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BIODIVERSITY VIEWPOINT

Protected areas and spatial conservation priorities for endemic vertebrates of the Gran Chaco, one of the most threatened ecoregions of the world

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ABSTRACT

Aim To evaluate the representativeness of the current network of protected areas (PAs) of one of the most threatened ecoregions in the world, the South American Gran Chaco, and determine priority conservation areas for endemic (and nearly endemic) terrestrial vertebrates of the region.

Location South America.

Methods We identified all those amphibians, mammals and birds whose distributions were at least 70% within the Gran Chaco. Then, we refined and corrected species' distributional ranges, first, using records from collections and expert knowledge, and second, by incorporating environmental and topographic data using a technique for range polygon refinement. Lastly, we used Zonation, a spatial conservation prioritization software, to evaluate representativeness of the current protected areas (PAs) network of the region and to define forest remnants to strategically expand PAs while maximizing the representativeness of the selected groups and considering human activities.

Results Current PAs cover 9% of the region and represent 9.1% of the total distribution of endemic species. Considering our prioritization, increasing the coverage to 17% to match the Aichi targets would substantially increase the representativeness of the PA network, covering on average more than 30% of the ranges of all endemic species and 77% of the distributions of threatened and DD endemic species.

Main conclusions Our results highlight that the need for well-informed decisions in the Gran Chaco is imperative. While the current PA network in the region ensures a very poor representation of endemic terrestrial vertebrates, opportunities to efficiently expand the PAs network are really high. This emphasizes the potential of complementarity-based systematic conservation planning tools as an essential support for conservation decisions. Given the great information gaps regarding biodiversity and human activities in the region, similar studies with updated data would improve conservation planning in the Gran Chaco in the future.

Keywords

Aichi targets, conservation policy, habitat loss, protected areas, systematic conservation planning, vertebrates.

INTRODUCTION

The Gran Chaco ecoregion is one of the most threatened subtropical woodland savannas in the world (WWF, 2015), with impressively high forest cover loss in the last 10 years (Hansen *et al.*, 2013) as a consequence of deforestation rates which are among the highest worldwide (Gasparri & Grau, 2009; Hoyos *et al.*, 2013). The primary cause has been the increase of international soybean prices, in synergy with an increase in rainfall in the region during the last decades and

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technological advances which have allowed intensive food production in previously non-accessible regions (Zak *et al.*, 2008). These land use changes have led to habitat loss and fragmentation, which directly affect biodiversity and ecosystem functioning (Naeem & Wright, 2003; Hooper *et al.*, 2012). Moreover, habitat loss is the main cause of population and species extinction (Green *et al.*, 2005; Pimm *et al.*, 2014) and leads to great negative impacts for terrestrial vertebrates (Jenkins *et al.*, 2013).

Most of the terrestrial vertebrate species of the Gran Chaco are greatly affected by this recent conversion process (Periago *et al.*, 2014; Torres *et al.*, 2014; Grau *et al.*, 2015; Lescano *et al.*, 2015). While the Gran Chaco is marginally inhabited by a large number of vertebrate species (most of them widely distributed at the continental scale), it also harbours an important number of species whose distributions are mostly contained within the Gran Chaco (Szumik *et al.*, 2012). Given the great current human pressures in the region, the consequent cost of land and the associated difficulty in the allocation of conservation resources (Zak *et al.*, 2008), conservation actions should focus on endemic or mainly endemic species, as their conservation can only be guaranteed inside the ecoregion. These endemic and small range size species are generally the strongest predictors of a species' risk of extinction (Manne *et al.*, 1999; Jenkins *et al.*, 2013).

Although the Gran Chaco has been identified as being in need of urgent conservation actions (Frate *et al.*, 2015; WWF, 2015), information available on Chacoan biodiversity is very limited and fragmented. However, the scarce information available shows clear signs of an alarming decline. For instance, among mammals, around 50% of the largest frugivores and 80% of the largest herbivores living in the argentine Gran Chaco are threatened and exhibit declining population trends (Periago *et al.*, 2014). Negative impacts of land conversion have also been observed for several other Chacoan taxa such as amphibians, birds and reptiles (Cardozo & Chiaraviglio, 2008; Torres *et al.*, 2014; Lescano *et al.*, 2015). Considering the great negative impact of biodiversity loss at an ecosystem level (Hooper *et al.*, 2012), the picture is even more worrying. Protected areas (PAs) are the cornerstone for conservation biodiversity; however, their coverage and effectiveness strongly depend on a suitable selection (Pouzols *et al.*, 2014; Watson *et al.*, 2014). Thus, it is imperative to efficiently use the scarce available information to identify habitat remnants that can strategically expand the current representativeness and connectivity of the PA network of the region.

A representative PA network should guarantee the survival and viability of key species and ecological and evolutionary processes. Unfortunately, PAs have historically been relegated to 'residual places'; that is, short-term economic interests have prevailed over conservation objectives (Fuller *et al.*, 2007; Faleiro & Loyola, 2013; Nori *et al.*, 2013), pushing conservation areas to those regions unsuitable for agricultural practices (Pressey *et al.*, 2002). Thus, PA networks show huge gaps in adequately representing biodiversity (Rodrigues *et al.*, 2004; Le Saout *et al.*, 2013; Nori & Loyola, 2015; Nori *et al.*, 2015; Sánchez-Fernández & Abellán, 2015). As expected, major gaps are located in those potentially productive ecoregions, including the Gran Chaco, for which forecasts are not optimistic (Volante *et al.*, 2016). In fact, PAs in the region are mostly ineffective, isolated from other PAs and immersed within a degraded or productive matrix, threatening the conservation objectives of the area (DeFries *et al.*, 2010; Matteucci & Camino, 2012).

The Gran Chaco Americano Ecoregional Assessment defined priority conservation areas for the region considering most of the vertebrate species (including many species marginally distributed in the region) (The Nature Conservancy *et al.*, 2005). However, that technical report had some shortcomings, such as the lack of an accurate and standardized procedure to select species and define species' distributions, as well as the use of an outdated methodology for the selection of priority areas. Moreover, those analyses were performed over 12 years ago, period in which the agricultural frontier drastically advanced in the ecoregion (Frate *et al.*, 2015).

Still, in spite of the above problematic and the urgency of the subject, little is known about the priority conservation areas of the Gran Chaco, and even less about the efficiency of the PA network in this threatened ecoregion. Therefore, we believe there is a need to update existing data and provide new and more accurate information that can guide current conservation decision-making processes. Thus, the main aims of this study were to determine (1) the representativeness of the existing PA network in the region and (2) priority conservation areas for endemic terrestrial vertebrates of the Gran Chaco ecoregion. For this, we used revised information of the distributional ranges of the species of three well-known taxa of terrestrial vertebrates (amphibians, birds and mammals; Jenkins *et al.*, 2013; IUCN, 2014) mainly distributed in the Gran Chaco, to determine areas to efficiently expand the current network of PAs using Zonation, a complementarity-based systematic conservation planning tool.

METHODS

Species' distributions

Range maps of three well-known terrestrial vertebrate groups at global scale (including 23,062 species of amphibians, birds and mammals) were downloaded from the International Union for the Conservation of Nature (IUCN, 2014). These vector maps are available in shape file format and contain the known ranges of each species, depicted as polygons. The per cent of the distribution of each species within the Gran Chaco (sensu Olson *et al.*, 2001) was calculated, and those species whose distributions were at least 70% within the ecoregion were selected. In total, 63 species were included in the analyses. Although this was an arbitrary threshold, it allowed the inclusion of all species whose persistence can only be guaranteed inside the ecoregion, while avoiding the inclusion of a great number of marginal and widely distributed species. Moreover, if we had only included strictly endemic species (threshold of 100%), many species that occur marginally in transitional areas outside the Gran Chaco (but that are essentially Chacoan) would be excluded (for additional details regarding the selected threshold please see Appendix S1 in Supporting Information). Non-avian reptiles were not considered as information from the last IUCN assessment is not published yet (M. Tognelli, pers. comm.). Finally, species endemic to the montane grasslands of Sierras Pampeanas Centrales were excluded, as these grasslands constitute an island inside the Gran Chaco with a different biogeographical identity (Nores, 1995).

Although the range maps were generated by experts in each taxonomic group and have been widely used previously in conservation planning (e.g. Faleiro & Loyola, 2013; Di Minin *et al.*, 2016), they are known to vary in their levels of accuracy among regions (Ficetola *et al.*, 2014). Thus, the authors in consultation with experts revised and redefined all the polygons by first manually correcting vector maps, using a database of localities of each of the species (containing data from the most important collections in the study area), and maps of elevation, political boundaries and urban centres. Second, a technique for range polygon refinement modified from that developed by Sangermano and Eastman (2012) was implemented, which uses the application of a bioclimatic envelope model based on presence-only data, to enhance the ecological and climatic coherence of each range polygon (see Appendix S2, Table S1 and Fig. S1).

Priority conservation areas

Zonation 4.0.0b (Moilanen *et al.*, 2005, 2014) was used to identify priority areas for the conservation of endemic vertebrates of the Gran Chaco. This software establishes a hierarchical prioritization of areas of the study region, allowing for the identification of the most important areas for the conservation of species (or the areas for an optimal, balanced expansion of an existing reserve network, if desired) based on species' distributions and optional data such as the economic value of land. The prioritization ensures maximization of species' occurrence levels while taking into account complementarity. Two different removal rules were implemented: core area Zonation (CAZ) and additive benefit function (ABF; Moilanen *et al.*, 2014); both results were compared, and areas of consensus were delimited. The most important difference between both removal rules is that as ABF gives higher importance to cells with many features, it retains a higher average proportion of feature distributions. Alternatively, CAZ gives higher importance to areas containing rare and/or highly weighted species (for details see Di Minin *et al.*, 2014).

We assigned the conservation weight to each species based on their conservation status (IUCN, 2014; Pouzols *et al.*, 2014; Di Minin *et al.*, 2016) (LC = 1; NT = 2, DD = 3; VU = 4, EN = 5, CR = 6). Existing PAs were included using a hierarchical mask, an approach developed to select optimal areas for PAs expansion (Di Minin *et al.*, 2014; Kukkala *et al.*, 2016). PAs were downloaded from the World Database of Protected Areas (IUCN & UNEP, 2015), where only 'designated' PAs belonging to any of the six categories by IUCN were considered.

Given that most of vertebrates cannot adequately be protected inside crop fields or in highly urbanized areas (Periago *et al.*, 2014; Pimm *et al.*, 2014), and most of them are highly vulnerable to high levels of habitat fragmentation (Periago *et al.*, 2014; Núñez-Regueiro *et al.*, 2015; Quiroga *et al.*, 2016), we excluded pixels already covered by crops or highly urbanized areas from the analysis. For this, we reclassified a land cover map of South America (Blanco *et al.*, 2013) into a binary map, discriminating all of the pixels covered by crops or urbanization from the other pixels. Using this raster map, we were able to 'mask' crops and urban centres. Finally, giving that, in general, human influence tends to diminish habitat quality, and therefore, the potentiality for conservation, we used the human Footprint v 2.0 (WCS & CIESIN, 2005) as a negative variable, 'penalizing' those pixels with high human influence. This variable was weighted as the negative value of the sum of the individual weights of each species, so that the sum of all features equals zero.

After running the prioritization analysis, we plotted performance curves which quantify the proportion of the original occurrences retained for each biodiversity feature, at each top fraction of the landscape chosen for conservation (Di Minin *et al.*, 2014; Moilanen *et al.*, 2014). This allowed us to determine the representativeness of the current PA network and the top priority 17% of the available territory (minimum surface suggested by The Convention on Biological Diversity; UNEP *et al.*, 2010) considering (1) all species together and (2) only threatened and data deficient species.

RESULTS

We found 63 vertebrate species with at least 70% of their distributions within the Gran Chaco: 21 amphibians, 20 mammals and 22 birds. *Ctenomys tucumanus* and *Hypsiboas varelae* were not included in the land prioritization, the first one because its distribution completely overlaps crops and/or urban areas; and the later because its description was based on few specimens of a single locality collected more than 50 years ago, but never recorded in the wild. Only six of these species are categorized as threatened (VU, EN, CR), and four of them are categorized as DD by the IUCN (Table S2).

Designated PAs cover 9.1% of the region (43.1% in Argentina, 40.6% in Bolivia and 16.2% in Paraguay) and, on average, represent 9% of the total distribution of endemic species and 30% of the distributions of threatened and DD endemic species. According to the current prioritization, by protecting an additional 7.9% of the total territory (i.e. 17% of the Gran Chaco; red areas in Fig. 1), the representativeness of the PA network would substantially increase, covering between 32% (considering CAZ) and 33% (considering ABF) of the ranges of all endemic species, and between 78% (considering ABF) and 79% (considering CAZ) of the distributions of threatened and DD endemic species (Fig. 2). In regard to the threshold of protecting 17% of the area, both algorithms showed highly consistent spatial patterns with the area of consensus between them corresponding with 69% of the priority selected surface (Fig. 1).

Priority conservation areas cover wide surfaces located in adjacent (or buffer) areas to current PAs (Fig. 1). Most of them are located within Argentina (64% considering CAZ prioritization and 59% considering ABF) and Paraguay (36% considering CAZ and 41% considering ABF). Areas of consensus between both algorithms are predominantly located in Argentina (73%).

DISCUSSION

We found that the current PA network of the Gran Chaco ensures a very poor representation of those terrestrial vertebrates whose presence must be guaranteed inside the ecoregion. However, opportunities to improve this scenario are quite high. Based on refined range maps of endemic terrestrial

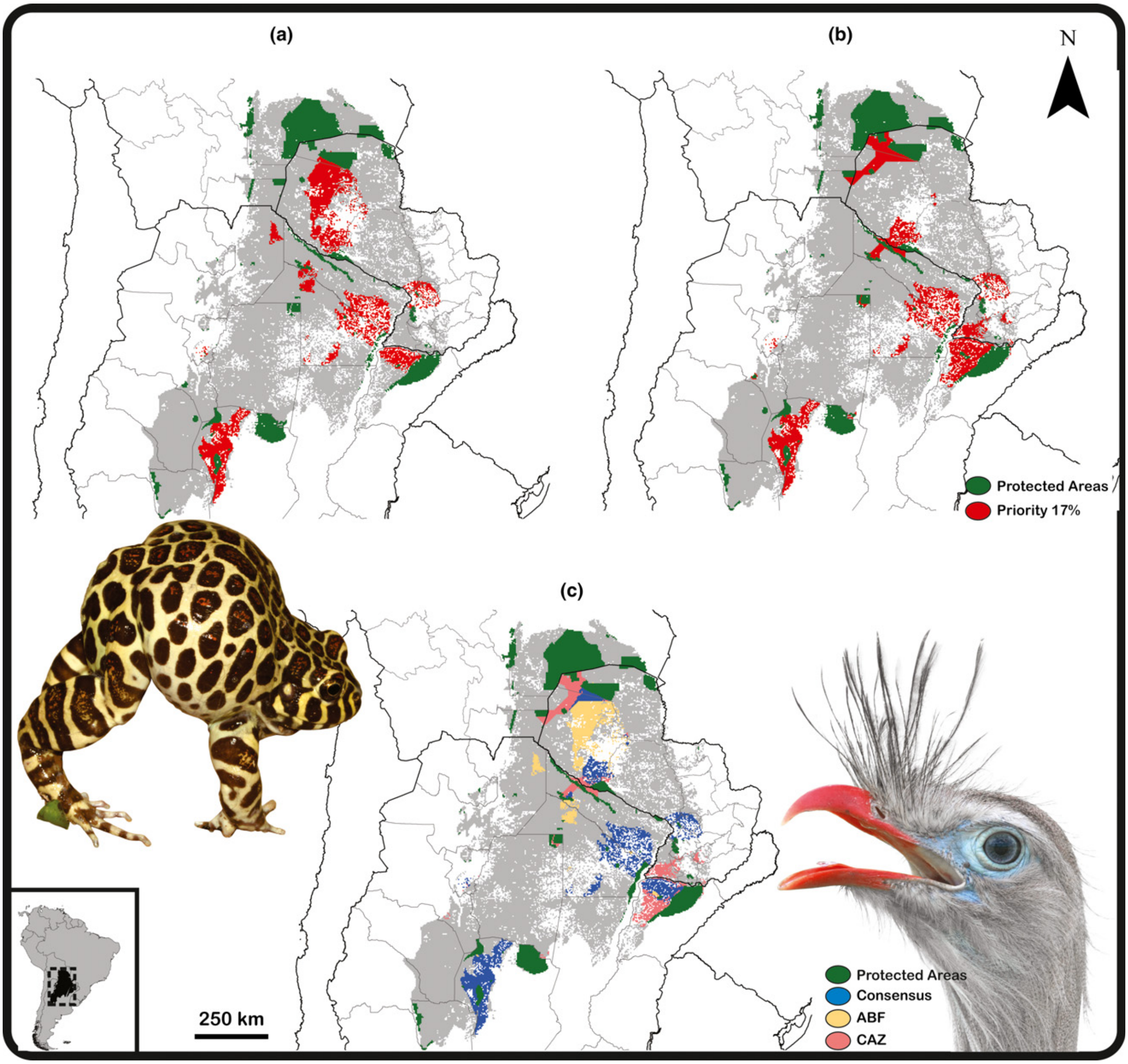

Figure 1 Maps showing existing protected areas of the region (green), potential expansion areas identified in the current spatial prioritization analysis for each removal rule (a: ABF; b: CAZ) and comparison between both removal rules (c). Red pixels (of a and b) correspond to 7.9% of the Chaco with high priority and complementary to protected areas (protected areas + red areas which correspond to 17% of the cells of Chaco).

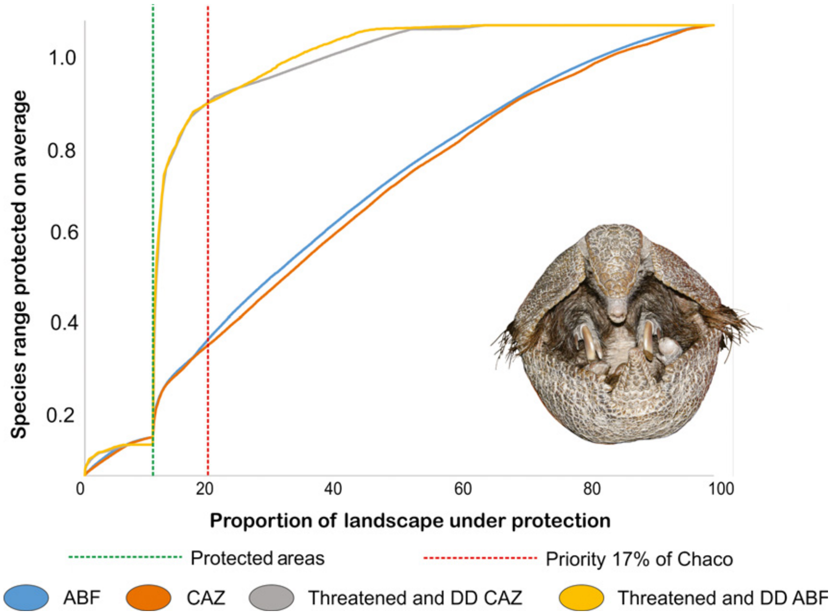

Figure 2 Performance curves of the prioritization models, showing the proportion of available cells that are protected (*x*-axis) and its corresponding average species range protected (*y*-axis), considering all the species together, and each of the distributions of threatened and data deficient species for both removal rules.

vertebrates of the region, and using the complementarity-based spatial conservation prioritization tool Zonation, we found that adding < 8% of priority territory to the existing PA network could, on average, include more than three times the total ranges of endemic species, resulting in an average representation of more than 75% of threatened and DD species. This highlights the great potential of identifying new high-priority areas for conservation and providing support for conservation decisions (Di Minin *et al.*, 2016). Considering the problematic context associated with one of the highest rates of habitat loss worldwide (Zak *et al.*, 2004, 2008; Gasparri & Grau, 2009; Hoyos *et al.*, 2013), and the high vulnerability of Chacoan terrestrial vertebrates to these big, rapid and continuous changes (Cardozo & Chiaraviglio, 2008; Periago *et al.*, 2014; Torres *et al.*, 2014; Lescano *et al.*, 2015; Núñez-Regueiro *et al.*, 2015; Quiroga *et al.*, 2016), the need for well-informed decisions is crucial.

While our results pinpoint potential important areas to efficiently expand the PA network in the Gran Chaco, it is important to note some limitations of our analyses, mainly associated with the scarce, limited and fragmented information regarding biodiversity and human activities in the region. Firstly, our results are based on three well-known groups of vertebrate species at a global scale (IUCN, 2014). While the conservation of these groups represents a global priority (Jenkins *et al.*, 2013; Le Saout *et al.*, 2013; Di Minin *et al.*, 2016) and our focus was on those endemic species that represent the greatest urgency inside the region, which are generally the strongest predictor of a species' risk of extinction (Manne *et al.*, 1999), we cannot know how well other taxa are represented. Thus, additional studies including new information regarding other surrogate groups should be performed. Additionally, with the extremely high conversion rates experienced by Chacoan forests (Hoyos *et al.*, 2013; Frate *et al.*, 2015; WWF, 2015), any source of information regarding land conversion at the regional scale (Blanco *et al.*, 2013) quickly becomes outdated. Finally, we acknowledge that in an optimal situation, the inclusion of additional information regarding ecosystem resources or economic value of land in our analysis would improve our results, sadly this information does not exist or is not publicly available.

Given such high conversion rates and the consequent rising land prices (due to the increase of the potential for agriculture of recently cleared land), the situation is particularly unsettling in those high-priority areas in zones of active advance of the agricultural frontier, such as the southernmost portion of the Gran Chaco in central Argentina (Hoyos *et al.*, 2013; Frate *et al.*, 2015) and central and south Paraguay, along the political boundary with Argentina (Hansen *et al.*, 2013; www.guyra.org.py/). This implies that the future of the region likely benefits on trans-boundary collaborations, highlighting the great importance of coordinating actions between countries (see Pouzols *et al.*, 2014). While Cabrera–Timane and Kaa-Iyá National Parks represent a first great antecedent of a coordinated effort between Paraguay and Bolivia for the conservation of the Gran Chaco, the articulation of trans-boundary policies between Argentina and Paraguay is critical. Fortunately, some trans-boundary projects are considering the creation of new PAs and the better implementation of existing ones (i.e. www.wwf.org.py/que_hacemos/proyectos/pacha/). Luckily, most of the potential priority areas are located in the vicinity of existing PAs, which would facilitate the implementation of new PA site selections and further improve the connectivity of the existing PA network.

Considering the dramatic conversion process occurring in the region (Zak *et al.*, 2008; Hansen *et al.*, 2013; Hoyos *et al.*, 2013), the susceptibility of vertebrate species to this phenomenon (Periago *et al.*, 2014; Torres *et al.*, 2014; Lescano *et al.*, 2015; Núñez-Regueiro *et al.*, 2015; Quiroga *et al.*, 2016) and the low degree of protection provided by the current PA network, it is worth noting that only six endemic vertebrate species are currently categorized as threatened (IUCN, 2014). Given this situation, it is important to permanently monitor and constantly update the actual conservation status of all endemic vertebrates of the region. In the same way, biological information regarding DD species is urgently needed (Howard & Bickford, 2014; Nori & Loyola, 2015). This information is indispensable to determine spatial priorities in the region and consequently to guide accurate conservation policies. Given the great information gaps regarding biodiversity of the region, future studies should update spatial priorities of the Gran Chaco as new information is generated.

Our current prioritization results based on ABF and CAZ were highly consistent, which implies that these areas may be of high priority for endemic vertebrates. It is also noteworthy that most of these areas were also included as potential priority areas in the Gran Chaco Americano Ecoregional Assessment (The Nature Conservancy *et al.*, 2005). Beyond the afore-mentioned technical differences, based on our results, we can deduce that endemic (and near endemic) vertebrates may be a good surrogate for a larger number of species, which is a key point for conservation planning (see Hermoso *et al.*, 2013).

As signatories to the Convention on Biological Diversity, Argentina, Bolivia and Paraguay made the commitment to conserve at least 17% of their terrestrial surface by 2020 (Butchart *et al.*, 2010). Here, we investigated the representativeness of the existing PA network of the Gran Chaco region and evaluated potential high-priority conservation areas for endemic vertebrates. The magnitude of the consequences of deforestation (WWF, 2015) and its associated environmental impacts could partially be mitigated if conservation decisions are taken immediately (Fuller *et al.*, 2007; Nori *et al.*, 2013). In this regard, collaboration between researchers, NGOs and decision makers plays a crucial role. Similar assessments to the current prioritization analysis with updated data on species distributions, incorporating additional surrogate groups and information (i.e. spatial distribution of ecosystem services) can be useful resources for future conservation decisions in the South American Gran Chaco, one of the most threatened ecoregions of the world.

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SUPPORTING INFORMATION

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

Figure S1. Binary maps showing the distribution of each endemic vertebrate of the Chaco included in the prioritization analysis.

Table S1. Sensibility of IUCN polygons, and sensibility and over prediction of suitability models based on those polygons.

Table S2. Representativeness of each of the target species within (a) protected areas, (b) protected areas plus red areas of Fig. 1 (i.e. 20% of available territory) and (c) protected area plus red and orange areas of Fig. 1 (i.e. 25% of available territory).

Appendix S1. Additional analyses to support the threshold selected to determine included species in prioritization analyses.

Appendix S2. Methodological details of range polygon refinement.

BIOSKETCH

Javier Nori is a professor and researcher at Universidad Nacional de Córdoba and CONICET, Argentina. His research focuses on conservation biogeography in general; however, he is especially interested in the conservation of amphibians, reptiles and South American environments.

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