todas as porções da Diagonal seca por ter sofrido a maior supressão da vegetação nativa nos últimos anos, tendo sido observadas taxas de desmatamento superiores a 4% ao ano (Grau & Aide 2008; Huang et al. 2009; Clark et al. 2010; Aide et al. 2012; Hansen et al. 2013; Vallejos et al. 2014; Graesser et al. 2015).

O Paraguai, no centro da América do Sul, está em uma região de ecótono com uma alta biodiversidade, mas com baixo endemismo de aves, aspecto atribuído à localização central no continente (Spichiger et al. 2004). Ao todo são reconhecidas 18 aves como endêmicas do Gran Chaco (Short 1975). O Chaco paraguaio caracteriza-se por ter um clima seco e uma sazonalidade bem pronunciada. A precipitação decresce desde o sudeste ao noroeste, e a vegetação responde a esse gradiente climático. As duas maiores ecorregiões reconhecidas são o Chaco Seco no noroeste, uma região mais seca com florestas semidecíduas lenhosas, e Chaco úmido no sudeste, além do Médanos, Cerrado e Pantanal.

A mudança na cobertura da terra do Chaco paraguaio ocorre devido a várias pressões externas oriundas do agronegócio, como demanda pela produção de grãos e de carne bovina, esta última bastante expressiva em virtude do aumento no preço internacional. Por outro lado, a configuração da paisagem é em parte determinada por leis estabelecidas pelo Governo do Paraguai, entre as quais destaca-se uma em particular que estabelece a obrigatoriedade dos proprietários de preservar faixas de vegetação entre as parcelas de desmatamento. Tais faixas são localmente conhecidas como quebra-vento possuem, em média, 100 metros de largura e conectam blocos maiores de vegetação nativa.

A ocupação da paisagem se traduz em perda de hábitat para as aves endêmicas, aspecto que é agravado pela fragmentação e perda de conectividade. Nesse sentido, a identificação de áreas potenciais para conservação da biodiversidade local são úteis para um planejamento mais adequado da paisagem. O objetivo geral deste estudo foi mapear os sítios potenciais para conservação das aves endêmicas baseados na fragmentação e conectividade da paisagem, resultado da dinâmica de cobertura da terra no Chaco paraguaio.

A cobertura da terra foi obtida a partir do processamento e classificação de imagens Landsat, tendo sido geradas duas classes básicas: uma referente à vegetação lenhosa (VL) e outra referente ao conjunto de áreas antrópicas (PVL) (ou áreas inicialmente ocupadas por vegetação lenhosa). Esse procedimento foi realizado para três períodos de estudo: 1995, 2005 (sensor *Thematic Mapper* do Landsat 5) e 2014 (sensor *Operational Land Imager* do Landsat 8). A classificação foi do tipo supervisionada, tendo sido baseada em espectros selecionados que caracterizaram cada ecorregião. Foi medida a perda de cobertura por ecorregião, nas Áreas Protegidas (AP) públicas e nas zonas de amortecimento. Neste estudo, o primeiro período do mapeamento (1995 a 2005) foi denominado de “primeira trajetória” e o segundo período (2005 a 2014) foi denominado de segunda trajetória. A comparação das mudanças no uso da terra e cobertura vegetal foi objeto de estudo do primeiro capítulo da dissertação.

Por meio de modelos de nicho ecológico desenvolvidos com o programa Maxent (Phillips et al. 2004), foi mapeada a distribuição potencial das 18 aves endêmicas a partir de pontos conhecidos de ocorrência no Gran Chaco. A qualidade dos modelos foi testada com a abordagem do ROC parcial, que compara o desempenho do modelo produzido com um modelo nulo (Peterson et al. 2008). A distribuição de cada espécie foi somada para obter o mapa de riqueza de aves endêmicas.

Para avaliar o grau de conectividade da paisagem atual e a identificação de grupamentos funcionais de fragmentos, foi utilizada a Teoria dos Graphos (Rayfiel et al 2011). A teoria sugere que fragmentos localizados a uma determinada distância uns dos outros podem formar unidades funcionais que permitiriam a sobrevivência da biota em uma área maior do que a área de cada fragmento. O modelo de conectividade funcional foi feito com o mapa de cobertura de 2014 e com o uso do programa *Graphab* (Foltête et al. 2012). Para tanto, foram considerados os fragmentos maiores a 500 ha para as duas classes VL e PVL, sendo esta última composta por pastagens, assumindo que a maior quantidade de área convertida foi para esse uso (Caldas et al., 2013). As duas classes utilizadas formaram os gradientes de permeabilidade para a dispersão das aves, que no modelo de conectividade funcional representa o custo ou o esforço de deslocamento das espécies entre os fragmentos da paisagem. As áreas menos custosas são aquelas que receberam os menores valores (valor de 1 para as áreas VL) e as áreas mais custosas, correspondentes à classe PVL, foram aquelas que receberam o valor arbitrário de (5). Os valores foram baseados na revisão de artigos científicos produzidos com o grupo taxonômico em questão e com a abordagem dos Grafos. O mapa de riqueza de aves endêmicas foi cruzado com o mapa da conectividade funcional para a identificação das áreas que apresentassem, ao mesmo tempo, um maior número esperado de espécies e também que estivessem mais conectadas. O mapeamento das áreas mais importantes para a conservação das aves endêmicas da região foi objeto de estudo do segundo capítulo da dissertação.

As mudanças na cobertura remanescente da vegetação nativa foram bastante distintas entre as duas trajetórias mapeadas (entre 1995-2005 e entre 2005-2014). Enquanto na primeira trajetória a taxa desmatada foi 0.74%, na segunda trajetória esse valor foi basicamente o triplo do período anterior, chegando a 1.99%. Tal pressão antrópica alterou profundamente a estrutura e configuração da paisagem, pois até a primeira a expansão da ocupação humana se dera de maneira radial e dispersa na segunda trajetória, ou seja, uma ocupação espacialmente indistinta. Todas as ecorregiões tiveram um aumento na mudança de cobertura da terra para os três anos mais recentes, ressaltando-se Médanos, que teve maior perda de VL em 2014, mesmo sendo a região com a maior quantidade de áreas protegidas. Foram detectadas perdas de VL nas zonas de amortecimento de 1 km no entorno das Áreas Protegidas (AP), chegando até o limite da AP e mesmo dentro delas. De maneira oposta, o Chaco Seco é a região com menor porcentagem de proteção, mas com maior perda de cobertura em faixas mais distantes das poucas APs existentes.

A região com maior riqueza esperada de espécies endêmicas localiza-se no Chaco Seco (porção nor-noroeste do Chaco), aspecto que corroborou avaliações anteriores (Nores, 1992). A mudança de cobertura da terra também foi crítica nessa região (Vallejos et al. 2014, Caballero et al. 2014; Cardozo et al. 2013; Caldas et al. 2013), exercendo uma pressão na área de distribuição das aves endêmicas. Os maiores e mais conectados grupos de fragmentos identificados pelo modelo de conectividade estão localizados na porção norte do Chaco, região que coincidentemente também possui APs com maior área. Na situação oposta encontra-se o Chaco Central, região que apresentou um grande número de pequenos e desconectados fragmentos. A análise de conectividade funcional revelou que as áreas identificadas com maior potencial de conservação foram seis conjuntos de fragmentos identificados no Norte. Na área do Chaco central, região com mais tempo de desenvolvimento, foram identificados pequenos grupamentos de fragmentos onde há a maior riqueza de espécies endêmicas e também com grande demanda de restauração ecológica.

A perda da cobertura natural dentro das AP e nas zonas de amortecimento evidencia a falta de interesse do governo do Paraguai para estabelecer limites de conservação e sua falta de compromisso para fiscalizar a conservação das áreas. Além disso, a pouca representatividade das ecorregiões em todas as APs é um agravante adicional para a conservação dos ambientes e suas espécies dependentes.

O modelo de conectividade foi resultante da atual configuração da paisagem, que talvez ainda ofereça as condições necessárias para a conservação das aves endêmicas. Ao mesmo tempo, o modelo permitiu o reconhecimento das regiões com maior pressão antrópica. A indicação de manutenção da conectividade entre as áreas nativas e a redução do desmatamento na porção norte do Chaco representam duas ações necessárias e muito menos custosas do que as ações de restauração requeridas no Chaco Central. Assim, ainda é possível manejar a paisagem na porção norte para evitar o que aconteceu historicamente no Chaco Central. As áreas com potencial de conservação apontadas no Chaco Central buscam identificar as áreas com maior risco de desaparecimento, que poderiam abrigar populações de aves endêmicas com alto potencial para serem pesquisadas, medindo sua resposta às mudanças ambientais. É sabido que diferentes espécies respondem de maneira diferente às mudanças da cobertura, o que faz com que a conectividade dos fragmentos considerada neste estudo seja vista como uma estratégia preliminar de conservação na região. Por isso recomenda-se que novos estudos sejam conduzidos com as espécies que sobrevivem em pastagens introduzidas, pois as ações de manejo podem ser distintas em função da capacidade de dispersão dessas aves. Por outro lado, as aves mais associadas com a vegetação seca poderiam depender da proximidade e de conexões físicas dos fragmentos, como os quebra-ventos, para facilitar a dispersão pela paisagem.

Talvez a principal contribuição deste trabalho relativamente à investigação da acelerada perda de habitat no Chaco paraguaio e a distribuição restrita das aves endêmicas seja a inédita utilização da Teoria dos Grafos para a identificação de áreas importantes para a conservação do Chaco Paraguaio. A partir dessa proposta, espera-se que um novo e mais conciso zoneamento ecológico da região seja realizado e, desta maneira, espera-se que esses esforços resultem em benefícios tanto para o desenvolvimento econômico quanto para a conservação das aves endêmicas do Paraguai.

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Capítulo 1

Dynamics of the land cover in the Paraguayan Chaco: a local assessment and ecological implications

Abstract

The Paraguayan Chaco is a great ecotonal region divided into five ecoregions: Wet Chaco, Dry Chaco, Pantanal, Médanos and Cerrado. This variety of environments allows the existence of a rich biodiversity that is threatened by high rates of land cover conversion. We analyzed the spatial-temporal land cover changes between 1995-2014, and verified whether the legislation is being complied with. We used Landsat 5 and 8 imagery to generate maps of the first and second trajectories of land cover change (1995-2005 and 2005-2014 respectively) in order to evaluate local landscape changes and their impact on public protected areas. Changes in cover almost tripled in the second trajectory, from 0.74 to 1.99, which was determined by drivers at local, regional and global scales. The landscape is connected by windbreaks, but least so in the Central Chaco, where connectivity is threatened. Moreover, we identified plots which were converted into Protected Areas, but whose boundaries were threatened by subsequent land cover changes taking place at a distance of up to 1 km, indicating that the buffer zones are not working as a prevention area. The lack of planning for landscape changes threatens landscape connectivity for biodiversity, and the lack of incentives for conservation expose the Paraguayan Chaco to the ecological consequences of land conversion in semi-arid environments.

Keywords: natural vegetation loss, Landsat, windbreaks, protected area, buffer zone

1. Introduction

The humanity modifies their environment as population grows and developing technologies expanded the scope and nature of this modification drastically, as consequences, the ecosystems are dominated directly by the humans. The land transformation represents the most substantial human alteration of the Earth system (Vitousek et al., 1997; Geist & Lambin, 2004; Mantyka-Pringle et al., 2015).

Latin America and the Caribbean have the largest area of tropical forest, the globe’s greatest amount of biodiversity, a large proportion of global aboveground carbon stock, and extensive protected area (PA), threatened by both internal and external drivers (Aide et al., 2012). Paraguay in the center of South America is a huge ecotone region with species diversity shared, presenting little endemism. The landscape is characterized by wide mosaic of forest-patches, intermingled with Palm-savannas, campos cerrados, fields and cultivated lands intermingling open vegetation formations, with climatic and edaphic gradients determining shifts from semideciduous forests in the southeast to Chaco vegetation in the northwest, separated by the Paraguay River in the centre (Werneck, 2011). Few efforts led to ecoregion assessment in the Chaco to establish areas of biological significance based on multiple taxa (TNC, 2005).

Deforestation continues to be the dominant land-use trend in Latin America (Grau & Aide, 2008) and one of the regions with the highest rate of tropical forest loss is the South American dry forest. The Gran Chaco is a kind of Seasonally Dry Tropical Forests and, along the Cerrado and Caatinga, forms the "Dry diagonal" of South America (Neves et al., 2015; Werneck, 2011; Prado & Gibbs, 1993). It covers part of Bolivia, Paraguay, Argentina and Brazil and it can be divided in two main regions: an eastern humid sector and a western drier one (Lewis et al., 1990, Olson et al., 2001).

Among the above-cited countries, Paraguay had the highest woodland loss of in the recent years (Grau & Aide, 2008; Huang et al., 2009; Hansen et al., 2013; Aide et al., 2012; Clark et al., 2010; Vallejos et al., 2014; Graesser et al., 2015). The Paraguayan Chaco has lost more than half million of hectares (ha) during the past 10 years, which correspond to a deforestation rate of 105,557 ha/year (Mereles & Rodas, 2014). Recent publications have pointed out that the deforestation process still persists with no trend of recrudescence (Cardozo et al., 2013; Caballero et al., 2014), aspect that can compromise local biodiversity. Some of the most important drivers of land transformation are the food international market and policy of development in Paraguay (Grau & Aide, 2008), a situation favored by projects of development with international financing. Cattle production and soybean plantation have grown substantially in Paraguay along the past 10 years. According to the Food and Agriculture Organization – FAO (FAO 2016), the Paraguayan production of cattle beef and soybean experimented an expansion of 150% and 236% from 2001 to 2011, respectively. Comparing to other neighbor countries, the expansion of cattle beef production puts Paraguay is bigger than Argentina for cattle beef and proportionally bigger than Argentina and Brazil for soybean expansion (FAO 2016).

Although the land change cover detected in the Paraguayan Chaco was made in large scale by using remotely sensed data (Clark et al., 2010; Aide et al., 2012; Hansen et al., 2013;; Vallejos et al., 2014; Graesser et al., 2015), few of them analyzed the spatially-temporal land cover change in a local context. The land use in rural properties must follow the Paraguayan legislation and rules, especially the Decree Nº 18831/86 (http://faolex.fao.org/). This particular legislation, which affects farms bigger than 100 ha, impose to the landowner the obligation to maintain of blocks of natural vegetation connected by narrow strips called windbreaks. The windbreaks are normally located along pathways, roads and the edges of a property and must be at least 100 m wide. They can potentially contribute to the dispersion and movements of small organisms and carbon storage. Nowadays, however, the rapid expansion of agriculture and cattle ranches has lead to a massive loss of natural vegetation and the legal accomplishment is being overlooked.

The combination of high deforestation rate with an uncontrolled landscape occupation can cause significant impacts on local fauna and flora, mainly if habitat isolation and loss of connectivity, usually provided by the windbreaks, is increasing. Thus, the objective of this study was analyzed the spatially-temporal land cover changes between 1995-2014 in the Paraguayan Chaco and verify whether the legislation is being complied with.

2. Methods

2.1. Study area

Paraguay has two very distinct natural regions, the Occidental and Oriental regions, both physically and biologically, that are separated by the Paraguay River (Spichiger et al., 2004). The study area is the Occidental Region, also known as Chaco, an area of 240.887 km^2, roughly the size of the United Kingdom. The Chaco corresponds to an alluvial plain with some hills in the North (Oakley & Prado, 2011), being part of the Gran Chaco (Fig. 1). The Gran Chaco is covered by an open vegetation biome of lowland alluvial plains of central South America located in northern Argentina, western Paraguay, south-eastern Bolivia, and the extreme western edge of Mato Grosso do Sul state in Brazil, covering about 840,000 km^2 (Pennington et al., 2000; Oakley & Prado, 2011; Prado & Gibbs, 1993). The Gran Chaco is considered a biogeographical province with a complex biota representing elements from many other adjacent biomes (Morrone, 2014).

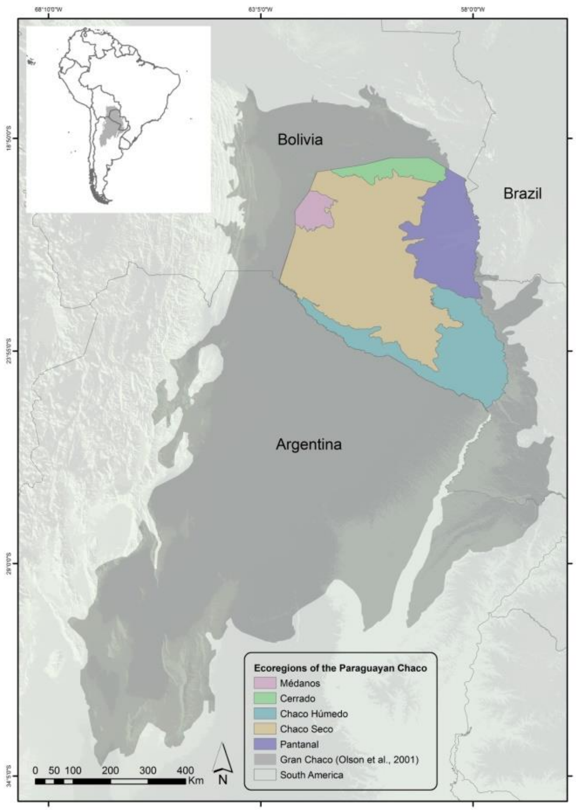

Fig. 1. Location of the Paraguayan Chaco in the Gran Chaco and the five ecoregions which occurs in the Paraguayan Chaco: Wet Chaco, Dry Chaco, Pantanal, Cerrado and Médanos (Mereles et al., 2013).

The soils of the Chaco plains are developed mainly from fluvial and eolic sediments in the north and from loessic material in the south, and range from sandy to heavy clay (Navarro et al., 2011). The climate of the region is mostly semiarid, responding to the rainfall values range from 564 to 1103 mm, in an increasing gradient from west to east and from south to north (Navarro et al., 2011), Thus, the aridity progressively increases to the west, culminating in the driest areas where the Chaco transitions to the Andean foothills (Adamoli, Sennhauser, Acero, & Rescia, 1990). It is also distinguished by its strong seasonality, with summer maxima of up to 49 °C, the highest temperatures recorded in South America, and severe winter frosts. With a dry season in the winter and spring and a rainy season in the summer; the dry season is generally negligible at the Chaco's eastern edge, and increases in duration from east to west. Thus, the vegetation of the Chaco is subjected to low soil moisture and freezing in the dry season and waterlogging and extremely high air temperatures during part of the rainy season (Pennington et al., 2000).

Two main assemblages representing well-defined and stable plant compositions frequently characterize the Chaco: the dry (Chaco Seco) and the wet divisions (Chaco Húmedo) (Spichiger et al., 2004; Olson, 2000). The main vegetation types are described in Mereles and Rodas (2014), which mentioned forests with the difference representation: sub-humid and semi-deciduous forests, riparian hygrophilous forests and floodable forests, xeromorphic forests, the cerrados (woodland savannah) and cerradones, savannahs (tall savannah) and wetlands. All this diversification of vegetation divides the Paraguayan Chaco in five ecoregions: Dry Chaco, Wet Chaco, Médanos, Pantanal and the Cerrado (Mereles et al., 2013). This study will follow this classification because it corresponds to the main vegetation.

2.2. Data sets

In order to map the natural vegetation coverage of the windbreaks and for timeframe of our analyses (from 1995 to 2014), we used two sets of images from Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) images, both with 30 m spatial resolution. Images were obtained from USGS (U.S. Geological Survey, from USA), which were already georeferenced (Tucker, 2004). The whole area includes 15 Landsat scenes and the land transformation dynamics was evaluated for three years: 1995, 2005 and 2014. A total of 45 Landsat images were analyzed and all of them corresponding to the driest season on the region (August and September) (Prado & Gibbs, 1993). Images with no cloud coverage were selected and processed in high contrast false color composite (5-4-3 RGB band combination) in the ENVI version 5.1 (Exelis Visual Information Solutions, Boulder, Colorado) and ArcGis 10.0 (ESRI 2010) software.

2.3. Land cover and change detection

Each image was initially processed for a radiometric calibration, where the pixel values were converted into the reflectance values in order to minimize the apparently noisy pixels that represent no change or actual forest canopy changes (Choppin & Bauer, 1994). After this correction, representative spectral values were selected for each ecoregion and a spectral profile was created. The resulting image was used in a Supervision Classification Spectral Angle Mapper (SAM) available in the ENVI 5.1 software (Fig. 2) with two classes, the natural vegetation (NV) and the natural vegetation loss (NVL).

The classified raster files were converted to a vector format for further editions, for joining polygons that belonged to a same class. To improve the production of the final map, the Paraguayan Chaco was divided into two regions: Dry and Wet Chaco. The riparian areas of the Paraguay River, permanent and seasonally wetland areas were eliminated from the Wet Chaco, because those areas are essentially covered by *Copernicia alba* palms (hydromorphic savannahs of caranda'y according to Mereles (1998). Classes that are not naturally covered by vegetation, such as sand, water bodies and saline lagoon in the central Chaco were also eliminated from the Dry and Wet Chaco maps. Thus, the final map produced for 2014 had two classes: NV and NVL. The NV representing the riparian hygrophilous forests, xeromorphic forests, woodland and tall savannas (the cerrados and cerradones according to Mereles & Rodas, 2014) the vegetation of the Cerro León.

The accuracy of the created map was tested by comparing it to a database produced by Vallejos et al. (2014). This database was manually generated by the cited authors to detect the deforestation in the Dry Chaco from 1976 to 2012. According to the authors, the database has an overall accuracy of 97.8%. The created map corresponded to 2014, so the database had to be updated manually until 2014 using the Landsat 8 OLI imagery.

The land cover for the years 1995 and 2005 was made by visual inspection using the post classification method, consisting in discounted the conversion area from the 2014 map. The change conversion area was defined as a complete removal of vegetation cover at the Landsat pixel scale (Hansen et al., 2012).

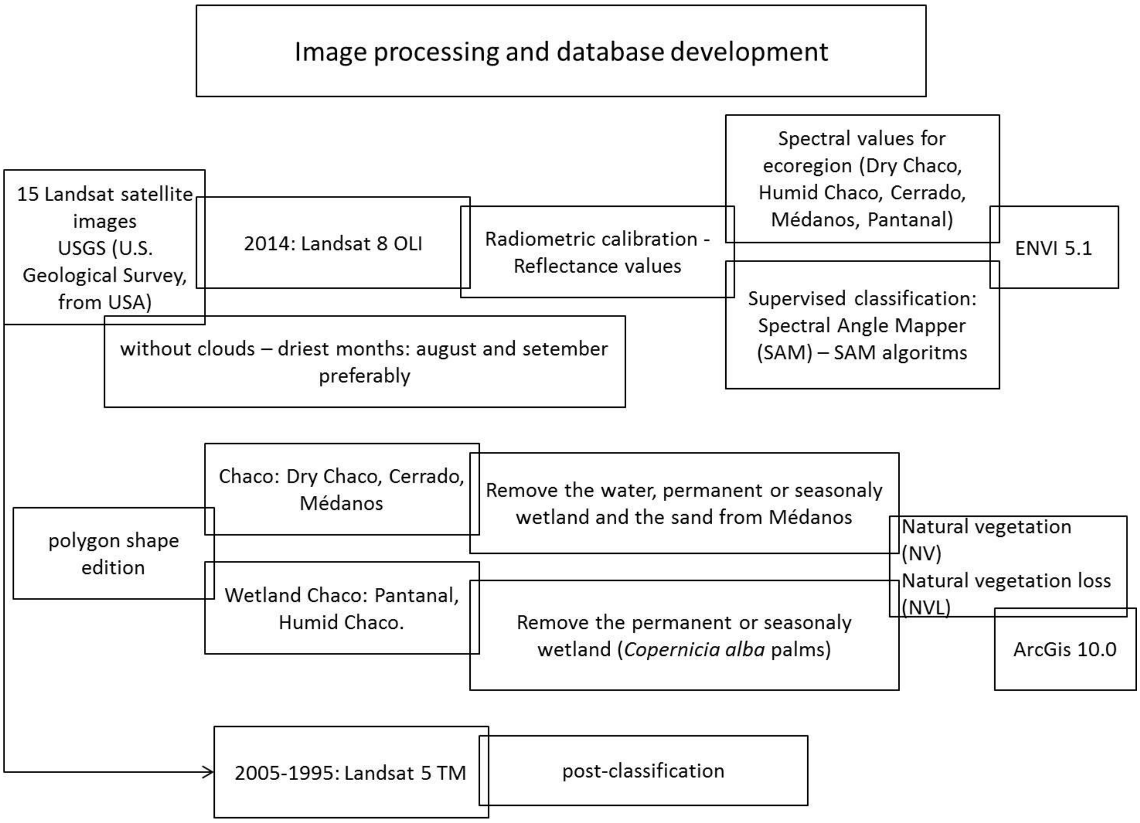

Fig. 2. Flow chart showing the datasets and the land cover used for changing detection.

2.4. Data analyses

The temporal analyses were divided in two trajectories, being the first one corresponding to 1995-2005 period and the second one to 2005-2014. The annual rate of transformation proposed by Food Agriculture Organization (FAO, 1995) was calculated for each trajectory by using the following formula:

$$q = 100 \times [(A_2/A_1)^{1/(t_2 - t_1)} - 1]$$

Where “q” is the rate of change in natural vegetation as a percentage; A_1 and A_2 represent the areas of natural vegetation in the years t_1 and t_2 (2005 and 2014, for instance).

The spatially analyses also considered the woodland loss in each ecoregions and the existing PA (SINASIP, 2007). This was done by creating different buffer zones (1, 5 and 15 kilometers surrounding each PA) and evaluating the level of land transformation during the considered timeframe.

3. Results

3.1. Spatial- temporal dynamics

The land cover map showed an overall accuracy of 98.86% and a kappa coefficient 0.88. The total area lost between 1995 and 2014 summed 5.29 million ha, while the remaining cover of woodland was 13.29 million ha for the Paraguayan Chaco. This conversion represents 28.46% and the NV cover 71.54% from the total area analyzed (Fig. 3).

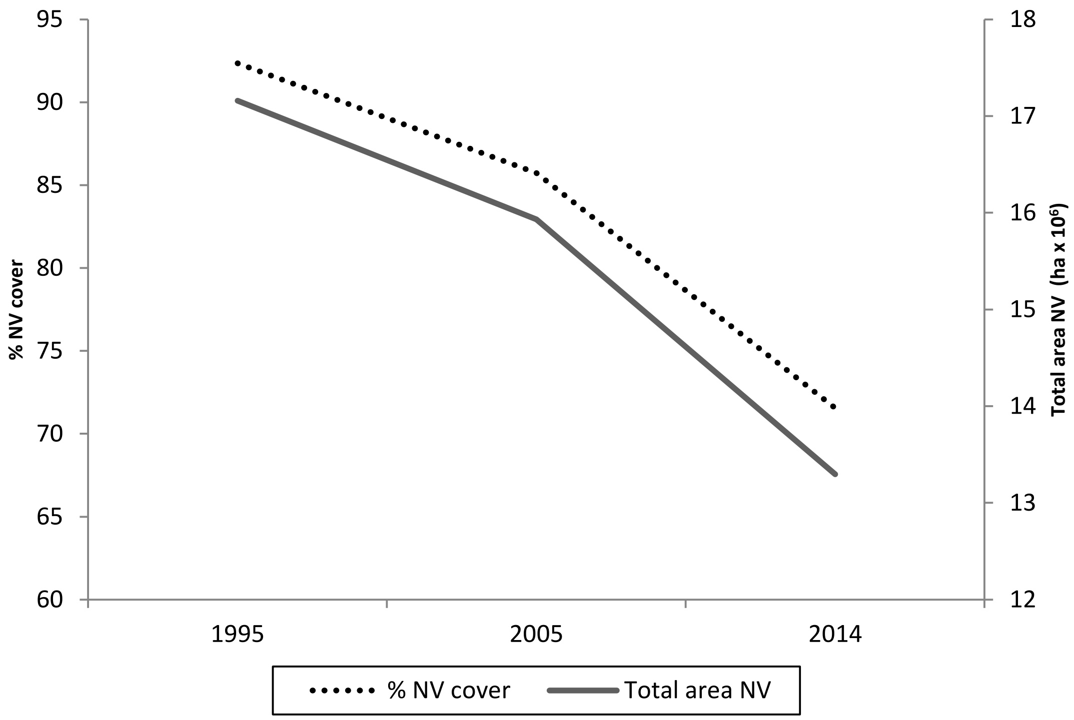

Fig. 3. Reduction of area and percentage of natural vegetation cover for the three periods 1995 – 2005 and 2014.

The rate of transformation for the first trajectory (1995-2005) was 0.74%, and for the second trajectory (2005-2014) was 1.99%, which indicates that land cover loss almost tripled in nine years. The same pattern was observed for all ecoregions, in which land cover loss increased each year (Fig. 4).

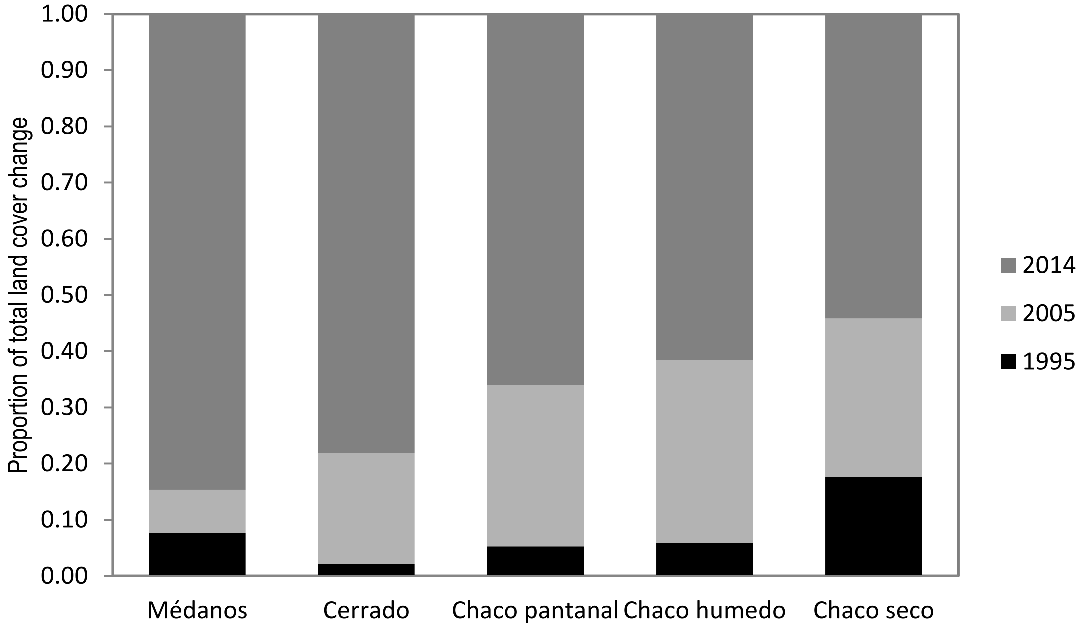

Fig. 4. Increase in the proportion of land cover change suppressed in all ecoregions for the three periods.

The deforestation pattern can be easily identified on the region, because the NV is removed in large squared blocks and only narrows strips, corresponding to the windbreakers, are left on the landscape. The converted plot had a mean of 0.09 ha. The extension of the windbreaker was changed in recent years and during the first trajectory most of them almost disappeared in Central Chaco. In the second trajectory, the windbreakers were more homogeneous in extension.

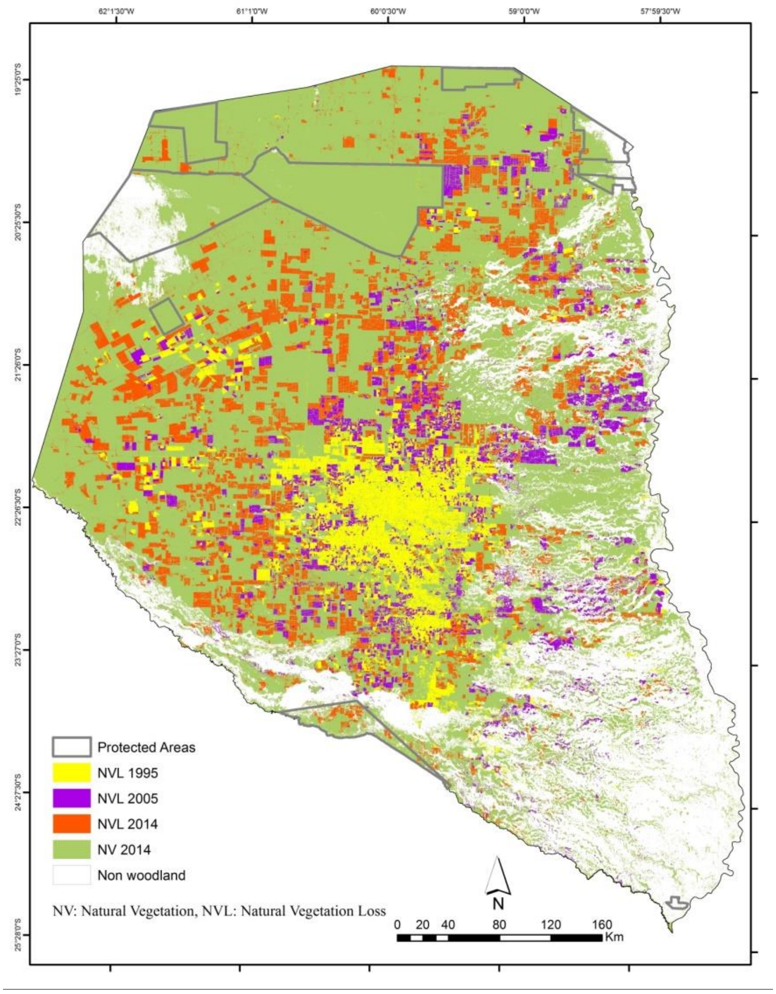

Fig. 5. Spatial and temporal land cover changes in the Paraguayan Chaco. The radial growth pattern characterized the conversion plots in 1995. For 2005 and 2014 the conversion plots had a disperse pattern in the landscape.

3.2. Protected Areas

The total NV until 2014 represented in the nine PA was 10%, and the majors are in the North of the Paraguayan Chaco (Huang et al., 2009). The protection of each ecoregion is relatively low, less than 15% for Cerrado, Dry Chaco and Wet Chaco, except for the Médanos ecoregion with 33%. All ecoregions had woodland loss within the 1-km buffer zones, except for the Cerrado, where conversion started in 2014. The Dry Chaco ecoregion lost the greatest amount of woodland area throughout all periods, while the Médanos lost the least amount of native vegetation (Table 1).

Table 1. Protected Area (PA) in each ecoregion and land cover changes in the buffer zones corresponded to 1- 5 and 15 km for the three periods 1995 – 2005 and 2014

The results indicate that the deforestation process is concentrated outside the existing PAs but our study identified a total 37125.9 ha deforested inside existing PA, being the Park Tinfunque the most impacted area with 24188.94 ha. Nevertheless, physical connections between adjacent PAs, as is the case of the Defensores del Chaco, Medanos del Chaco and Cabrera Timane National Parks, had been compromised by deforestations located on the 5 km buffer zone (Fig. 6a).

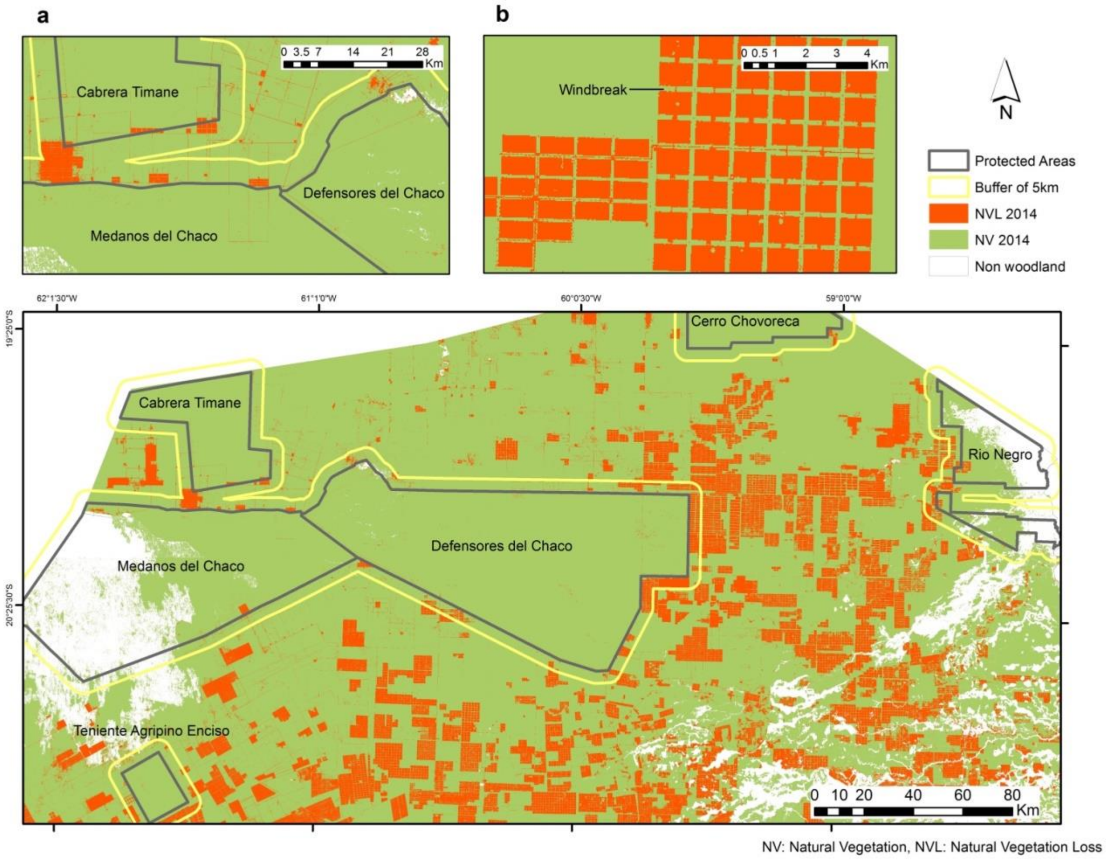

Fig. 6. Forest cover and change within the Protected Areas and the 5-km buffer zones surrounding them in the North of the Paraguayan Chaco. Structural connectivity between the Cabrera Timane, Medanos del Chaco and Defensores del Chaco National Parks with the 5 km buffer (a). The windbreaks between the conversion plots (b).

4. Discussion

4.1. Drivers of land cover dynamics

Ours results, obtained by using Landsat images for different periods, indicated that habitat loss on the Paraguayan Chaco is severe and has caused the suppression of 21.9% of the region's natural coverage over the last 19 years. This data corroborate the results of other studies, which put Paraguay among the top countries with high deforestation rate in Latin America (Clark et al., 2010; Aide et al., 2012; Hansen et al., 2012; Vallejos et al., 2014; Graesser et al., 2015).

Paraguay, like others countries of Latin American, is largely influenced by external pressures that drive the land cover change dynamics, mainly by changing economic opportunities that are linked to social, political, and infrastructural aspects (Lambin et al., 2001). While since the 1980s soybean cultivation has been a major driver of land-cover change in the Argentinian Chaco and in the Amazon region (Caldas et al., 2013), in the Paraguayan Chaco was the cattle ranching (Graesser et al., 2015). The limiting factors for soybean cultivation in the region is the rainfall regime and soil texture (Grau et al., 2005; Gasparri et al, 2015), which demand more investment in developing this practice. However, this scenario can change and contributes to the activity's expansion, principally because the changes pattern in precipitation could increase rainfall, as observed in Argentina (Zak et al., 2008). On top of that, new varieties of soybean, including glyphosate-resistant transgenic cultivars, are increasing yields and overcoming the environmental constraints, making this a very profitable agricultural endeavor (Grau et al., 2005). This actually occurs in the arid region of the Paraguayan Chaco, but all the studies to detect the land use was made at a global or regional scale and not be classified or detected, so it is recommendable to do it at a local scale to detect this treatment.

We divided the drivers in three groups, considering the scale of influence of each one. First, in a global scale, are the socioeconomic drivers linked to the international market and commodity prices. The demands for beef, for instance, increases as population grows and stimulates more investments that, in its turn, caused a faster conversion of the region (Caldas et al., 2013; Campos & Wisley, 2011). The observed differences in the quantified deforestation rate for the two trajectories of our study can be also related to international indicators. The FAO Food Price Index (FPI), a number that monthly averages the international prices of five food commodities (see FAO, 2016 for details) has changed significantly between the two deforestation trajectories. From 1990 to 2004 (our first trajectory), the annual mean of real FPI was 98.9, while for 2004 to 2014 (our second trajectory) the index was 147.2 (roughly 1.5 bigger than the previous period).

Second, at local scale, are the drives representing the infrastructure projects, such as roads, that was null in the first trajectory, and that could contributed in the dynamics on the second one like happened in Argentina (Gasparri et al., 2015). One example is a planned infrastructural project in the Occidental Region, aimed to create and maintain roads to connect the entire Paraguayan Chaco (IDB Report, 2011).

Finally, the third group of drivers is represented by the changes on the Paraguayan legislation, which caused a shift in the deforestation patterns or, as pointed out by Aide et al. (2012), the displaced deforestation. In 2004 the Paraguayan Government launched the Zero Deforestation Act that covered the Eastern region of Paraguay (Law 2524/04). The Law prohibited any conversions from forest to other forms of land use in eastern Paraguay (Grossman, 2015), especially where the forest was already fragmented (Huang et al, 2009). As a consequence, it was observed a displacement of the deforestation from the Oriental to the Occidental or Chaco region. For this region the annual rate of deforestation increased from 2005, a situation also indicated by other studies (Vallejos et al., 2014; Caldas et al., 2013).

Furthermore, while studies indicated the reduction of deforestation in the Amazonas (Hansen et al., 2013, Graesser et al., 2015), the Paraguayan Chaco has received new investing immigrants arriving from Brazil, which were looking for opportunities to increase meat production (Mereles & Rodas, 2014, Graesser et al., 2015). They were basically motivated by the cheap lands, but with the necessary money for investing in the hostile region (Lambin et al., 2001). This movement involves changes in the frontier development and policies by national governments that pull and push migrants into sparsely occupied areas (Rudel et al., 1993). This process is well known as indirect land-use changes (Lapola et al., 2010), which indicates the displacement of the productive land.

4.2. Patterns spatial changes on the windbreaks

The NVL in 1995 correspond majority to the historic deforestation (Vallejos et al., 2014), particularly strong in the central region known as Chaco Central, that was began in 1940 with Mennonite colonies, as a result of extensive mechanization processes (Mereles & Rodas, 2014; Caldas et al., 2013). The dynamic of loss was growing radially from the center of the Chaco. Perhaps, in the land cover of 2005, the change has intensified in the Northeast department of Alto Paraguay where the land was favored with rainfall in the Chaco Pantanal and the Cerrado ecoregions (Fig. 5). The radial spatial pattern disappears in 2014, (Caldas et al., 2013) the deforestation was widespread in the landscape.

Historic deforestation in the Central Chaco promoted a disordered disposition of the legally required windbreaks, being in many landscape portions there is a clear law inobservance. The produced maps show the lack of natural vegetation between plots where there is a consolidated land-use (such as close to cities or livestock systems (Mereles & Rodas, 2014)). During the second trajectory the Paraguayan Government created the Resolution N 303/04, which defined how agricultural areas or cattle ranches should be disposed in the landscape. Before this legislation was implanted, landowners did not had the obligation to present to local authorities an occupation plan for their rural properties. We believe that this particular legislation contributed expressively to have a less heterogeneous landscape, i.e., it is quite common to observe large blocks of land dominated by agricultural activities. A typical plan, necessary to obtain the right for land clearance, is elaborated without considering the situation of neighboring properties. To aim to planning and maintain the structural connectivity of the landscape, this plots could spatially ordered to maintain a representative area of NV and avoid the fragmented landscapes of the Oriental Region of the Paraguay (Quintana & Muse, 2005; Graesser et al., 2015).The landscape connectivity can be defined as the capacity of the landscape to facilitates movements of the biota and matter (Forman and Godron, 1986; Baguette and Van Dyck, 2007), being the fragmentation process the disruption of the links between natural habitats (Tischendorf and Fahrig, 2000). The NV of the Paraguayan Chaco was once considered to be a large continuous area (Vallejos et al., 2014). Except for the fragmented NV in an agricultural matrix in the central Chaco, the rest of the landscape appears to be connected due to the presence of windbreaks. As we saw among the compared years, the degradation of these connectors might become a risk for the landscape connectivity of the Paraguayan Chaco NV. Just like the Paraguayan portion of the Chaco, the Argentinean side is also facing a potential threat that may compromise the landscape connectivity. According to Piquer-Rodízguez et al. (2015), a new Argentinean legislation can allow different provinces to implement their own land-use plan. Similarly to the Paraguayan recent situation, the lack of a broad view of any zoning plan can cause the loss of landscape connectivity, with serious consequences for the biodiversity.

The public policies should ideally have a broad view of a region, where natural and productive areas should be planned on the first hand. At the local scale, concessions for vegetation suppression should safeguard the necessary connections to maintain local dynamics of dispersal and movement of the biota. This means that regional plans must avoid the analysis of individual properties, but considering the role that a set of croplands and pastures with windbreaks might have to ensure the functional connection for keystone species. At the end, it is expected a major contribution from rural landowners for the preservation of the Paraguayan Chaco and its biodiversity.

4.3. Protected areas and conservation

In the past, the proportion of land allocated to parks and reserves in Paraguay used to be higher than the average in South America (2.7%) (Yahnke et al., 1998). Since then, the PA in the country has grown to 14.9% (SINASIP, 2007), including the private reserves and the El Chaco Biosphere Reserve, designated as such in 2005 (UNESCO, 2005). Our study shows that the current set of PA in the Paraguayan Chaco represents 10.64% of the remaining natural vegetation. As in any other region, Paraguayan reserves and parks do not receive the proper financial support or management, essential to ensure the real protection of the PA.

The low representation protection of environmental diversities (Redford et al., 1990) is a consequence to the criteria used to establish the PA. In 1969, areas identified as potential parks were chosen according to their scenic attributes or for being historic sites where the Chaco war has happened. At that time, no area was designated specifically to preserve unique natural features, flora, fauna or ecological systems (Yahnke et al., 1998.)

It is well known that PA ensures the conservation of biodiversity components better than outside their boundaries (Bruner et al, 2001), but significant impacts over the PA should be avoided by promoting a better environment management of their buffer zones, which is not this case, specially we highlight the pressure of the land transformation for the PA, in the buffer of 1 km. Such zones should promote the regional integration of a PA (Thomas and Middleton, 2003), shielding the PA from being exploited and maintaining wildlife corridors from the PA to other native areas on its surroundings. The high rate of loss of native vegetation can adversely impact the PA, promoting the rapid forest loss within the PA and left them isolated as an ecological "island" (Huang et al., 2009).

Another consideration is the habitat loss detected inside the PA, which was previously detected by Huang et al. (2009). The plots converted are within the boundaries of each PA, which suggests the uncertainty of the boundaries, the need for an update of these boundaries (SINASIP, 2007), or the advance of the deforestation frontier. Furthermore, the fact that official georeferenced boundaries are unavailable leads to a lack of transparency and commitment to the preservation of these areas, and the weakness of the environmental law enforcement in Paraguay.

The structural connectivity refers to the contiguity of habitat (Tischendorf and Fahrig, 2000). Between Defensores del Chaco and Medanos del Chaco National Parks exist a structural connectivity which can be increased with the addition of Cabrera Timane National Park, attending the buffer of 5 km, ensuring the connection between the majors PA in the North of the Paraguayan Chaco (Fig. 6a). The identification of priority areas for conservation must receive urgent attention from the Paraguayan Government, because important structural connections between the PA are threatened by the uncontrolled expansion of agriculture and cattle raise activities in the region, as shown by our study.

4.4. Ecological consequences

The land cover change process alters the function and the structure of ecosystems, compromises the carbon natural cycle and affecting local and regional climate regimes (Vitousek et al., 1997). The complexity of ecological process of the Chaco region is not well known, so is unclear how local biota and ecological processes would react upon those impacts caused by deforestation and habitat fragmentation. The land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities could cause desertification (UNEP, 1994). Some of these factors that could contribute with desertification can be observed in the Paraguayan Chaco, such as fasten land cover change, increased aridity, both indirectly through greater rainfall variability and directly through prolonged droughts, the fire regimes caused for the reposition of the grassland before the seasonal rainfall and greater soil erosion (Bestelmeyer et al., 2008; Geist & Lambin, 2004). Also, it is well known that the loss of dominant perennial plants leads to a reduction in soil water infiltration, accelerated erosion that reduces soil fertility, rising water tables resulting in salinization, or even changes in local climate (Bestelmeyer et al., 2008).

The degradation of the Paraguayan Chaco is a process, is a state of change that happens now with its complexity, and in this way need to be focus for more studies that could determine the risks and the spatial consequences for the variability of environments.

5. Conclusions

The Paraguayan Chaco still have a large representative landscape of the Gran Chaco, but the high rate of the land conversion, the low representative protection of each ecoregion and the lack of a more effective regional planning can jeopardize local biodiversity and ecological processes. It is urgent to develop incentives to protect the Paraguayan Chaco, incentive the land’s owner to participate of the payment for ecosystem services and to develop research to improve the planning connectivity of the windbreaks to ensure the landscape connectivity between the land use and the PA.

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Figures caption

Fig. 1. Location of the Paraguayan Chaco in the Gran Chaco and the five ecoregions which occurs in the Paraguayan Chaco: Wet Chaco, Dry Chaco, Pantanal, Cerrado and Médanos (Mereles et al., 2013).

Fig. 2. Flow chart showing the datasets and the land cover used for changing detection.

Fig. 3. Reduction of area and percentage of natural vegetation cover for the three periods 1995 – 2005 and 2014.

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Table 1. Protected Area (PA) in each ecoregion and land cover changes in the buffer zones corresponded to 1- 5 and 15 km for the three periods 1995 – 2005 and 2014

				1995			2005			2014		
	NV area (ha)	NV pro (ha)	% NV pro	1km	5km	15km	1km	5km	15km	1km	5km	15km
M	321 088.23	104 366.02	33	5.22	64.08	878.67	5.22	64.08	878.67	5.22	271.17	5733.45
C	1 141 488.56	96 175.95	8	0	0	401.76	0	301.68	3814.92	451.8	2499.75	13120.92
P	2 228 100.59	75 515.69	3	185.13	786.51	4142.07	520.47	3309.03	8126.64	1901.88	12584.43	32805.54
WC	1 436 023.65	109 354.52	8	103.05	542.52	1415.97	232.02	1395.72	4583.97	1549.71	6856.92	14993.82
DC	8 167 603.06	1 028 555.13	13	1257.48	7497.45	28125.27	3162.96	20317.32	77661.99	8514.18	63783.36	205386.48

M: Médanos, C: Cerrado, P: Pantanal, WC: Wet Chaco, DC: Dry Chaco; NV pro: natural vegetation protected; 1km, 5km and 15 km are refers to the buffers area in hectares (ha

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Appendix 1 Landsat images used in this study

	Path/ Row	Date
1995 (Landsat 5 TM)		
	Path/ Row	**Date**
	226/076	1995/11/04
	226/077	1995/09/01
	227/074	1995/08/07
	227/075	1995/09/08
	227/076	1996/08/16
	227/077	1995/12/29
	228/073	1995/08/14
	228/074	1995/08/14
	228/075	1995/05/26
	228/076	1995/11/02
	228/077	1995/08/30
	229/073	1995/08/21
	229/074	1995/08/21
	229/075	1996/08/24
	229/076	1995/09/06
2005 (Landsat 5 TM)		
	229/076	2005/09/01
	229/075	2005/07/31
	229/074	2005/10/03
	229/073	2005/08/16
	228/077	2005/09/26
	228/076	2005/08/09
	228/075	2005/09/26
	228/074	2005/09/26
	228/073	2005/08/09
	227/077	2005/09/19
	227/076	2005/09/19
	227/075	2005/09/03
	227/074	2005/09/19
	226/077	2005/08/27
	226/076	2005/09/28
2014 (Landsat 8 OLI)		
	226/076	2014/09/21
	226/077	2014/09/21
	227/074	2014/08/11
	227/075	2014/10/14
	227/076	2014/11/19
	227/077	2014/11/15
	228/073	2014//08/02
	228/074	2014/08/02
	228/075	2014/08/02
	228/076	2014/08/02
	228/077	2014/08/18

	229/073	2014/10/12
	229/074	2014/10/12
	229/075	2015/02/01
	229/076	2014/07/24
	230/075	2015/02/08

Capítulo 2

Potential sites for conservation of the Paraguayan Chaco endemic birds

Abstract

The Paraguayan Chaco is a region with endemic birds, threatened by high rates of land cover conversion. Our main goal was to evaluate potential sites for the conservation of endemic birds based on community richness and landscape fragmentation in the Paraguayan Chaco. We modeled the distribution of endemic birds, identified the regions with higher richness, and crossed the resulting map with that of the 2014 land cover, excluding the area lost by deforestation. We characterized the landscape fragments with potential to harbor stable populations and measured a connectivity index between them based on a least-cost approach. The region with the greatest richness of birds was the Dry Chaco, which is also the region with the greatest loss of habitat. Fragments are larger in the Northern region, which is comprised primarily of protected areas, while the smaller fragments, mainly composed of windbreaks, were concentrated in the Central Chaco, a highly anthropogenic region. The connections between patches are favored in the North because of the proximity between them, while in the Central Chaco they were considered weak connections due to higher isolation rates. Potential sites for conservation are represented by clusters in the North, and noteworthy sites for restoration are in Central Chaco. Our study allowed the mapping of the Paraguayan Chaco landscape, and the identification of sites with high biological significance. These areas can be used as a basis for new zoning policies that promote and create strategies for landscape connectivity.

Keywords: fragmentation, connectivity, habitat loss, richness, clusters, landscape.

1. Introduction

Land use and cover change are the main drivers that promote habitat loss (Vitousek et al. 1997; Geist and Lambin 2004; Sala et al. 2010; Mantyka-Pringle et al. 2015) and fragmentation worldwide. Among the consequences of these processes are the reduction of natural habitat, increasing of isolation of remaining patches, modification of patches' shape and orientation, as well as the structure and type of matrix where the fragments are inserted (Fahrig 1997, 2003). Ecologically, such alterations affect population sizes, the dynamic and probability of extinction (Haski 1991) and the processes that could allow the species persistence in fragmented landscapes (Fahrig 2003).

The Gran Chaco is the second largest dry forest formation in South America (Prado and Gibbs, 1993; Pennington et al. 2000; Werneck 2011; Oakley and Prado 2011; Morrone 2014) and one of the regions with highest rate of deforestation. The Paraguayan Chaco has sadly leaded the rank of dry forests conversion in South America over the last years (Grau and Aide 2008; Huang et al. 2009; Clark et al. 2010; Hansen et al. 2013; Aide et al. 2012; Vallejos et al. 2014; Graesser et al. 2015), reaching 4% in 2010 (Vallejos et al. 2014). The recent loss of natural vegetation had changed the landscape structure of the Paraguayan Chaco, which used to be represented mainly by blocks of natural vegetation connected by windbreaks. Windbreaks are narrow strips of natural vegetation usually 100 meters wide located along roads, streams, and property fences. The Paraguayan legislation and rules, especially the Decree Nº 18831/86 (http://faolex.fao.org/), obligates that windbreaks must be maintained by the landowner whose rural property is bigger than 100 ha. At the regional scale, is important to understand how a massive suppression of the vegetation will affects connectivity and how local species, particularly those endemic to the region, would respond to such changes, assuming that corridors as critical to ensuring the persistence of populations (Piquer-Rodríguez et al. 2015).

Compared to other countries, Paraguay has few endemic birds due to its central position on the continent (Spichiger et al. 2004). Actually, there are 694 species of birds documented (see http://www.museum.lsu.edu/~Remsen/SACCCountryLists.htm for more details), 495 birds inhabit in the Paraguayan Chaco and 18 of them are endemic from the Gran Chaco (Short 1975; Porzecanski and Cracraft 2005). The studies about distribution of the Paraguayan Chaco birds are few (Neris and Colman 1991; Brooks 1997; Ericson and Amarilla 1997; Brooks 2000; Zyskowski et al. 2003) and the majority is based on the presence data or complements the geographic distribution formulated by Hayes (1995). As far as we know, none had analyzed the situation of the endemic birds on the region. On top of that, few studies surprisingly have evaluated the effect of habitat fragmentation in the Paraguayan Chaco. Mereles and Rodas (2014) for instance, compared the evolution of the natural vegetation from 1975 to 2007 and investigated how the average size of the fragments changed through the time. These authors, however, did not consider a biological group and the study was restricted to physical characteristics of the fragments. Another study (Vallejos et al. 2014) also dealt exclusively with fragmentation and no biological group was included on the analysis. For regional future planning it is necessary to have a better understanding on how current distribution of the endemics birds might be affected by habitat fragmentation and how the connectivity between fragments should be kept. Several methods to identify areas with high biodiversity value have been proposed, including quantitative approaches like hotspots of richness, hotspots of rarity and complementary areas (Williams et al. 1996; Margules and Pressey 2000).

The aim of our study was to identify important areas for endemic bird species on the Paraguayan Chaco, taking in account the fragmentation status the natural vegetation. Thus, we expect that the massive habitat destruction of the Paraguayan Chaco would substantially reduce the conservation opportunities to endemic bird species. In order to demonstrate that, we mapped the potential occurrence of endemic birds richness and used the graph theory to identify clusters of connected or nearby fragments, estimating habitat connectivity represented by a set nodes (habitat patches) and links that connect pairs of nodes.

2. Materials and methods

2.1.Study area

The Chaco is considered a biogeographic region, and can be characterize as an open vegetation biome of lowland alluvial plains of central South America. This biome or ecoregion covers an area of 840,000 km^2, extending from northern Argentina, western Paraguay, south-eastern Bolivia, and the extreme western edge of Mato Grosso do Sul state in Brazil (Prado and Gibbs 1993; Pennington et al. 2000; Werneck 2011; Oakley and Prado 2011) (Fig. 1).

The climate of the Chaco is generally semiarid, responding to the rainfall values ranging from 564 to 1103 mm, with a remarkable gradient from west to east and from south to north (Navarro et al. 2011). The aridity increases progressively to the west, culminating in the driest areas where the Chaco transitions to the Andean foothills (Adamoli et al. 1990). The biome can be also distinguished by its strong seasonality and severe winter frosts. Thus, the vegetation of the Chaco is subjected to low soil moisture and freezing in the dry season and waterlogging and extremely high air temperatures during part of the rainy season (Pennintong et al. 2000).

There are two main assemblages that represent well-defined and stable plant compositions conspicuous to the Paraguayan Chaco: the dry Chaco (locally names as Chaco Seco) and the wet Chaco (locally named as Chaco Húmedo) (Olson et al. 2001; Spichiger et al. 2004). The main vegetation types are described in details by Mereles and Rodas (2014), which mentioned the vegetation with the difference representation: sub-humid and semi-deciduous forests, riparian hygrophilous forests and floodable forests, xeromorphic forests, the cerrados and cerradones, savannahs and wetlands.

2.2.Ecological niche modeling and endemic richness

We obtained georreferenced data of 18 endemics birds from the Guyra Paraguay Biodiversity Datasets (BDBGP 2014), which includes scientific papers and Museums occurrence, and from the Global Biodiversity Information Facility (www.gbif.org).

We used climatic variables from the WorldClim bioclimatic database (Hijmans et al. 2005; see http://www.worldclim.org for more details) for present day as our environmental data. In order to avoid the spatial autocorrelation for species occurrences, all environmental data were in 2.5’ resolution (approximately 5x5 km). In order to exclude variables that were too correlated with each other (Dormann et al. 2013), we performed a factor analyses (i.e. by selecting variables with the highest loadings in the first five eigenvectors; Terribile et al. 2012). This analysis was done in the program R 3.1.2 (R Development Core Team, 2010) and were selected five: Isothermality (BIO3), Max Temperature of Warmest Month (BIO5), Mean Temperature of Warmest Quarter (BIO8), Precipitation of Driest Month (BIO14), and Precipitation of Driest Quarter (BIO17).

We used the maximum entropy algorithm (Maxent) for the ecological niche modeling, which an algorithm based in the relationship and restrictions between the geographic presence data and the environmental data (Pearson and Dawson 2003) and results in the most plausible distribution (Phillips et al. 2004, 2006). The absence data are generated by randomly selecting ‘‘pseudo-absence’’ points in a major area (background), (Anderson et al., 2003). In this case, we used the Chacoan region (Löwenberg-Neto 2014) as a geographical mask. The resulting model is a map of environmental suitability, which represents the potential distribution of a species (Guisan and Thuiller 2005).

We kept only one of any duplicated points of presence that occurred in a single grid cell and randomly divided the points into two groups: the training data group (70% of the points for species with more than 100 occurrences and 80% for those with less than 100 occurrences) and test data (30% or 20% of the points). Thus, we used the training points to generate the models (the average of 10 replicates cross-validate) and the testing points to evaluate their quality. We used an approach suggested by Peterson et al. (2008) to test the models. The procedure, called Partial Receiver Operating Characteristic (Partial ROC), consists in a series of iterations that uses a subset of the training points to compare the area under the curve (AUC) at the given 1-omission threshold to the random AUC (50%). Then, a ratio between the partial ROC-AUC and the random AUC is calculated. This proceeding was implemented in a Partial ROC program (Barbe 2008). Once the results were obtained from the Partial ROC program, we performed a *t* Test to verify if the Partial AUC was significantly greater than expected by chance. All statistical analyses were done with program R 3.1.2 (R Development Core Team 2010).

After the models were tested, we converted each species model to a presence/absence map by reclassifying the environmental suitability value according the threshold value Maximizing the Sum of Sensitivity and Specificity (Max SSS). This threshold is not affected by pseudo-absences (Liu et al. 2013), which is the case of our dataset. For the purposes of this study, we called the original species distribution model –

SDM as the species the historical distribution (hereafter just SDMh), i.e., the expected distribution without deforestation. On the other hand, we defined the remaining distribution of the species (SDMr) by eliminating all anthropic areas on the region implemented after the natural vegetation has been removed. The endemic bird richness region was obtained by sum each raster SDM map and then calculated the SDMh and SDMr for this region.

In order to map the windbreaks and natural vegetation loss on the Paraguayan Chaco landscape, we used Landsat images from 1995 and 2014. Therefore, our analysis compare the changes observed along 19 years. Although there are other natural vegetation formations on the region, we restricted our analysis to the dry forest vegetation type, since it is the main natural vegetation for the endemic birds (Short 1975). We made all map calculations and classifications with the ArcGIS v. 10.0 (ESRI 2010) software.

2.3.Connectivity modeling technique and potential sites for conservation

We used the Graphab 1.2.3 in order to identify potential connectivity between fragments on the studied region. Due to restrictions of computer processing, we degraded the raster map regarding the remaining natural vegetation coverage in 2014 to a spatial resolution of 150 m (i.e., the pixel size). Graphab software indicates the landscape connectivity after identifying the least-cost-path between pairs of fragments. Thus, the pathways represent the shortest distance to be travelled between two patches when considering a dispersal-cost surface (Foltête et al. 2012). The dispersal-cost surface is a raster grid where each pixel's value represents dispersal cost of interpatch-crossing distance between two fragments. (Lecher et al. 2014),

The minimum area of each path considered here was 500 ha because we aimed to include only large patches suitable to maintain viable population. Furthermore, we also assumed that those patches would be able to contribute to local dispersal, recolonization of unoccupied habitat patches, seasonal migration, and metapopulation persistence (Hanski 1991). This assumption, of course, depends on the ability of different bird species to move and disperse from one path to another, which on the other hand is related to their plasticity to move among the matrix, body size, dietary requirements (Tksisky et al. 1999; Castellon et al. 2006; Velez et al. 2015). Nevertheless, we collect some data on the specialized literature (Marini 2010; Castellon et al. 2015) in order to define the minimum dispersal distance necessary to characterize the functional connectivity between patches (*sensu* Taylor et al. 1993). Therefore, we used two generic values to identify clusters of patches on the Paraguayan Chaco, being 500 m as the maximum distance to structurally link one patch to another, and 300 m for the functional connectivity of the graph. As the analysis requires a cost-surface map, the values, represented as percentage, were assigned to each land cover type in order to reflects the ecological costs for species to move through it (Tksisky et al. 1999; Rayfiel et al 2011; Lecher et al. 2014). For natural vegetation coverage and for habitat loss classification we used 1 and 5 respectively, based on Gil-Tena et al. (2014) to forest and grassland. Details about the input values can be viewed in the Table 1.

To identify potential sites for conservation, the richness of endemic bird on the region was intersected with the map created on the connectivity analysis. We used the Zonal Statistic of the Spatial Analysis Tool in the Arc Map 10.0 software (ESRI 2010) in order to map the priority areas.

3. Results

3.1. Distribution of endemic birds and land cover conversion

We collected a reasonable set of occurrence points for the 18 endemic bird species of Paraguayan Chaco (Table 2), aspect that contributes to the quality of the final models. In average, we had 101.3 training points (ranging from 18 to 288 points) and 45.2 testing points (ranging from 5 to 124 points). The final continuous maps for each species' allowed us to map suitable areas in the region for each species, (Appendix 1).The test of partial ROC values showed that all individual species models were better than expected by change (Table 2), enabling us to use all the models in the subsequent analyses.

The SDMh models (historical species distribution) indicate that endemic bird species could occupy, in average, up to 84% of the Paraguayan Chaco. The endemic birds with higher historic occupancy were *Knipolegus striaticeps, Ortalis canicollis* and *Xiphocolaptes major* (99%), and with the smaller one was *Rhynchospiza strigiceps* (48%). Our results indicate that the endemic bird richness region is restricted to the Dry Chaco, as pointed out by other authors (Short 1975; Porzecanski and Cracraft 2005) (Fig. 2).

The SDMr (current species distribution) represent the present distribution or the available habitat for each endemic bird by 2014. Considering the 1995-2014 period, human activities caused loss up to 32% on natural vegetation during the last 19 years. In average, bird species lost 24.4% of their original habitat on the Dry Chaco between up to 2014 (Table 2). The most impacted species was *Rhynchospiza strigiceps*, which has lost 32% of its original area (annual loss of 2.47%) and the least impacted were *Campephilus leucopogon, Knipolegus striaticeps, Strix chacoensis*, and *Xiphocolaptes major,* which lost 22% of their original area (an average loss of 1.5% per year).

From the set of 18 endemics birds, seven species can be found on the converted habitat, i.e., the grassland. Five of them correspond to species adapted to open vegetation areas, such as *Furnarius cristatus* or *Pseudocolopteryx dinelliana* are associated with grassland (Table 3).

Up to the date, none of the endemic species are considered threatened by extinction and only one, *Pseudocolopteryx dinelliana,* is recognized as Near Threatened (IUCN 2015). All other are classified as Least Concern (LC) (Table 3). *Pseudocolopteryx dinelliana* inhabits flooded rushy and grassy marsh vegetation and shrubbery near watercourses in lowland scrub (Birdlife International 2016), so the habitat loss to the grassland conversion may not affect its distribution.

3.2.Connectivity modeling and potential sites for conservation

A total of 1083 patches greater than 500 ha were identified. Each patch represents the nodes of clusters that may or may not be linked to other nodes. Our analysis shows that the highest concentration of big clusters is observed on the northern part of Dry Chaco, and small clusters or isolated fragments are located on the southern part (Fig. 3). The largest clusters correspond to big protected areas in the region: the Defensores del Chaco and Medanos del Chaco National Park, representing 33% of the total patch area. Other six important graphs do not have a formal legal protection and they are located in the North (Fig. 4). Those areas represent 19% of the total patch area. Thus, the most important clusters (two large clusters on the north and six other located on the center of the region) represent 52% of all remaining natural seasonal forest fragments. All other remaining areas are represented by small or isolated fragment that are scattered through the region and they form small or no clusters at all (Fig. 3).

The Central Chaco is highly fragmented consisting in few small and isolated patches, which are represented by the windbreaks principally. Those patches are already broken apart from the largest patches identified in the North and few significant clusters were identified in this region (Fig. 3). The crossing process of the map of endemic species richness with the cluster map suggests that priority clusters for conservation are located on the North, while priority clusters for landscape management are located on the center of the region (Fig. 4). Our least-cost analysis suggests that the connections between fragments located on the existing clusters in the center of the region and in part of the northern region.

4. Discussion

4.1. Distribution of endemic birds

This study provides an innovate analysis about the conservation strategies for the endemic birds of the Paraguayan Chaco, where the combination of ecological niche models, current land use map and the graph theory were used to identify priority areas for conservation and for maintenance of landscape connectivity. This approach can be very helpful to draw conservation scenarios in regions where human pressure on natural ecosystems is of a great concern, as in the Paraguayan Chaco. Our analysis also brings an update of the situation of endemic bird species in the region, considering that previous studies that dealt to this subject are from the 70's and the 80's (Short 1975; Cracraft 1985).

Although conservation scenarios can be drawn and negotiated with local authorities and society, the high rate of natural vegetation conversion in the Paraguayan Chaco, which is prognosticated to continue because the available land for conversion (Lambin et al. 2013), immediate actions to reduce deforestation are required. The pressure over natural areas is favored for the Paraguay government to develop the Chaco, supported by international financing projects to construct highways promoting the access and the demand for beef (Grau and Aide 2008; Campos and Wisley 2011; Caldas et al. 2013; Graesser et al. 2015).

Species distribution modeling is an important tool to know where is the potential distribution of the bird and, therefore, can potentially help scientist and specialized technicians to identify important regions for additional research and conservation. The distribution modeling (Phillips et al. 2004; Guisan and Zimmermann 2000; Peterson 2001) is currently the main tool used to derive spatially explicit predictions of environmental suitability for species (Guisan et al. 2013; Elith and Leathwick 2009; Guisan and Thuiller 2005), an information useful for formulate conservation management decisions (Guisan et al. 2013; Elith and Leathwick 2009).

Although all produced models in our study had a good quality, i.e., the models adequately previewed where the species actually occur, the results must be viewed with precaution. The modeling process of confirmed occurrence does not provide much information about the extrapolated regions where a species could occur (Rondinini et al. 2006). Nevertheless, ecological niche models are indicated as a valid approach to propose conservation actions worldwide, including South America (Avalos and Hernández 2015; Ramirez-Villegas et al. 2014; Teixeira et al. 2014).

Our analysis of land use mapping indicates that areas with high concentration of endemic bird species are those highly affected by habitat loss in the Paraguayan Chaco. Habitat loss, as detected by other studies on the Paraguayan Chaco (Torres et al. 2014), can create local barriers and operating as a habitat restriction for local biodiversity. The availability of habitat also determines how birds will respond and how they will be locally distributed (Maqui et al. 2015; Mastrangelo and Gavin 2014; Machi and Grau 2012; Mastrangelo and Gavin 2012). Birds with little distribution or requirements for specific habitats to survive could be more affected to the land conversion process, and pronounced changes in local richness patterns or ecosystem services can be altered (Torres et al. 2014; Sala et al. 2010).

The endemic bird richness region, resulting from the overlaid distribution of 18 endemic birds, is restricted to the Dry Chaco, confirming the geographic distribution adopted by Hayes (1995). According to this author, the ornithological region of Alto Chaco has birds species not recorded elsewhere in Paraguay, with a marginal occurrence in other Chaco regions. The area along the Bermejo and Pilcomayo rivers represents the conjunction of woodland and grassland habitats where the distributions of several species of birds met (Nores 1992). In addition of being the most important area for the endemic birds, the region is one of the most threatened areas due to the habitat conversion (Vallejos et al. 2014, Caballero et al. 2014; Cardozo et al. 2013; Caldas et al. 2013). The high deforestation rate observed in this and other studies (e.g. Vallejos et al. 2014) is consequence of the radially anthropic expansion of the Central Chaco, favored with the construction of roads to connect the Chaco (IDB Report 2011).

4.2. Landscape connectivity

The adoption of the graph theory in our study resulted in a connectivity map of the Paraguayan Chaco landscape, being the first time that this kind of analysis is used for the country or for the Chaco ecoregion. Whenever it is created by natural or anthropic causes, habitat fragmentation is a process that can reduce the availability of suitable natural areas for species and led to biodiversity loss. A recent compilation of habitat fragmentation studies (Haddad et al. 2015) indicates up to 75% of local biodiversity can be reduced and important ecosystem functions can be heavily impacted. Besides, the structure of remaining natural ecosystems left in a landscape is important to define how species will survive and how they will use the natural resources, although some authors have suggested that species are more or less tolerant to habitat fragmentation (Villard et al. 2014). The way that species dealt with habitat fragmentation is through the use a set of nearby fragments, aspect related to the functional connectivity in a landscape. Thus, clusters of fragments can be viewed as a single unit connected by logical links that compose a local network of natural patches. In our case, links between remaining fragments of natural vegetation were identified by using to the least cost dispersion through the matrix, a clear generalization of specie's ecological characteristics.

According to the landscape connectivity analysis combined with species distribution modeling, our region can be divided in two important areas for priority actions, an action for increased protection and other for environmental management (Fig. 4): one, composed by large patches and little fragmented region represented by the existing Protected Areas and adjacent natural vegetation areas located in the northern Chaco; the second region can be characterized by small and isolated patches plus the windbreaks and is located in the

Central Chaco, where exists a high endemic bird richness and high fragmentation. It is known that patches size is correlated to the abundance of resources, especially in areas with high quality (Rayfiel et al 2011) and we can expect that the Protected Areas probably offers conditions to maintain stable population of birds. On the other hand, the bird population in the Central Chaco could remain like isolated population and act like a metapopulation (Hanski 1991). The fragments in the North can result in corridors extending the protection area. Studies refers that birds moved more often between forest patches connected by forest corridors than between forest patches without a connection (Andrade and Marini, 2002) reducing the effects of fragmentation (Fahrig 1997). In comparison to the North region, the Central Chaco was heavily impacted and had most of its natural coverage suppressed. Not only the habitat loss, but also isolation of the remaining vegetation is also another huge difference between these two parts of the Dry Chaco as a consequence of historical development of the region (Mereles and Rodas 2014; Caldas et al. 2013). This fragmented region is a threatened region where the species are more at risk (Williams et al., 1996) and where the fragments are more susceptible to disappear for being in an anthropogenic region, sensitive to influences of the land use and consequences of intensification (Grau et al. 2008) that could result in habitat degradation and habitat loss compromising the landscape connectivity.

The nodes and links define and determine whether the habitat cluster represents structural, potential or functional connectivity among habitat patches (Rayfield et al. 2006). This aspect supposedly depends on the birds' movements, which may be affected in different ways by the type of habitat conversion or the matrix (Antongiovanni and Metzger 2005) compromising the dispersal and maintenance viable populations in the fragmented landscapes (Marini, 2010). In fact, birds respond negatively to habitat conversion, principally in an agricultural dominated landscape (Machi et al. 2015; Torres et al. 2014), otherwise, in a grassland expansion, the silvopasture could maintenance a tradeoff between bird diversity and production (Mastrangelo and Gavin 2012). In the Paraguayan Chaco the most important pressure to natural vegetation areas is the introduction of planted pastures (Campos-Krauer and Wisel2011; Caldas et al. 2015). Thus, seven bird species conspicuous in the region (*Ortalis canicollis, Chunga burmeisteri, Eudromia Formosa, Nothoprocta cinerascens, Furnarius cristatus, Rhinocrypta lanceolata, Pseudocolopteryx dinelliana*), that use grasslands, could have their dispersal capacity favored by habitat fragmentation, since that there is no indication they could find suitable habitats on the open habitats created by cattle ranch production (Torres et al. 2014). Castellon and Sieving (2006) suggested that these birds should be focal species for a conservation planning on the region because a landscape that provides functional connectivity for the group would probably meet the dispersal requirements for other species. On the other hand, in the case of woodland-dependent species, the matrix could be unsuitable and potentially hostile (Arendt 2004; Antongiovanni and Metzger 2005), but it is rarely a complete barrier to dispersal. The dispersal will highly depend on the patches that are connected (or close enough to be reached), or the movement ability of the bird (Antongiovanni and Metzger 2005; Castellon and Sieving 2006; Marini 2010). Further and specific analyses are indicated for these particular birds in order to review their population status because of the accelerating land cover change in the last years.

Habitat loss is currently the most important threaten to biodiversity worldwide, and it is expected that local extinctions will be observed by the year 2100 (Sala et al. 2010). Species with small geographical distribution, as the endemic birds are, can be viewed as a strategic indicator to lead the process of protected area creation, which should be established to form a representative network that benefits different biodiversity components (Williams et al. 1996; Myers et al., 2000). Considering that the Paraguayan Chaco is a poorly studied region, we believe that more fieldwork is necessary to clarify how local biodiversity, and especially endemic bird species, responds to habitat loss and habitat fragmentation. Specifically, it is important to stimulate studies aimed to identify the ecological mechanisms, such as dispersion dynamics through the human dominated matrix, that are important for bird communities persistence. Also, compared to others vertebrates' distribution, the region should be evaluated like endemic hotspots (Williams et al. 1996; Myers et al. 2000) or Important Bird Area (IBA) for the patches that have not been included yet.

We hope that our analysis will stimulate the development of policies aimed to improve the zoning process in the Paraguayan Chaco. Like other countries in South America, there is an urgent need to implement feasible conservation actions that involves a common ground to conservationists and policy-makers. There is no question about the importance of food production, but wise strategies toward to combine an efficient land use with the conservation of biodiversity are urgently demanded demand on the Paraguayan Chaco.

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Table 1. Landscape parameters and input layers used in the connectivity model.

Description	Value	Source
Dispersal and habitat characteristics		
Patch size	500 ha	
Interpatch-crossing distance threshold with structural connectivity and no dispersal costs	500 m	Marini, 2010; Castellon et al., 2015
Gap-crossing distance threshold	300 m	Marini, 2010; Castellon et al., 2015
Dispersal cost surface		
Natural vegetation	1	Gil-Tena et al. (2014)
Habitat loss	5	Gil-Tena et al. (2014)
Geoprocessing		
Land cover and vegetation layer	30 m	Land cover layer based on 2014 Landsat image classification
Pixel size for connectivity model	150 m	Based on smallest pixel size processed

Table 2 Spatial statistics for the endemics birds of the Chaco.

Species	N (training)	N (testing)	Partial ROC (Ẋ) *	SDMh (km^2)	SDMr (km^2)	SDM loss (km^2)	% Loss	% Annual loss (km^2)
Campephilus leucopogon	151	65	1.003	235 930.49	183 465.98	52 464.52	22	1.51
Chunga burmeisteri	80	34	1.039	219 050.37	168 743.04	50 307.33	23	1.57
Drymornis bridgesii	140	60	1.012	212 823.12	164 213.40	48 609.72	23	1.56
Dryocopus schulzi	26	7	1.124	134 506.41	94 602.86	39 903.55	30	2.22
Eudromia formosa	39	10	1.096	204 858.92	156 571.16	48 287.76	24	1.62
Furnarius cristatus	108	47	1.049	206 458.46	157 562.20	48 896.26	24	1.63
Knipolegus striaticeps	86	37	1.022	240 532.07	187 883.81	52 648.26	22	1.47
Nothoprocta cinerascens	92	39	1.003	178 072.03	132 089.88	45 982.15	26	1.83
Ortalis canicollis	215	92	1.036	240 386.83	187 746.19	52 640.64	22	1.48
Poospiza melanoleuca	288	124	1.000	235 566.96	183 321.36	52 245.60	22	1.50
Pseudocolopteryx dinelliana	18	5	1.236	211 299.45	160 059.37	51 240.08	24	1.68
Rhinocrypta lanceolata	86	37	1.030	191 420.68	144 451.23	46 969.45	25	1.71
Rhynchospiza strigiceps	68	17	1.010	117 963.55	80 330.46	37 633.09	32	2.47
Saltatricula multicolor	124	53	1.010	220 526.96	169 148.11	51 378.84	23	1.60

Spiziapteryx circumcincta	47	12	1.040	120 459.61	84 844.16	35 615.46	30	2.21
Strix chacoensis	46	12	1.028	235 494.48	183 267.68	52 226.81	22	1.50
Tarphonomus certhioides	73	31	1.028	195 171.34	148 730.08	46 441.26	24	1.64
Xiphocolaptes major	138	59	1.014	240 653.10	188 001.86	52 651.24	22	1.47
Endemic bird richness region	-	-	-	94 330.90	60 419.73	33 911.17	36	2.95

N (training): numbers of points using to obtain the SDM (Species Distribution Modeling); N (testing): number of points to evaluate the SDM (for species with more than 100 occurrence points was used 70% for training and 30% for testing; Underlined numbers on Testing column indicate species with less than 100 occurrence points); Partial Roc ($\dot{X}$): mean of the Partial Receiver Operating Characteristic. The '*' means $p<0.05$ or that models are better than expected by chance; SDMh: distribution modeling area for the birds; SDMr: SDM less conversion area; SDM loss (km^2): SDMh – SDMr; % Loss: (SDMh – SDMr)/ SDMh*100; % Annual loss (km^2): (((SDMh – SDMr)/ 19)/ SDMr)*-100; Endemic bird richness region: region where the 18 endemic birds occurs.

Table 3 Conservation status of the endemic bird species of the Paraguayan Chaco.WL: dry forest-dependent species; GL: grassland; LC: least concern; NT: near threatened.

Species	Family	Habitat	IUCN conservation status (2015)
Campephilus leucopogon	Picidae	WL	LC
Chunga burmeisteri	Cariamidae	GL	LC
Drymornis bridgesii	Dendrocolaptidae	WL	LC
Dryocopus schulzi	Picidae	WL	LC
Eudromia formosa	Tinamidae	GL	LC
Furnarius cristatus	Furnariidae	GL	LC
Knipolegus striaticeps	Tyrannidae	WL	LC
Nothoprocta cinerascens	Tinamidae	GL	LC
Ortalis canicollis	Cracidae	GL	LC
Poospiza melanoleuca	Emberizidae	WL	LC
Pseudocolopteryx dinelliana	Tyrannidae	GL	NT
Rhinocrypta lanceolata	Rhinocryptidae	GL	LC
Rhynchospiza strigiceps	Emberizidae	WL	LC
Saltatricula multicolor	Emberizidae	WL	LC
Spiziapteryx circumcincta	Falconidae	WL	LC
Strix chacoensis	Strigidae	WL	LC
Tarphonomus certhioides	Furnariidae	WL	LC
Xiphocolaptes major	Dendrocolaptidae	WL	LC

Figures caption

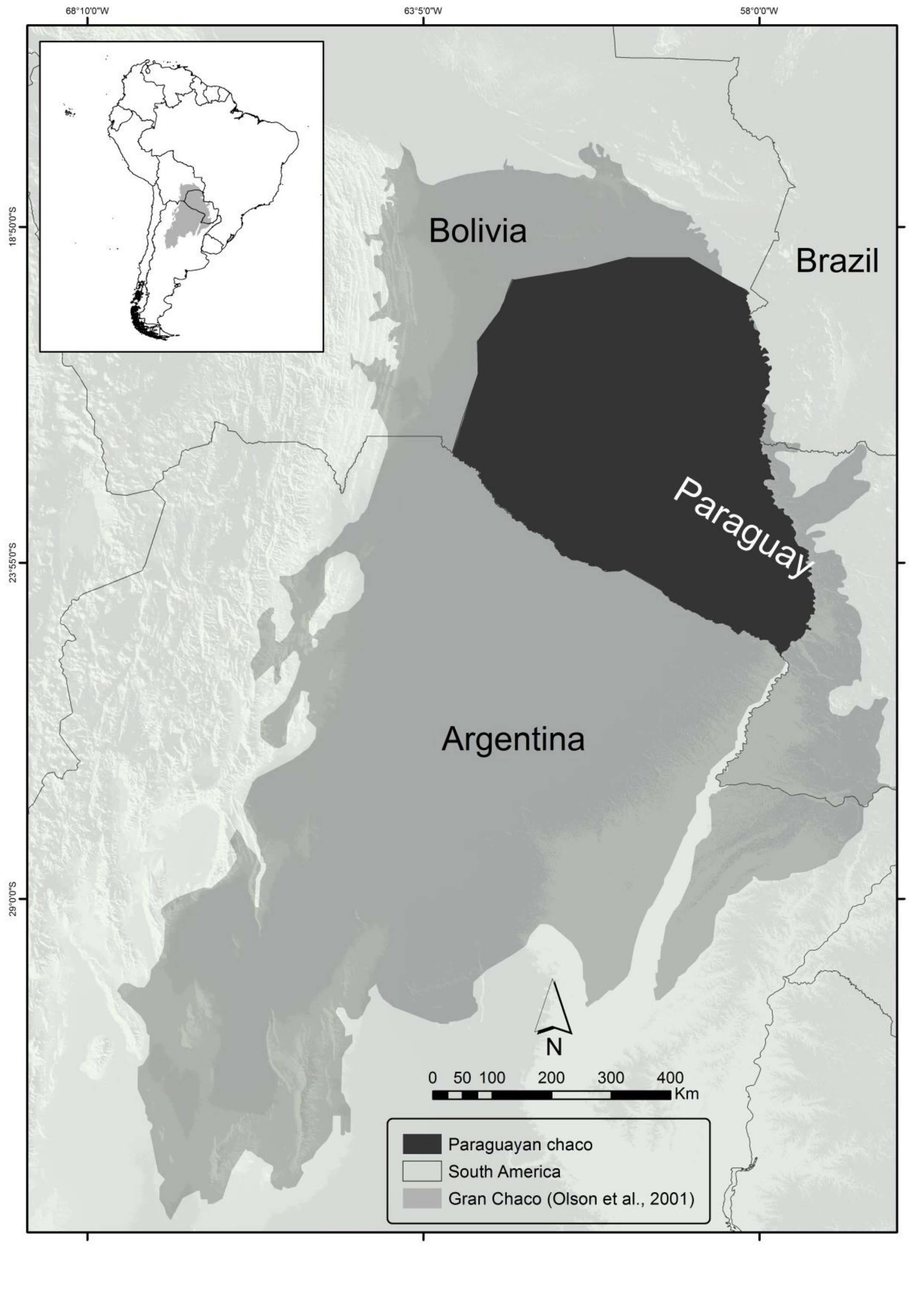
Fig. 1 Location of the study area within the Gran Chaco (Olson et al. 2001), which includes Argentina, Brazil, Bolivia and Paraguay.

Fig. 2 Historical and current distribution of endemic birds in the Paraguayan Chaco. The current distribution refers to the remaining natural vegetation in 2014. The black area corresponds to the endemic bird richness region.

Fig. 3 Connectivity modeling using least–cost paths for patches greater than 500 ha. Circular graduated symbols describe patch area located at the center of each patch and links to connect the patches with the functional connectivity.

Fig. 4 Potential sites for conservation and landscape management on the Paraguayan Chaco. Black clusters are those with a high concentration of endemic species and high percentage of remaining natural vegatation. The black lines in the center and in the north of the region represents potential connections based on a least cost analysis between major fragments in the Central Chaco.

Fig. 1



68°10'0"W
63°5'0"W
58°0'0"W
18°50'0"S
23°55'0"S
29°0'0"S
Bolivia
Brazil
Paraguay
Argentina
N
0 50 100 200 300 400
Km
Paraguayan chaco
South America
Gran Chaco (Olson et al., 2001)

Fig. 2

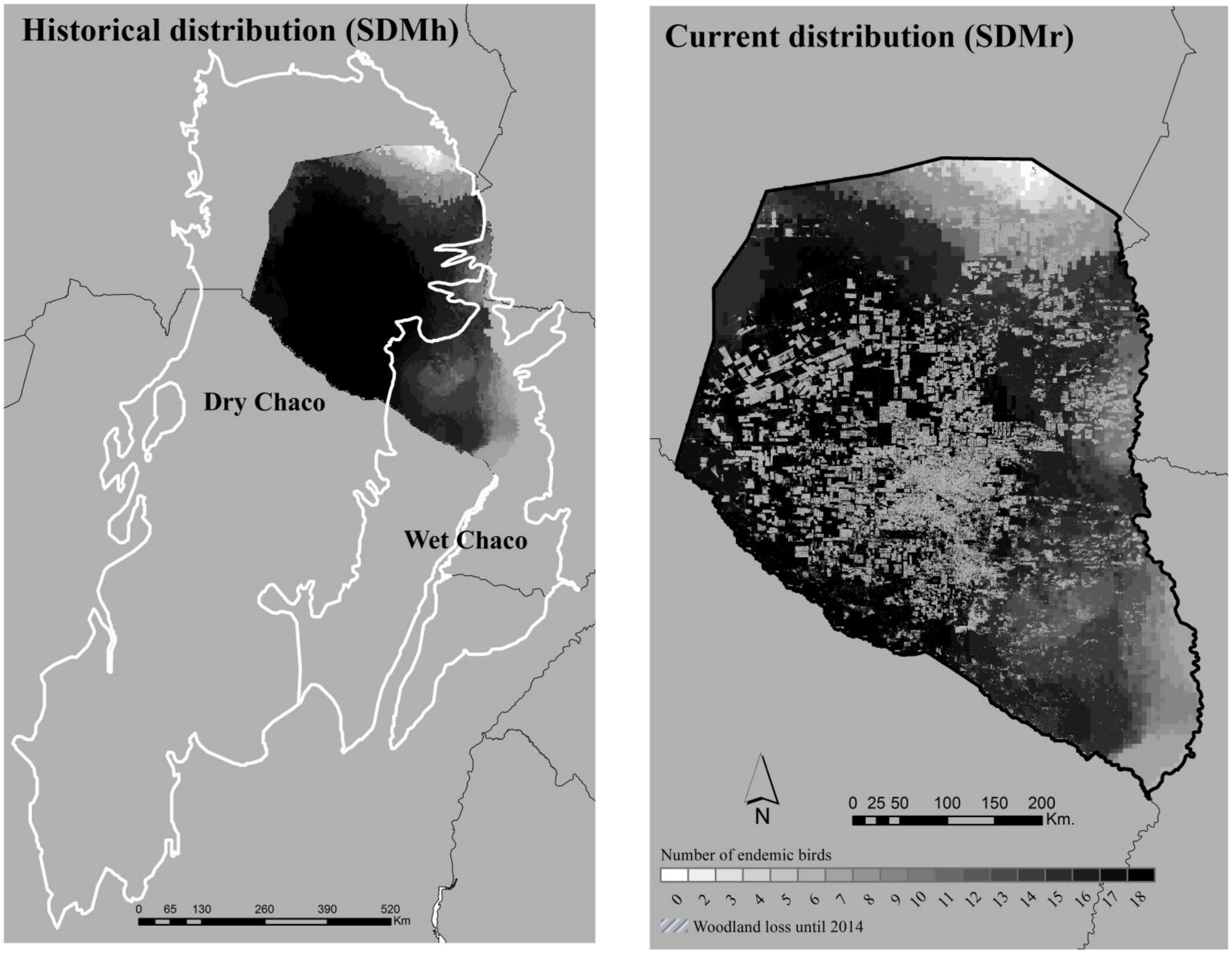
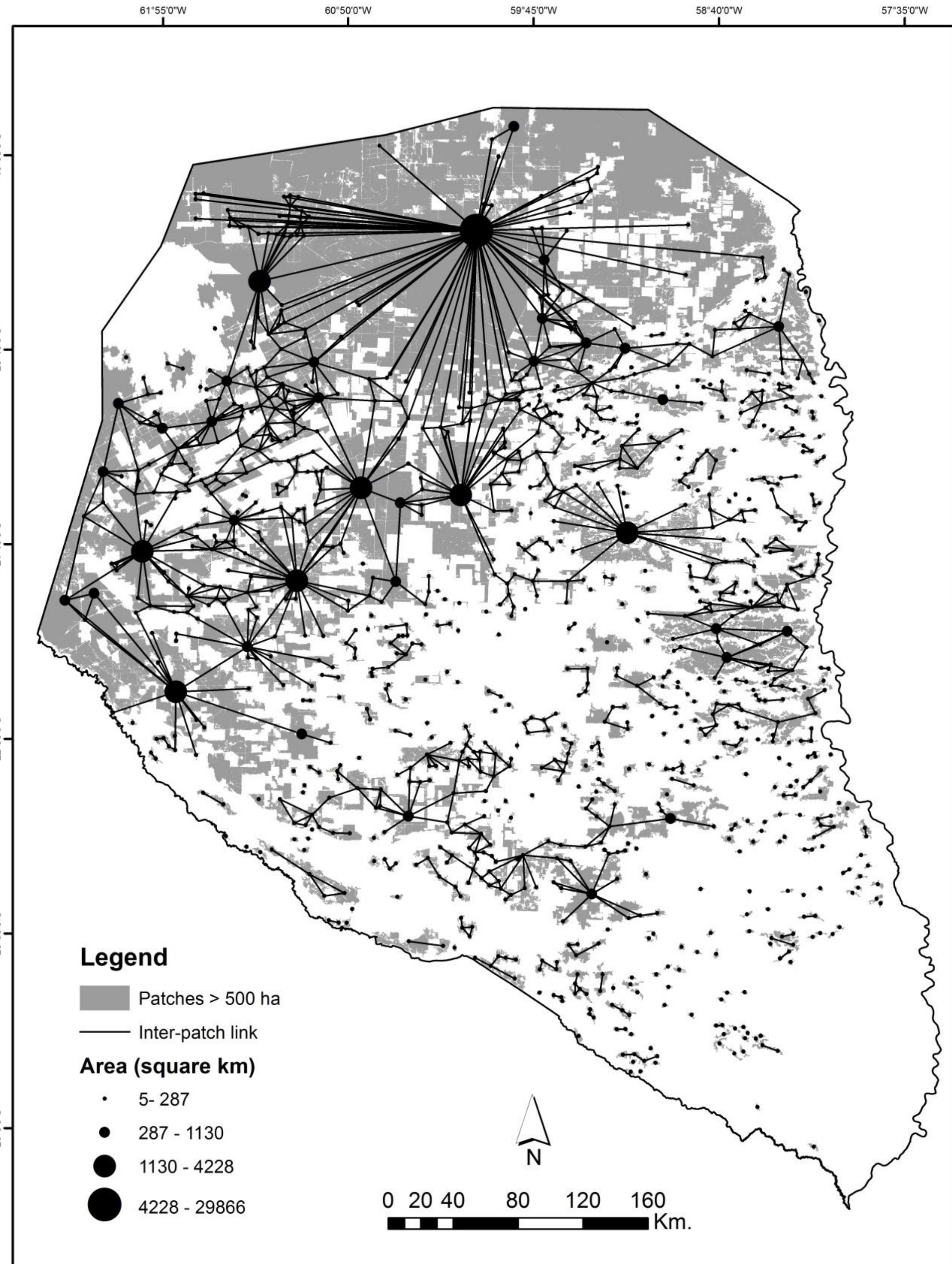
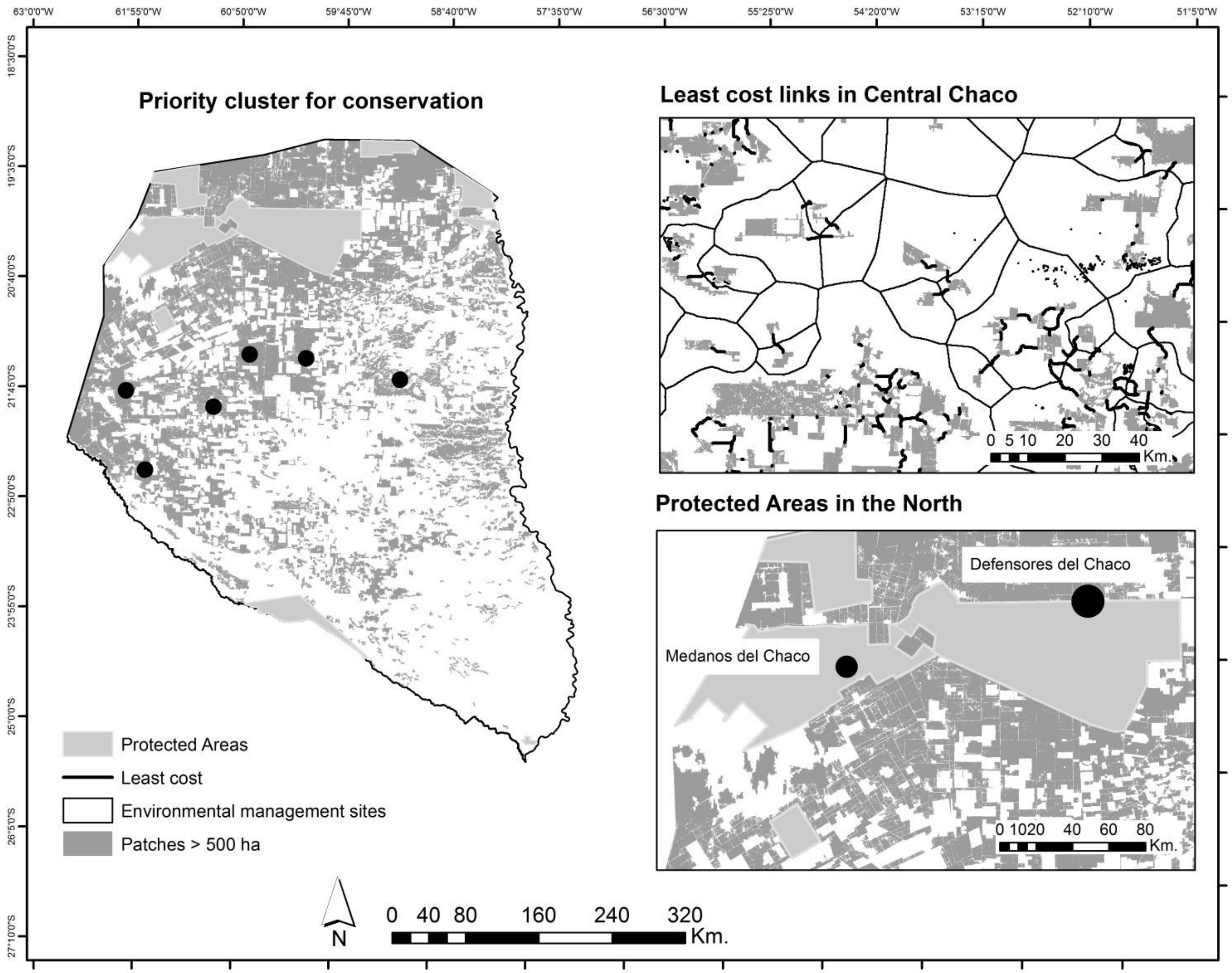

Historical distribution (SDMh)
Dry Chaco
Wet Chaco
0 65 130 260 390 520
Km
Current distribution (SDMr)
N
0 25 50 100 150 200
Km.
Number of endemic birds
0 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Woodland loss until 2014

Fig. 3



61°55'0"W
60°50'0"W
59°45'0"W
58°40'0"W
57°35'0"W
19°35'0"S
20°40'0"S
21°45'0"S
22°50'0"S
23°55'0"S
25°0'0"S
Legend
Patches > 500 ha
Inter-patch link
Area (square km)
5- 287
287 - 1130
1130 - 4228
4228 - 29866
N
0 20 40 80 120 160
Km.

Fig. 4



Priority cluster for conservation
Least cost links in Central Chaco
Protected Areas in the North
Defensores del Chaco
Medanos del Chaco
Protected Areas
Least cost
Environmental management sites
Patches > 500 ha
0 40 80 160 240 320
Km.
N
0 5 10 20 30 40
Km.
0 1020 40 60 80
Km.

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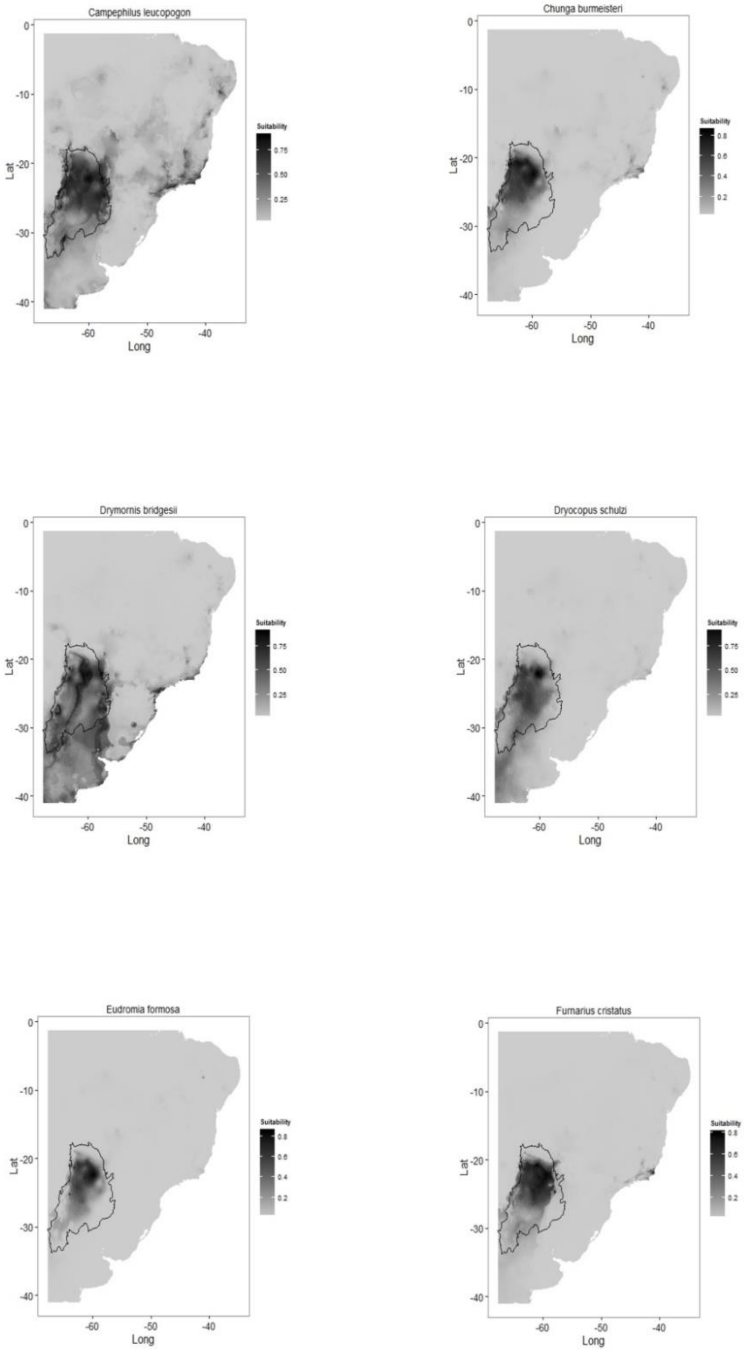
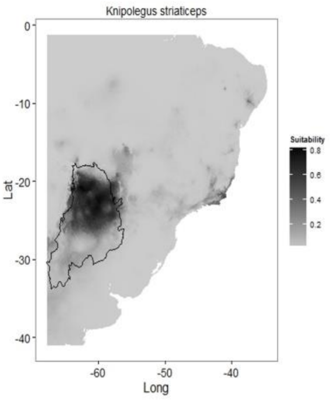
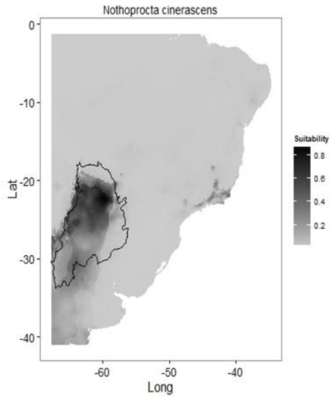
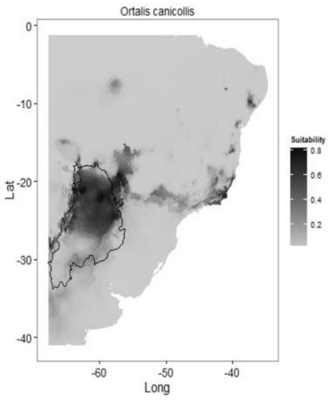
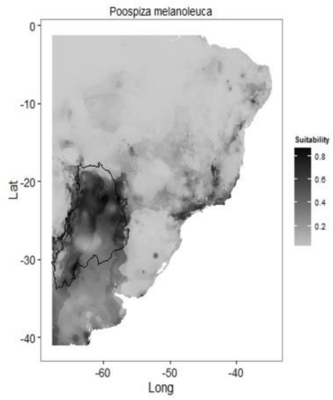
Appendix 1 Historical suitability maps in the Chacoan region generated for each endemic bird.

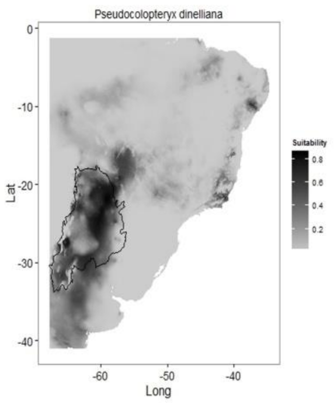


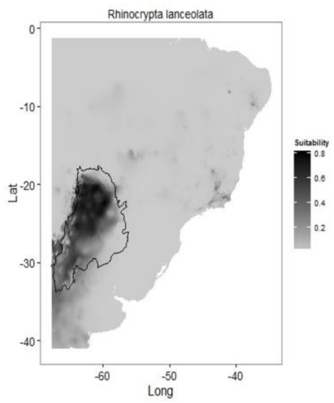

Knipolegus striaticeps
Lat
Long
Suitability

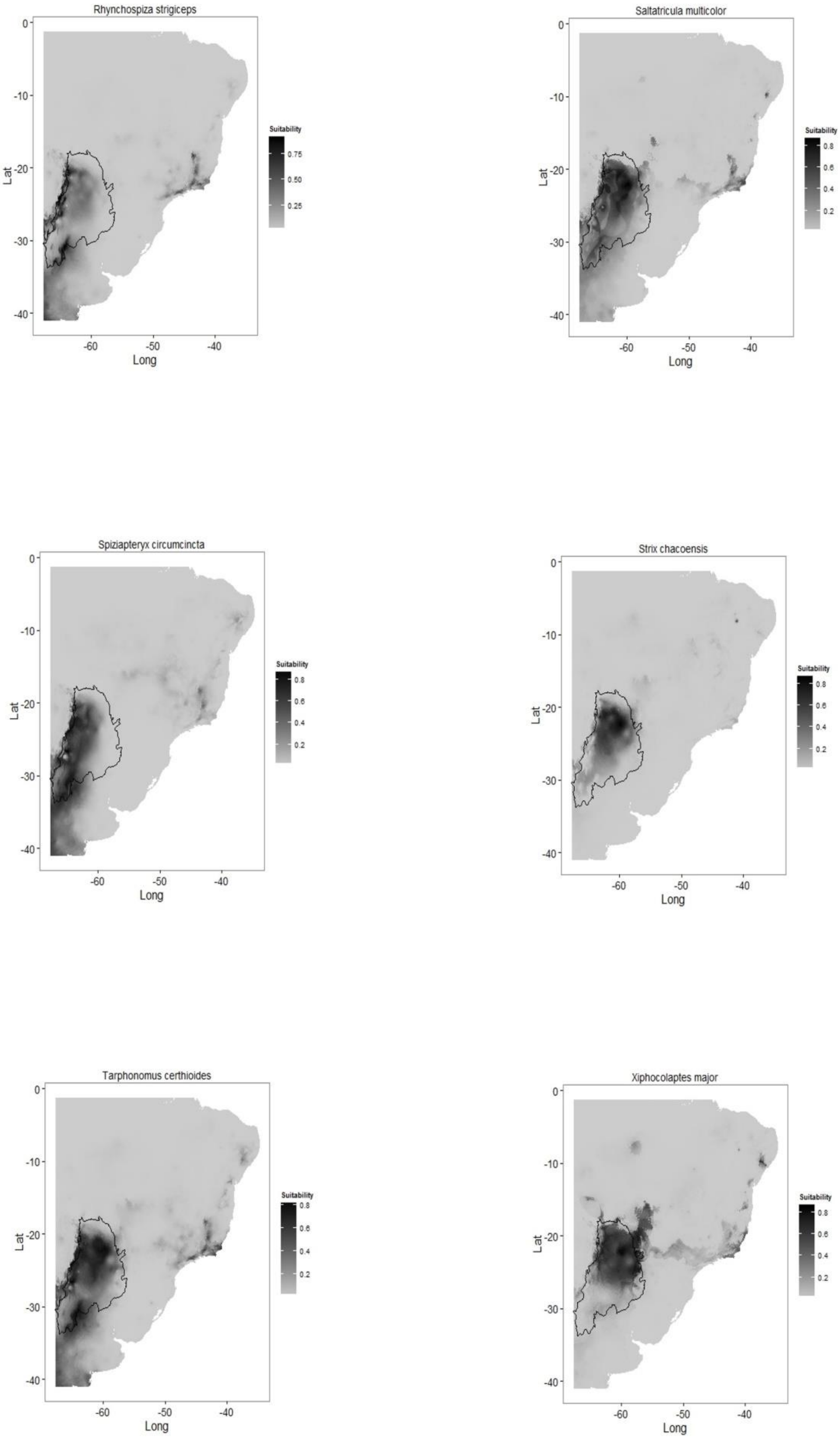

Nothoprocta cinerascens
Lat
Long
Suitability


Ortalis canicollis
Lat
Long
Suitability


Poospiza melanoleuca
Lat
Long
Suitability


Pseudocolopteryx dinelliana
Lat
Long
Suitability


Rhinocrypta lanceolata
Lat
Long
Suitability


Rhynchospiza strigiceps
Saltatricula multicolor
Spiziapteryx circumcincta
Strix chacoensis
Tarphonomus certhioides
Xiphocolaptes major
Lat
Long
Suitability