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Identifying priority conservation areas for birds associated to endangered Neotropical dry forests

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ABSTRACT

Neotropical dry forests (NDF) are widely distributed and possess important levels of species richness and endemism; however, they are considered a highly endangered ecosystem. Today, the protected areas network (PAs) located within NDF covers < 10% of the total forests' extent; and it's still unknown if PAs adequately represent its biodiversity. Thus, we selected 695 bird species associated to NDF and used ZONATION software to assess the species distribution's representativeness within the PAs network. Additionally, we defined priority conservation areas to strategically expand the current PAs considering the most important human pressures. Current PAs cover only 8.4% of NDF and represent on average ~10% of the total distribution of avifauna inhabiting these forests. Approximately 19% of NDF's birds possess < 5% of their distribution represented in PAs, from which ~13% have < 1% of their ranges protected. Further, ~77% of the most-priority species (*i.e.* with restricted range and categorized as threatened) possess < 10% of their distribution protected. However, our results pointed out great possibilities to improve the picture. By considering our prioritization, the protection coverage would increase to 17% to match the Aichi targets and would substantially increase the representativeness values, covering on average > 36% the ranges of all species and, particularly, 62% for the most-priority species. Priority conservation areas identified are mainly distributed in Peru (23.1%), Brazil (21.3%), Ecuador (18.8%), and Bolivia (11.4%). Our novel results represent an important step to guide future establishment of new and efficient conservation areas across the NDF.

1. Introduction

Neotropical dry forests (NDF) are considered one of the most threatened ecosystems in the world as a consequence of an intense anthropogenic disturbance associated to logging and agriculture; indeed, they have been drastically exacerbated during the last two decades (Miles et al., 2006; Portillo-Quintero and Sánchez-Azofeifa, 2010; Banda et al., 2016). The growing demands for agricultural products, accompanied by technological advances related to intensive production, have generated strong economic interest and pressure in most of these areas. This scenario entails several conservation problems (Dobrovolski et al., 2014), such as population declines, species extinction and ecosystem transformation (*e.g.* Quesada et al., 2009, 2011; Barnagaud et al., 2017). Because NDF areas have been the preferred zones for agriculture and human settlement in certain regions (*e.g.* Ecuador and Mexico), nearly 65% of the original vegetation has been lost, creating a major reduction on species ranges, low connectivity, or even complete isolation among populations, as well as affecting pollinator foraging patterns and plant reproduction (*e.g.* Quesada et al., 2009, 2011; Sánchez-Azofeifa et al., 2013). Moreover, increasing evidence indicates that NDF distribution and survival of inhabiting species could be affected by climate change because could lead to a widespread reduction of current species richness and ecological integrity throughout NDF areas (*e.g.* Meir and Pennington, 2011; Prieto-Torres et al., 2016).

This vulnerable ecosystem, which encompasses 42 ecoregions according to Olson et al. (2001) is heterogeneously distributed from northwestern Mexico to northern Argentina and southeastern Brazil (Fig. 1), with forest remnants strongly fragmented in areas that vary in size and extent (Portillo-Quintero and Sánchez-Azofeifa, 2010; Sánchez-Azofeifa et al., 2013). Despite the rapid and continuous transformation process associated to NDF, there are only few studies focused on the

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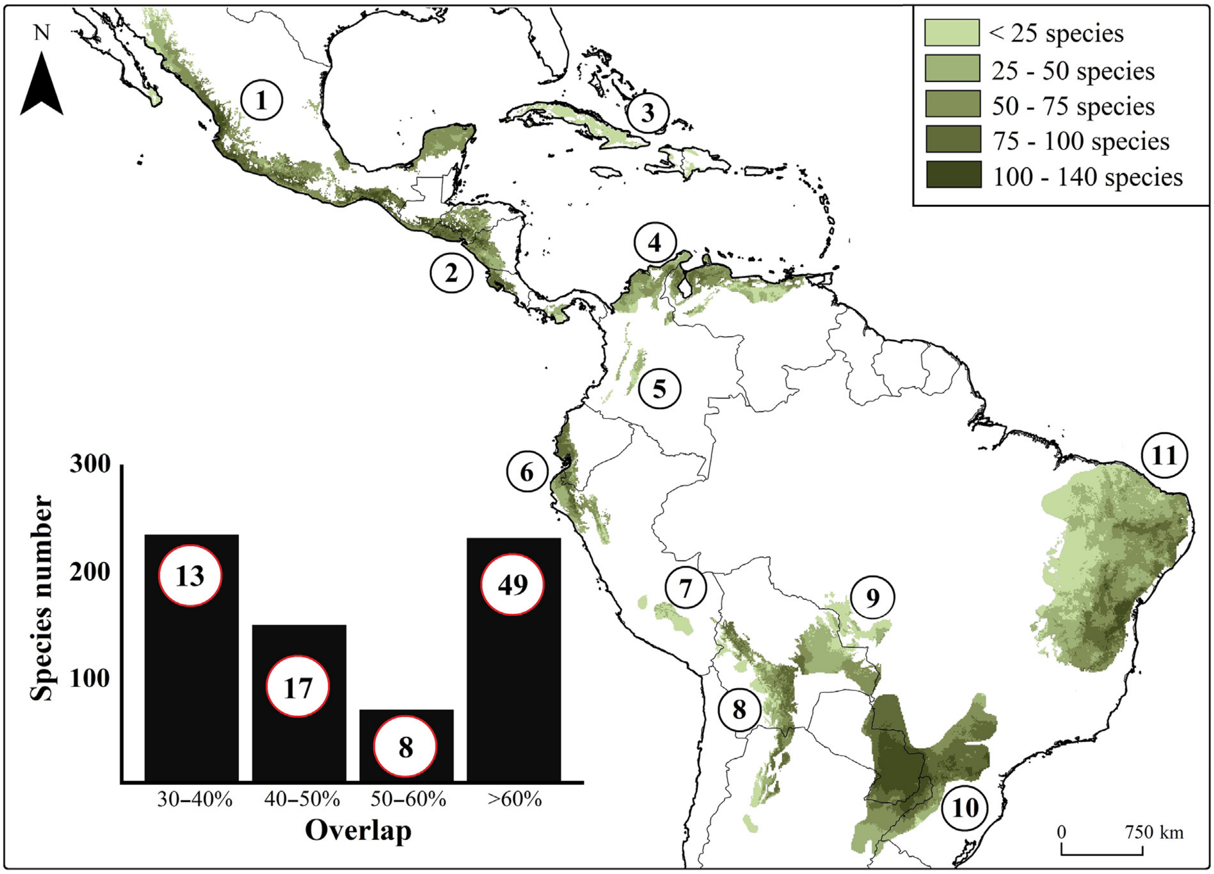

Fig. 1. Species richness distribution patterns of avifauna (n = 695) associated to Neotropical dry forests (NDF). Bars in the figure represent the relationship between each species' occurrence extension and its overlap with the NDF areas, considering all species together (black bars) and only threatened species (circles within bars). Numbers correspond to the largest NDF areas (*i.e.* main sub-regions) identified by Pennington et al. (2000) and Banda et al. (2016): Mexico (1); Central America (2); Caribbean-Antilles (3); Caribbean coast of Colombia and Venezuela (4); Inter-Andean valleys of Colombia (5); Pacific Equatorial (6); Inter-Andean valleys of southern Peru (7); Sub-Andean Piedmont (8), Chiquitano forests (9); Misiones Province (10); and Caatinga (11).

identification of conservation areas in specific political regions containing NDF (*e.g.* Peralvo et al., 2006; Lessmann et al., 2014; Banda et al., 2016). This scenario justifies the need for defining priority areas for the long-term NDF's conservation, as it has been done for other threatened dry ecosystems as the Cerrado (Strassburg et al., 2017; Ballesteros-Mejia et al., 2018) and Gran Chaco (Nori et al., 2016).

Although NDF are widely distributed and possesses high levels of species richness and endemism, as well as offer important ecosystem services (*e.g.* Gordon and Ornelas, 2000; Ríos-Muñoz and Navarro-Sigüenza, 2012; Banda et al., 2016), these forests have received relatively little attention from policy makers to slow down the on-going erosion of biodiversity (Janzen, 1988; Banda et al., 2016; Escribano-Avila et al., 2017). One evidence of this fact is that the degree of protection of NDF in the Americas represents < 10% of their extent. In most of the countries harboring NDF, the current protected areas (PAs) coverage is really low, with < 6% of these forests represented in PAs included in the IUCN's categories I–IV (Miles et al., 2006; Portillo-Quintero and Sánchez-Azofeifa, 2010). This degree of protection is really low, in comparison with other ecosystems as Amazonia (> 20%; Soares-Filho et al., 2010; Barber et al., 2014) and Andes Montane forests (> 18%; Brown and Kappelle, 2001; Cuesta et al., 2017); and is far away to the goal of 17% proposed in the Aichi targets (UNEP, 2010). Additionally, relevant discussions have arisen on whether current PAs fulfill the global conservation goals (*e.g.* Rodrigues et al., 2004; Venter et al., 2014) because the efficiency of the PAs network has not been assessed across the entire NDF areas in terms of species and ecosystem services representativeness (Miles et al., 2006; Portillo-Quintero and Sánchez-Azofeifa, 2010; Banda et al., 2016).

Despite PAs could be considered as the cornerstone of *in situ* conservation of biodiversity, their designation in areas with intensive human land-uses is extremely difficult (Castillo et al., 2005). Thus, it is urgent generating a PAs network that adequately represents the biodiversity of NDF with clear conservation goals, and at same time compatible with the sustained human development (Sánchez-Azofeifa et al., 2005, 2013; Peralvo et al., 2006; Escribano-Avila et al., 2017). In this sense, different conservation planning schemes have been developed over the last decade (Ball et al., 2009; Ciarleglio et al., 2009; Sarkar and Illoldi-Rangel, 2010; Moilanen et al., 2014) promoting a representative and connected network of PAs that contributes to the viability of biodiversity and ecosystems functioning (Watson et al., 2011). These approaches are based on the distribution of key biodiversity features and anthropic variables, and identifying the most important sites for conservation and compatibles with a sustainable human use (Kukkala et al., 2016; Brum et al., 2017). In this sense, the integration of species-level surrogates is necessary to ensure that critical habitats and ecosystems within the region are not missed (*e.g.* Peralvo et al., 2006; Lessmann et al., 2014; Prieto-Torres and Rojas-Soto, 2016).

Here, using detailed geographical information on occurrence data of 695 bird's species (all of them with > 30% of their ranges in NDF) as focal group, combined with Species Distribution Models (SDMs) and conservation planning protocols (ZONATION), we aim to: (i) assess the current representativeness of the PAs for the NDF avifauna and (ii) determine priority conservation areas, complementary to the current PAs network, to maximize species representation considering the anthropic context. This information allows us to provide new and more accurate evidence of which NDF's regions must receive attention, to guide the conservation decision-making processes in the long-term protection of NDF's biodiversity.

2. Material and methods

2.1. Study area

We adopted the proposal by Pennington et al. (2000) for the historical distribution of Neotropical dry ecosystems, which separated the NDF from the savannas and the Chaco by soil pH and fertility. In this sense, we defined NDF as an ecosystem typically dominated (≥50%) by deciduous trees, climatically defined by frost-free areas, with a mean annual temperature > 25 °C, a total annual precipitation between 700 and 2000 mm, and at least three or more dry months (precipitation < 100 mm) per year. The NDF vegetation is heterogeneous, including formations ranging from tall forests to cactus-dominated scrubs, but mostly dominated by semi-deciduous to deciduous trees (Murphy and Lugo, 1986; Pennington et al., 2000, 2006; Sánchez-Azofeifa et al., 2005).

Currently, the NDF are discontinuously distributed from northwestern Mexico to northern Argentina and from southwestern to northeastern Brazil (Fig. 1). The main patches of NDF are separated from one another by other natural ecosystems (*e.g.* Humid Montane Forests, Savanna-like habitats). For Mesoamerica, NDF are distributed mostly in Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama. While, in South America, NDF are located mainly among eight countries: Venezuela, Colombia, Ecuador, Peru, Bolivia, Argentina, Paraguay, and Brazil. Important NDF's fragments are also located in the Caribbean islands, including Cuba, Dominican Republic, and Haiti (Fig. 1).

2.2. Species and occurrence records

We created a complete checklist of bird species ecologically associated to and inhabiting NDF (Appendix 1), compiled from sources that offer information on the habitat distribution for each species (*e.g.* Stotz et al., 1996; Ríos-Muñoz and Navarro-Sigüenza, 2012; Gill and Donsker, 2015) and from a compiled database of presence records. Then, we excluded all inter-tropical migrants species and those that inhabit the NDF in a marginal fashion (*i.e.* species with occasional or accidental records within NDF). Therefore, the selected species correspond mainly to those ecologically restricted or whose geographical distributions were at least 30% within the NDF (*sensu* Pennington et al., 2000). Then, considering the performance of individual species models (see the Species distribution models (SDMs) section below), we discarded those that were not statistically significant. The final list included a total of 695 species from 325 genera and 52 families (Appendix 1). All species names followed those proposed by Gill and Donsker (2015).

Occurrence records for each species were gathered from diverse sources: (1) Atlas of Birds of Mexico (Navarro-Sigüenza et al., 2002, 2003); (2) Atlas de Registros de Aves Brasileiras (ARA; http://ara.cemave.gov.br/); (3) collection records available for specimens from ornithological collections worldwide (Appendix 2); and (4) records obtained through author's fieldwork in Mexico and Venezuela. Additionally, in order to complete the information for areas in South America, we referred to online scientific collection databases (Global Biodiversity Information Facility [GBIF], eBird, and SiB-Colombia [sibcolombia.net]). To identify problematic or imprecise species' occurrences, we compared the spatial distribution of records obtained with the ranges for species defined by Neotropical Birds' website (https://neotropical.birds.cornell.edu) and removed all those mismatch records. For those cases where the geographic information of localities were dubious (*e.g.* data transcription errors), the lat–long coordinates were verified using the Google Earth and LONGITUDE (http://www.longitudemaps.com/). We omitted those records with geographical information that could not be verified, as well as those records without data for the bioclimatic variables used (see below). All geographic coordinates were transformed to decimal degrees, based on the WGS84 datum.

2.3. Species distribution models (SDMs)

In globally extensive studies, species distribution ranges are frequently represented by polygons (*e.g.* Schnell et al., 2013; Li and Pimm, 2015) and are often used for conservation decisions. However, these approaches suffer from the effects of multi-level conflicts among scales and resolutions (*i.e.* polygons are coarse spatially) and are likely to frequently include many areas not holding populations (Peterson et al., 2016) or exclude some others where populations occur. In contrast, data-driven techniques (including the ecological niche modelling and species distribution modelling) integrate primary data on biodiversity occurrence with interpolated data from climatic stations records that summarize environmental dimensions. These approaches offer widely accepted methods for summarizing species' distributional patterns for conservation applications (Peterson et al., 2016), which have been applied on a global scale in biogeography, and particularly in macroecology (*e.g.* Costa et al., 2010; Nori et al., 2017; Prieto-Torres and Pinilla-Buitrago, 2017).

For each species, we obtained a potential distribution model using MaxEnt 3.3.3k, which uses the principle of maximum entropy to calculate the most likely distribution of focal species as a function of occurrence localities and environmental variables (Phillips et al., 2006; Elith et al., 2011). Although recent works have shown that there are uncertainties when forecasting species distributions depending on the algorithm used (Heikkinen et al., 2006), we used the maximum entropy algorithm (MaxEnt) due to its proved performance to calculate the most likely distribution of the focal species as a function of occurrence localities and environmental variables (Elith et al., 2006, 2011; Elith and Leathwick, 2007). Nevertheless, since the low sample size in occurrence records can affect the model performance (Elith and Leathwick, 2007; Owens et al., 2013), we avoided modelling poorly surveyed species. Thus, for restricted geographically or endemic species, we did not consider those with less than five occurrence records; while for widely distributed species, we did not consider those with < 20 occurrence records. The classification of species as endemic was established based on Stotz et al. (1996) and the Neotropical Birds' website; which offer information about the life histories and distribution habitat for each species.

To characterize the species' distribution (based on ecological niche modelling), we downloaded interpolated climate data at 30″-resolution (~1 km^2 cell size) from the WorldClim project 1.4 (Hijmans et al., 2005). On the other hand, we used specific areas for model calibration for each species (*i.e.* accessible area or "M", *sensu* Soberon and Peterson, 2005; Barve et al., 2011), which were established based on the intersection of occurrence records with the Terrestrial Ecoregions and the Biogeographical Provinces of the Neotropical region (Olson et al., 2001; Morrone, 2014). Such consideration was based on the assumption that these regions may define the accessible historic area and specific restriction region for each species. In addition, to test the performance of models, we used jackknifing of available data following the criteria in Pearson et al. (2007) for species with < 20 records; while for species with 20 or more records, potential distribution models' performance were evaluated by calculating the commission and omission error values and the Partial-ROC curve test (Peterson et al., 2008). All models were run with no extrapolation neither clamping to avoid artificial projections of extreme values of ecological variables (Elith et al., 2011; Owens et al., 2013).

We used the logistic output to obtain digital maps containing the values for habitat suitability for each species (continuous probability from 0 to 1; Phillips et al., 2006), which were subsequently converted into binary presence-absence data, by setting the decision threshold of "tenth percentile training presence". We used this threshold criterion to minimize the over-predictions in our final binary maps, allowing better recovering species distributional areas (Liu et al., 2013). Finally, all binary maps were added to obtain the species richness pattern across the NDF.

2.4. Priority conservation areas

We used ZONATION 4.0.0b (Moilanen et al., 2005, 2014) to identify priority areas for the conservation of avifauna in NDF. This software establishes a hierarchical prioritization of areas of the study region, allowing the identification of key areas for the conservation of species (or the areas for an optimal and a balanced expansion of an existing reserve network, if desired) based on their distributions. ZONATION uses a raster for each biodiversity feature (herein birds species and anthropic variables), where each pixel contains information of either the occurrence or intensity of each feature (Di Minin et al., 2014). The way the value of "loss of conservation" is aggregated across features (occurring in a pixel) depends on the so-called "cell-removal rules". In this sense, the software produces a complementarity-based and balanced ranking of conservation priority over the entire landscape maximizing the species' occurrence and considering the different "penalization" variables used (Di Minin et al., 2014; Moilanen et al., 2014). A detailed explanation about the use of ZONATION is available in Di Minin et al. (2014).

We decided to use Additive Benefit Function (ABF) as a removal rule given that most of the included species are not restricted to the study area (Fig. 1) and, therefore, we needed to select a removal rule independent from rarity such as Core Area Zonation. ABF gives higher importance to cells with many features, retaining a higher proportion average of feature distributions (that is, high species richness; Di Minin et al., 2014). For our prioritization analyses, we assigned weights (from 0.3 to 5.0) to species based on their conservation status and degree of restriction in NDF. For this, we developed a single index in which we multiplied the value indicating conservation status of each species according to the IUCN (2014) (LC = 1, NT = 2, VU and DD = 3, EN = 4 and CR = 5) by the degree of restriction or endemicity of the species in NDF. The degree of restriction for each species was defined herein as division of the estimated range of the species within NDF (*i.e.* the overlap between SDM and NDF's distribution map) by the total estimated range of the species (obtained from SDM).

Existing PAs were included using a hierarchical mask, an approach developed to select optimal areas for PAs expansion (Di Minin et al., 2014). In this sense, the program identifies the best part of the landscape for an optimal and balanced expansion of existing PAs (which are preferably selected as the first option in the analysis), and also to compensate for specific ecological losses and satisfy the targets with minimum cost (Di Minin et al., 2014). Here, we included the following IUCN categories of PAs: Strict Nature Reserve (Ia); National Park (II); Natural Monument or Feature (III); Habitat/Species Management Area (IV); Protected Landscape/Seascape (V); and Protected area with sustainable use of natural resources (VI) (see Appendix 3 for details). Shape file of PAs were downloaded from the World Database of Protected Areas (IUCN and UNEP-WCMC, 2012). In addition, prioritizations were run with the "edge removal" function of zonation activate. This function forces the program to remove cells from the edges of remaining landscape, increasing the connectivity of priority and protected areas in the landscape (Moilanen et al., 2014). Also, ZONATION's warp factor was setting as default (warp factor = 10).

Given that most bird species cannot adequately be protected inside highly modified areas (Pimm et al., 2014), we assigned negative weights or "penalization" value to pixels covered by crops or urbanized areas. This last step prevented the software from selecting highly modified areas and assigning high conservation values to such areas. In this sense, we used a reclassified land cover map (Defourny et al., 2016) discriminating pixels with > 50% cover loss and extremely disturbed landscapes. Additionally, considering that human influence tends to diminish habitat quality, and therefore, the potentiality for conservation, we used the Global Terrestrial Human Footprint's map (WCS and CIESIN, 2005; Venter et al., 2016) as another negative variable, "penalizing" those pixels with high human influence. We assigned negative weights to these features (*i.e.* pixel in highly modified areas) so that the sum of the positive and negative weighted was zero, allowing a balanced solution for prioritization (Moilanen et al., 2011; Faleiro et al., 2013).

For the first priority areas analysis, we used all birds' species from our final list; while in a second analysis, we used only those 66 species ecologically associated or restricted to forests (at least 50% ranges within the NDF) and categorized as threatened (CR, EN, VU) or Data Deficient (hereafter "most-priority species"). We compared both results (prioritization performed with all 695 species and with only most-priority species) and delimited areas of consensus. All variables for the final priority analyses were used at a spatial resolution of ~10 km^2 in order to reduce computation times-consumption by orders of magnitude. For those PAs smaller than 10 km^2, the whole pixel was considered as currently protected.

After running the prioritization analyses, we plotted performance curves for both analyses considering the general and individual (NDF's sub-regions) patterns. Performance curves 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 PAs network and the top priority 17% (that represents the Aichi targets; UNEP, 2010) of the available territory. Also, using the ZONATION's groups function, we were able to plot individual performance curves for the endemic species of each of the sub-regions of the NDF (Fig. 1). This step allowed us to easily interpret the different conservation needs for each group of endemic species from sub-regions in the general context. Finally, to determine the relative importance of current PAs within the NDF distribution, we repeated the prioritization analyses but did not include the shape file of PAs features as a hierarchical mask. Graphic results from this last step are shown as supplementary material (Appendix 4).

3. Results

Our models showed high values of AUC ratios from the partial ROC test (ranking from 1.15 to 1.99; $p < 0.05$) for the species with > 20 occurrence records, while the Jackknife test showed that models tended to be statistically significant ($p < 0.01$) for those species with < 20 occurrence records. Thus, performance values for both modelling approaches indicated that species' distribution models were accurate. On the other hand, we observed that 45.4% of the birds' species possess at least 50% of their distribution within the NDF, while 20.7% are between 40 and 50%, and 33.9% have ranges that overlap with the NDF areas between 30 and 40% (Fig. 1). In addition, species richness patterns in NDF increases in some areas that are considered boundaries with other highly biodiverse ecosystems (Fig. 1). Likewise, we found that, according the IUCN, 87 species are classified as threatened (VU, EN, CR), 39 as near threatened (NT), 554 species as least concert (LC) and 15 as data deficient (DD; see Appendix 1).

Designated PAs network cover 8.4% of the current NDF distribution and represent, on average, the 9.9% (± 10%) of the distribution of NDF avifauna, and only 11.2% (± 17.3%) of the distribution of threatened species (Fig. 2a). A total of 18 countries were found throughout NDF's distribution; four of them (Brazil [35.3%], Bolivia [20.2%], Mexico [13.3%] and Venezuela [12.4%]) encompass ~81% of current PAs extent within these forests (Table 1). We observed that 18.9% of NDF birds (n = 131) have < 5% of their distribution represented in PAs, of which 13% (n = 17) have < 1% of their ranges protected. While most of the species (53.5%, n = 372) possess between 5 and 10% of their ranges protected, 23.5% (n = 163) are between 10

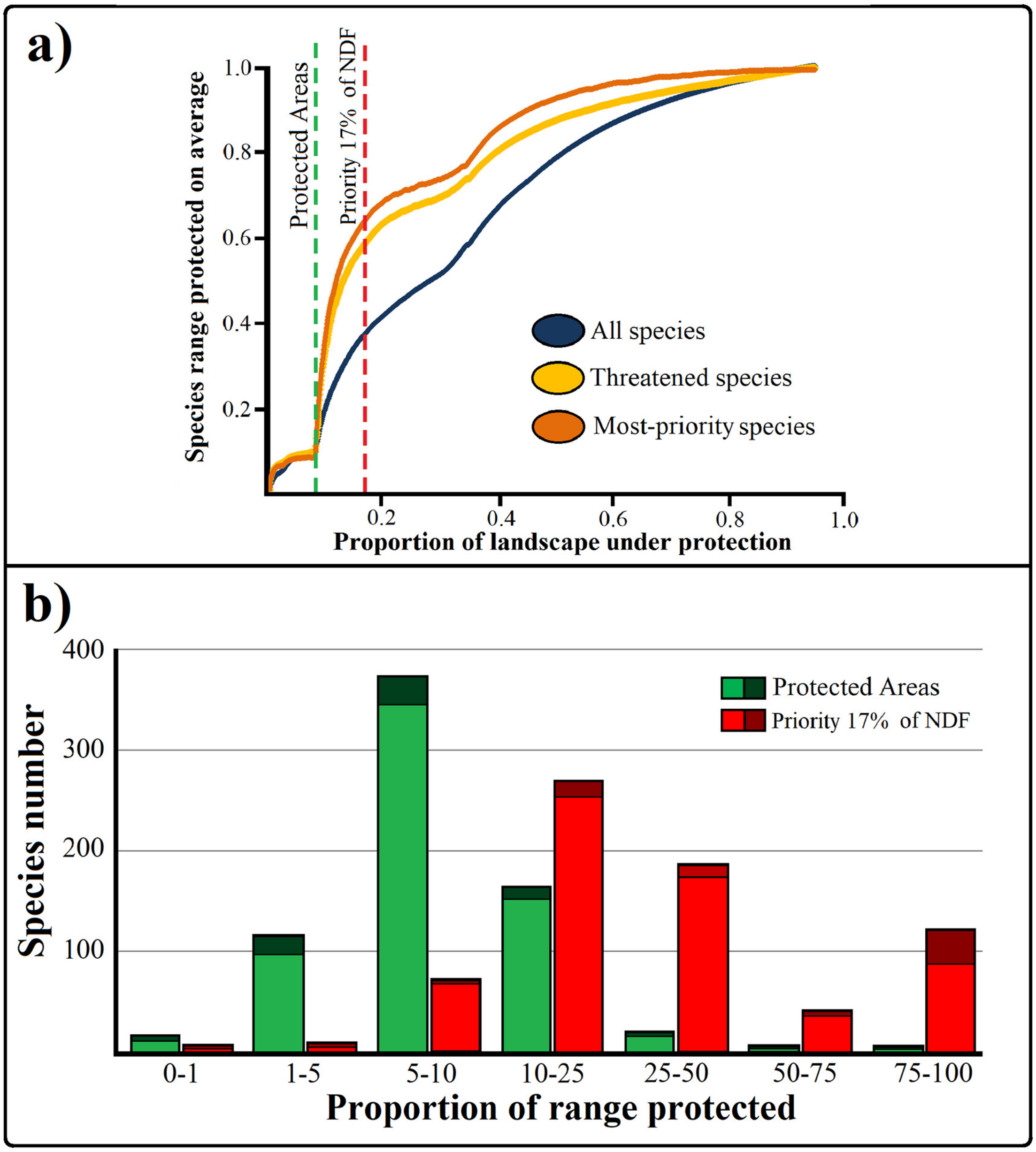

Fig. 2. Levels of protection for avifauna associated to Neotropical dry forests (NDF) considering the current protected areas network and the 17% of NDF with high priority and complementary to protected areas. (a) Performance curves of the spatial prioritization scheme showing the proportions of available grid cells that are protected (x-axis) and their corresponding average species range protection (y-axis), considering all species together, only threatened species, and those most-priority species. (b) Histogram showing the average percentage of geographic distribution and number of bird species (dark colors correspond to most-priority species) found inside the current PAs network and the priority 17% of NDF. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and 25%, and only 29 species (4.1%) include > 25% of their distributions under protection (Fig. 2b). If we considered only the most-priority species, our results showed that, on average, only 9.9% (± 14.4%) of their distributions are represented within the current PAs. For these species, we observed that 34.8% (n = 23) have < 5% of their ranges protected, while 16.7% (n = 11) have between 10% and 25% of their distribution protected, and only five (7.6%) have > 25%. Further, 40.9% (n = 27) of most-priority species have between 5 and 10% of their distribution represented in PAs (Fig. 2).

Despite the relatively high percentage (38.8%; n = 270) of species shared among the NDF's sub-regions, we observed important and contrasting differences for the PAs coverage and representativeness values of distribution for the exclusive species to these NDF's patches (Fig. 3). The higher values for current PAs coverage were observed in the sub-regions of the Chiquitano (17.3% of extent considered as PAs), the Caribbean coast of Colombia-Venezuela (15.1%), the Sub-Andean Piedmont (11.7%), the Caribbean-Antilles (9.8%), and Mexican forests (8.6%). For the rest of NDF sub-regions, the current PAs represent < 6% of coverage. On the other hand, the highest values for representativeness of exclusive species (including those most-priorities) within current PAs network were observed in the sub-regions of the Caribbean coast of Colombia-Venezuela (48.7% of the distribution of avifauna), the Caribbean-Antilles (26.1%), the Chiquitano (16.1%), Mexico (12.5%) and the Sub-Andean Piedmont (12.0%). Contrarily, the lowest species representativeness values (Fig. 3) were observed in Central America (with 8.2% of species distributions), the Caatinga Brazilian (6.1%), the Misiones Province (4.1%), and the Pacific Equatorial (3.6%) sub-regions showed. The Inter-Andean valleys located in

Table 1
Current extension (in km^2 and percentage) by countries for the 8.2% of Neotropical dry forests (NDF) under protection and the proportions of the complementary conservation areas estimated for each country to increase coverage to match Aichi targets (17%). The number and total area per protected area was obtained from maps produced by World Database of Protected Areas (IUCN and UNEP-WCMC, 2012).

Country	No. current PAs	IUCN category included	Extent PAs (km^2 [%])	Priority conservation areas analyses		
				695 bird species (km^2 [%])	Most-priority species (km^2 [%])	Consensus areas (km^2 [%])
Argentina	41	Ia, II, IV, V, VI	3410 (8.91%)	249 (0.64%)	578 (1.48%)	200 (0.74%)
Bolivia	34	Ia, II, IV, VI	7740 (20.22%)	3310 (8.46%)	4686 (11.98%)	3056 (11.38%)
Brazil	122	Ia, III, IV, V, VI	13,530 (35.34%)	6210 (15.87%)	13,180 (33.68%)	5714 (21.27%)
Colombia	11	II, III, IV, VI	250 (0.65%)	2243 (5.73%)	867 (2.22%)	836 (3.11%)
Costa Rica	33	Ia, II, IV, V, VI	330 (0.86%)	249 (0.64%)	160 (0.41%)	169 (0.63%)
Cuba	33	–	650 (1.70%)	1894 (4.84%)	1286 (3.29%)	677 (2.52%)
Dominican Republic	22	II, III, IV, V, VI	360 (0.94%)	–	–	–
Ecuador	5	II, VI	140 (0.37%)	5104 (13.04%)	5254 (13.43%)	5057 (18.83%)
El Salvador	1	II	20 (0.05%)	698 (1.78%)	459 (1.17%)	468 (1.74%)
Guatemala	5	Ia, III, VI	60 (0.16%)	1176 (3.01%)	568 (1.45%)	567 (2.11%)
Haiti	2	III	80 (0.21%)	–	–	–
Honduras	24	Ia, II, III, IV, VI	330 (0.86%)	798 (2.04%)	1127 (2.88%)	299 (1.11%)
Mexico	147	Ia, II, III, VI	5080 (13.27%)	409 (1.05%)	379 (0.97%)	1812 (6.75%)
Nicaragua	36	Ia, II, III, IV, VI	380 (0.99%)	70 (0.18%)	10 (0.03%)	348 (1.30%)
Panama	6	II, VI	90 (0.24%)	270 (0.69%)	–	–
Paraguay	18	Ia, II, III, IV, VI	600 (1.57%)	6939 (17.73%)	6260 (16.00%)	–
Peru	12	II, III, IV, VI	500 (1.31%)	2841 (7.26%)	2502 (6.39%)	6212 (23.13%)
Venezuela	52	Ia, II, III, IV, V, VI	4730 (12.36%)	249 (0.64%)	578 (1.48%)	1445 (5.38%)
Total	624	–	38,280 (100%)	39,130 (100%)	39,130 (100%)	26,860 (100%)

Colombia and the southern Peru (not included in Fig. 3) not showed exclusive species.

According to our prioritization analyses, by protecting an additional 8.6% of the total area (reaching a summed coverage of 17% of study area; Fig. 4), the representativeness of the PAs network would substantially increase, covering 36.2% (± 29.5%) of the ranges when all species where considered, and 57% (± 35.6%) of the distributions of the threatened species (Fig. 2a). Additionally, the analysis performed considering the most-priority species showed that it is possible to represent the 62.5% (± 36.9%) of their distributions by protecting this additional percentage of the NDF areas. Protecting the areas herein identified as priorities we observed that only 11.5% (n = 80) species would have < 10% of their distribution ranges protected, while the 38.7% (n = 269) of species would have between the 10 and 25%, the 26.6% (n = 185) between the 25 and 50%, and the 23.2% (n = 161) would include > 50% of their distributions under protection (Fig. 2). Considering the values for the species distribution's representativeness obtained for each NDF's sub-region, we observed an average increase of > 20% (ranking from 3.9% [in Misiones sub-region] to 88.0% [in Pacific Equatorial sub-region]) for the proportion of the species under protection in each region (Fig. 3). Only in the Chiquitano forests sub-region we did not observe this trend because current PAs coverage is higher than conservation goal herein proposed.

Regarding the threshold of protecting 17% of the area, both prioritization analyses showed consistent spatial pattern with a consensus area of 42.2% for the priority surface selected (Fig. 4). This consensus of priority conservation areas cover wide surfaces located in areas adjacent to PAs, mostly located in Peru (23.1% of identified priority areas are located in this country), Brazil (21.3%), Ecuador (18.8%), Bolivia (11.4%), Mexico (6.8%), and Venezuela (5.4%) (Table 1). Finally, results of the prioritization without including the current PAs showed low overlap (13%) between these priority areas and the current PAs network (Appendix 4). From this 13% of overlapping areas, we observed that 34.1% correspond to PAs categorized by IUCN as type V and VI, and 65.9% as types I-IV (with conservation objectives).

4. Discussion

Neotropical Dry Forests meet the main conditions (*i.e.* highly vulnerable and extremely irreplaceable) to be considered a global priority in terms of conservation (*sensu* Margules and Pressey, 2000). However, the current picture for these forests seems to be really frail. As suggested by our results, and despite the increase in the extent of terrestrial PAs during the last decade (Watson et al., 2011, 2014; Jones et al., 2018), PAs NDF's are markedly inefficient to cover the conservation needs. In fact, current PAs network cover < 15% of distributional ranges of 80% of the bird species and shows a very large spatial mismatch (~87%) with the priority conservation areas identified herein. Thus, well-informed decisions are crucial for policy makers (Miles et al., 2006; Portillo-Quintero and Sánchez-Azofeifa, 2010).

Several authors have previously highlighted the need for additional PAs to reduce in the long-term major losses of species diversity in NDF (*e.g.* Sánchez-Azofeifa et al., 2013; Collevatti et al., 2013; Prieto-Torres et al., 2016). Here, we showed that it is possible to strongly improve the efficiency of PAs for this ecosystem, by strategically expanding the current PAs network. It is noticeable that coverage of the top priority 17% of NDF (*i.e.* protecting an additional 8.6% of NDF to reach Aichi targets) coincides with the breaking-point of the performance curves regarding the average representativeness of most-priority and threatened species (Fig. 2). Therefore, the inclusion of this strategic portion of land, would exponentially increase representativeness of PAs, which offers an excellent opportunity to improve the protection of NDF, based on the political goals suggested by The Convention on Biological Diversity (UNEP, 2010).

We detected important conservation gaps (*i.e.* higher percentage of priority areas) located in Brazil, Bolivia, Mexico, Venezuela, Peru and Ecuador; which at the same time conform distinct NDF sub-regions (*sensu* Pennington et al., 2000; Banda et al., 2016) with particularly high levels of bird diversity (*e.g.* da Silva et al., 2003; Rodríguez-Ferraro and Blake, 2008; Ríos-Muñoz and Navarro-Sigüenza, 2012); and whose conservation priority have been previously identified by BirdLife International (Devenish et al., 2009). According to our results, it would be needed to (at least) double PA's surface of NDFs of these countries in order to accurately include their biodiversity (Fig. 3). Particularly the picture seems to be alarming for the NDF from Pacific Equatorial sub-region (*i.e.* southwestern Ecuador and northern Peru), where our results suggest that an extension of > 20 times the PAs surface is needed. Fortunately, the official protection of some remnants of NDF in this sub-region has progressed through a variety of regional, national and internationally recognized reserves, including the declaration of the

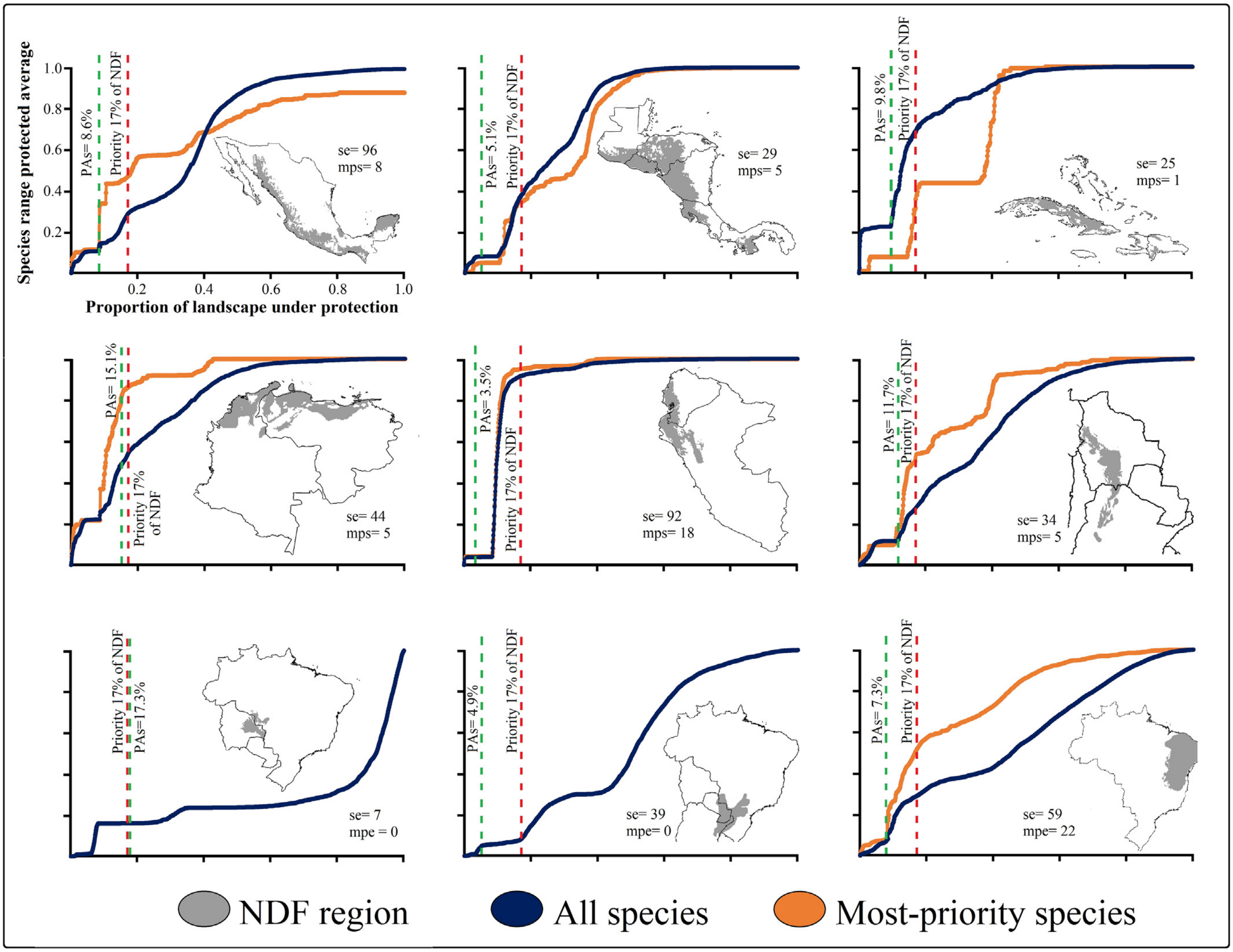

Fig. 3. Individual performance curves of the spatial prioritization scheme showing the proportions of available grid cells that are protected (x-axis) and their corresponding average species range protection (y-axis) for each Neotropical dry forests' sub-region (see Fig. 1), considering all exclusive-species together and those most-priority species. Acronyms correspond to: number of exclusive species (se) and number of most-priority species (mps).

"*Bosque Seco*" Biosphere Reserve (UNESCO, 2014). Most of these selected prioritized areas agree with another previous conservation proposals (Lessmann et al., 2014; Fajardo et al., 2014).

Considering that most NDF's sub-regions encompass more than one country, the conservation of the NDF across political boundaries is crucial to achieve a properly connected PAs network (Kark et al., 2009). Unfortunately, most countries lagged significantly behind the Aichi Target connectivity element, of which only about half of the area currently under protection is effectively connected (Saura et al., 2018). The Mesoamerican Biological Corridor (Hilty et al., 2012) represents a first great antecedent of a coordinated effort among Central American countries. Likewise, the trans-boundary project developed in the threatened region of the Gran Chaco (see www.wwf.org.py/que_hacemos/proyectos/pacha/) could be considered as good example to guide the implementation of conservation policies in NDF. However, more efforts are still needed; therefore, since most of the selected prioritized areas are connected with current PAs network (Fig. 4), our results represent an important global framework to guide future efforts to accomplish a representative and connected network of PAs.

Despite this clear evidence about the possibility to improve the role of PAs in NDFs, it is important to note that, for most of the countries within the region, the financial resources for conservation are limited and shadowed by the economic interests (Pouzols et al., 2014; Lessmann et al., 2016; Pringle, 2017). Moreover, while this study provides essential information based on scientific foundations to strongly improve the scenario for NDFs conservation, this could be executable only through the joint action among academia, NGOs, local communities and policy-makers. From this perspective, we argued that not only more land is needed to meet a given conservation goal, but also that implementation of interdisciplinary and complementary programs (including vegetation restoration) are crucial to ensure NDF's conservation (Janzen, 2000; Allen, 2001; Strassburg et al., 2017). Fortunately there are some recent examples about joint action among public and private entities in pursuit of NDF conservation, as the Costa Rica's Área de Conservación Guanacaste (see Janzen, 2000; Allen, 2001 for additional information), the "*Ejidos'* Conservation Areas" project (Mexico; see Castillo et al., 2005) or the "*Palo Santo*" project (Ecuador; see Nature and Culture, 2014; Escribano-Avila et al., 2017).

The use of birds as surrogates represents an excellent first step to delineate conservation efforts as it is a charismatic and well known group of vertebrates (*e.g.*, Mikusiński et al., 2001; Kati et al., 2004; Barnagaud et al., 2017). However, future studies including additional taxa are needed to generate a comprehensive proposal of PA's expansion. In addition, despite SDM's advantages over the polygon layers (Cantú-Salazar and Gaston, 2013; Peterson, 2017), this approach depends on detailed occurrence data, and the information is scarce for

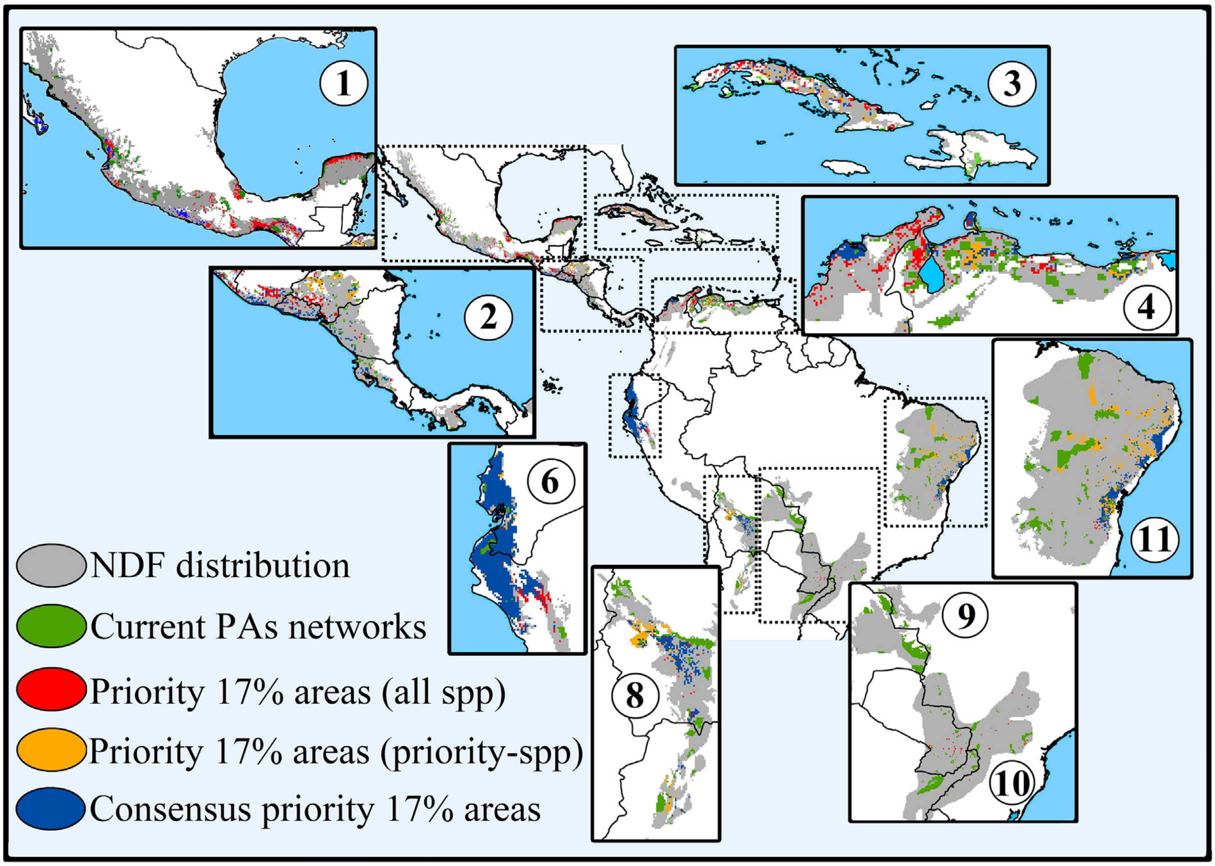

Fig. 4. Maps showing existing protected areas of the region (green), potential expansion areas identified in our spatial prioritization analysis for each analysis (all species *vs.* most-priority species) and comparison between them (consensus). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

many range-restricted and threatened species of birds (Pimm et al., 2017). Therefore, it is important to permanently monitor and constantly update the taxonomic status, the geographic distribution and the current conservation status of poorly studied species of NDF (Barnagaud et al., 2017). Besides, other important challenge to generate more accurate guidelines in NDF is related with the current climate context of the world and its effect on biodiversity (Garcia et al., 2014). Under global climate change NDF's species will be pushed towards higher elevations in order to track their climatic niches, which could produce local extinctions or drastic modifications in the distribution of habitat specialists (*e.g.*, Collevatti et al., 2013; Prieto-Torres et al., 2016). Thus, the identification of conservation areas including the potential effects of future climate change would maximize the performance of the current PAs network (Hannah et al., 2007; Prieto-Torres et al., 2016; Triviño et al., 2018). Finally, it would be also important the inclusion of information regarding ecosystem services, or the economical cost of land (Balmford and Whitten, 2003; Naidoo and Iwamura, 2007). Thus, we encourage future researchers to include detailed cost maps that summarize acquisition, management, and opportunity costs for designing and complementing national and regional PAs network.

Notwithstanding that existing PAs network provides an invaluable service in shielding this endangered ecosystem, our analysis demonstrates that representativeness within current PAs is still far from complete in NDF. Clearly, the task ahead is as urgent as it is challenging, as much biodiversity still remains unprotected. Thus, large-scale studies could represent important steps to guide future establishment of new and efficient conservation areas across the NDF.

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Competing interests

The authors declare no competing interests in this study.

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