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Areas of endemism conservation hot spots of Paraguay: A study using a multiscale and diverse taxa approach

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SUMMARY

Areas of endemism are the basic units for the analysis of historical biogeography, in addition to representing areas of conservation importance. An area of endemism is understood to be the congruence of the distribution areas of two or more species, which are considered primary biogeographic homologies resulting from a presumed common biogeographic history of the taxa that are shared by these areas. The objective of this work was to establish biogeographic patterns in Paraguay through the analysis and identification of areas of endemism. The analyses are based on a matrix composed of 8,117 records of 300 species, including 100 species of Plantae, 50 species of Insecta, 50 species of Amphibia, 50 species of Reptilia, and 50 species of Aves. The analyses performed included an endemicity analysis with cells of 0.3, 0.4, and 0.5 degrees of latitude and longitude. Using the endemicity analysis method, 129 areas of endemism were identified, which were summarized in 13 consensus areas, 2 in the Chaco and 11 in the Eastern Region. By comparing the areas of endemism found, we can identify and propose three hot spot priority areas for conservation based on the endemic richness of the biota.

INTRODUCTION

Knowledge of the geographic distribution of organisms is relevant in various fields of research such as biogeography and conservation. Historical biogeography is used to understand the distribution patterns of taxa in space and time (Morrone 2012).

The concept of area of endemism has been extensively discussed (Anderson 1994, Mendoza-Fernández et al. 2014, Apodaca and Crisci 2018). An endemic taxon is a species or supraspecific taxa, that occupies exclusively, in natural way, a spatially delimited area, therefore, every taxon is endemic within the limits of its natural distribution (Morrone 2008). Meanwhile, an area of endemism is a region where the ranges of two or more species overlap for non-random reasons related to historical and ecological factors (Platnick 1991, Noguera-Urbano and Escalante 2015). Therefore, the limits of the endemism areas are generally diffuse (Noguera-Urbano 2016, Apodaca and Crisci 2018). Endemism areas are considered primary biogeographic homologies, as they have a common biogeographic history among the taxa that share these areas (Noguera-Urbano and Escalante 2015, Sánchez et al. 2019). In turn, such a common history is assumed to explain the clustering of areas based on the shared taxa (Löwenberg-Neto and Carvalho 2004, Morrone 2012). Therefore, areas of endemism are basic units in biogeographic studies that are useful for studying conservation (Escalante 2015, Oliveira et al. 2015).

Martínez-Hernández et al. (2015) argued that the definition of areas of endemism is crucial for identifying and prioritizing areas in terms of biodiversity conservation. Likewise, applying biogeographic principles and methods is desirable for prioritizing and choosing an area to evaluate its representativeness and effectiveness in terms of conservation (Giraudo and Arzamendia 2018). As such, the conservation of species' geographic ranges and identifying areas of endemism are essential not only for historical biogeography studies but also for the application of public policies that help establish criteria for determining and choosing protected wild areas (Mendoza-Fernández et al. 2014).

Moreover, despite the presence of several continental and global scale schemes (e.g., Holdridge 1947, Cabrera and Willink 1973, Udvardy 1975, Huek 1978, Dinerstein et al. 1995), the biogeography of Paraguay has been poorly studied; see Avila et al. (2018) for a review on the subject. The most recent study of biogeography in Paraguay was that conducted by Cabral et al. (2020). Paraguay is a Mediterranean republic located in the center of South America. Its name comes from the Paraguay River, which crosses the country from northeast to southwest and divides the country into two areas that have typically been used to divide the country into separate regions. These are the Eastern Region and the Western Region, also known as Chaco. Paraguay is typically further divided into five ecoregions, according to Dinerstein et al. (1995) (Figure 1).

Currently, most public policies for conservation and habitat development in Paraguay use the ecoregion regionalization scheme presented by Acevedo et al. (1990), Dinerstein et al. (1995), and Mereles et al. (2013). Some of these proposals were developed at a continental scale for only a fraction of Paraguay or are based on limited sets of taxa and without an explicit methodology. A proposal that integrates a broad group of taxa and applies well-defined methods is much needed to establish a more robust zonation. The objective of this study is to identify conservation hot spots by detecting areas of endemism.

MATERIALS AND METHODS

The study area was the entire territory of Paraguay (Figure 1). For the identification of areas of endemism, we performed analyses on a data set matrix composed of 8,117 records of 300 species comprising 100 species of Plantae, 50 species of Insecta, 50 species of Amphibia, 50 species of Reptilia, and 50 species of Aves, which were analyzed together. Datasets are freely accessible at https://www.researchgate.net/publication/328074919_Lista_sppxlsx.

The following criteria were established for selecting species: Any species whose range of distribution exceeded 75% of the territory was excluded. This criterion was used following the protocol established by Morrone (2012) that established that the distribution areas of analyzed species should be relatively minor in relation to the area under study.

The primary data sources were as follows:

For plants, the database of the National Forest Inventory of Paraguay, the Arecaceae dataset used in Gauto (2015), the main scientific collections on the flora of Paraguay held at the Conservatoire et Jardin Botaniques de la Ville de Genève accessed from https://www.ville-ge.ch/cjb/fdp/publications/familias_publicadas.html, and the Missouri Botanical Garden database of the flora of Paraguay found at http://www.tropicos.org/ were used.

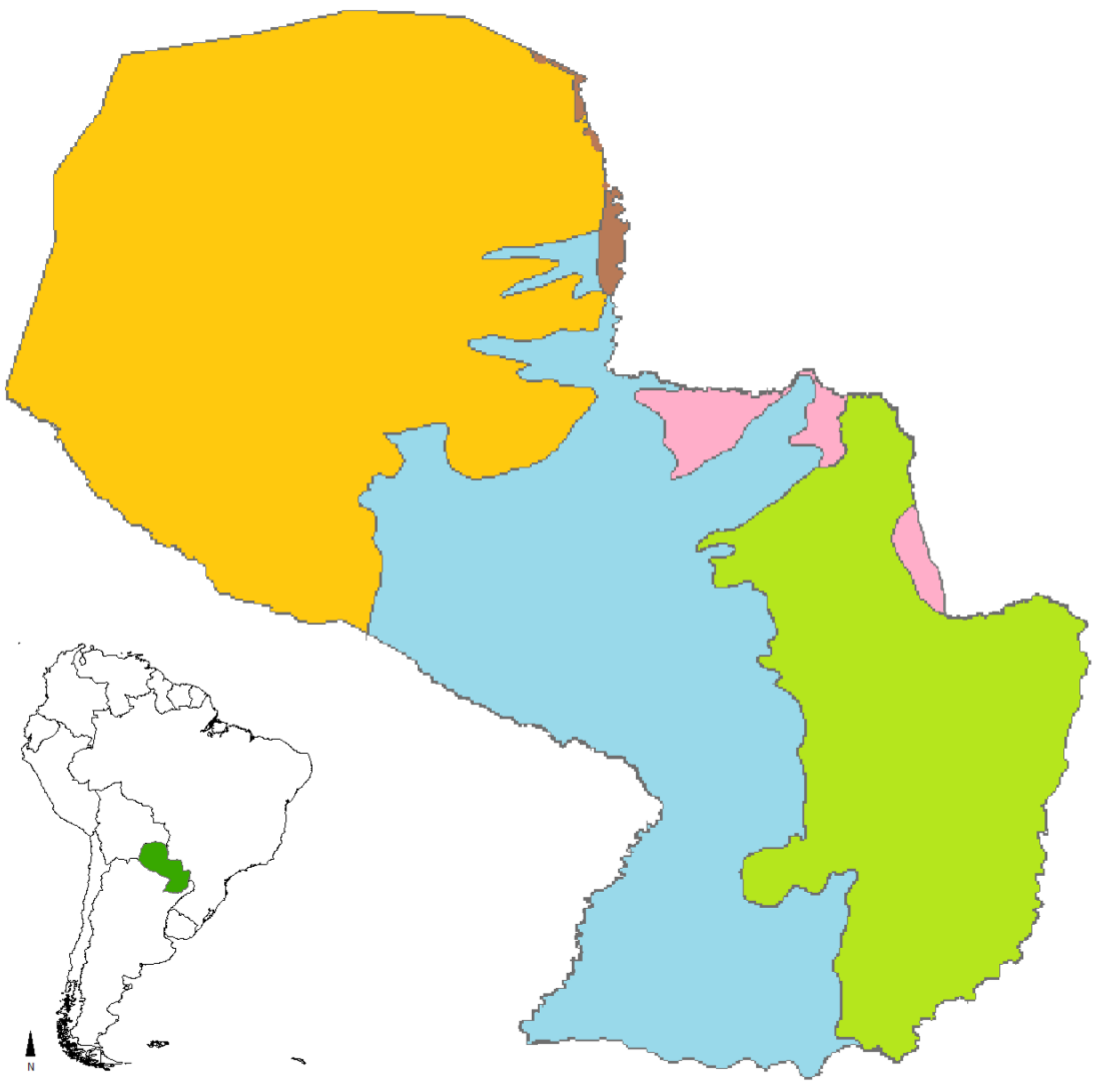

Figure 1. Paraguayan ecoregions (Dinerstein et al. 1995). Green: Alto Parana Atlantic Forest. Light Blue: Humid Chaco. Pink: Cerrado. Orange: Dry Chaco. Brown: Pantanal.

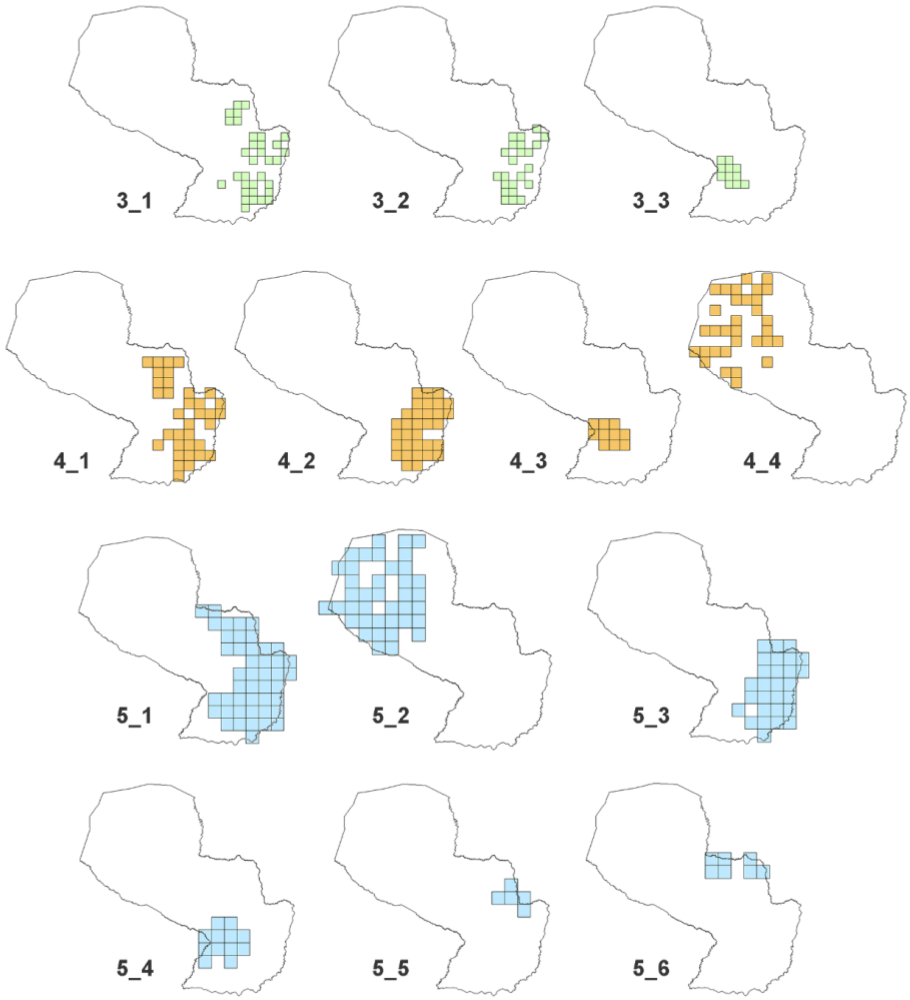

Figure 2. Areas of consensus: Grid size of 0.3º x 0.3º: 3_1, 3_2, 3_3. Grid size of 0.4º x 0.4º: 4_1, 4_2, 4_3, 4_4. Grid size of 0.5º x 0.5º: 5_1, 5_2, 5_3, 5_4, 5_5, 5_6.

For insects, the Hymenoptera dataset of Garcete-Barrett (2014) was used.

For amphibians, the data set of Weiler et al. (2013) was used.

For reptiles, the dataset from Cacciali et al. (2016) and Cacciali and Ubilla (2016) was used.

For birds, we used an authoritative dataset provided by the Cornell Lab of Ornithology from Paraguay records (Cornell Lab of Ornithology 2017).

We used the endemicity analysis proposed by Szumik et al. (2002) and optimized by Szumik and Goloboff (2004) to search for and identify areas of endemism. The analysis was run with NDM/VNDM (Goloboff, 2004) software ver. 3.1.

The endemicity analysis required a grid of cells of the territory to be analyzed, for which three grid sizes (0.3 by 0.3 degrees, 0.4 by 0.4 degrees, and 0.5 by 0.5 degrees of latitude and longitude) were used; in this way, the effect caused by this variable was analyzed, enabling us to observe the stability of the areas of endemism identified at different spatial scales. All areas rescued at a single grid size were discarded.

The optimization criterion used to determine areas of endemism using

NDM/VNDM can result in a large number of candidate areas of endemism, especially when the data set is ambiguous, thus requiring a consensus technique to summarize the results. We used the flexible consensus criterion offered by the software, by which an individual endemism area was included in the consensus as long as it shared a minimum percentage of 30% endemic species with any other endemism area (Aagesen et al. 2013).

RESULTS AND DISCUSSION

In total, 129 areas of endemism were obtained, summarized in 13 consensus areas. For a better understanding, the consensus areas found with a cell size of 0.3° were given the acronym "A3_n," those with a cell size of 0.4° were labeled "A4_n," and those with a cell size of 0.5° were labeled "A5_n," where n is the consensus area number (Figure 2).

Areas of endemism, multiscale analysis at different grid sizes

A biogeographic analysis based on areas of endemism under Platnick's (1991) concept seeks to explore to what extent different taxonomic groups can coexist in these areas, as generally, one or several factors, either historical or ecological, affect the distribution of taxa. All repetitive patterns that are not the result of sampling artifacts are the result of some common factor (Szumik et al. 2012).

The multiscale analysis was performed by comparing the areas of endemism found at different scales, as studying different grid sizes can influence the recognition of biogeographic shape. Thus, areas of endemism are better supported when identified at more than one grid size (Cabral et al. 2020). The results show some of the areas we identified at two or all three study scales, regardless of grid size.

In this framework, a group of sympatric areas found in two different grid sizes (0.4° and 0.5°) corresponding to consensus areas A4_4 and A5_2 (Figure 3A), consistent with the Dry Chaco ecoregion, supported by 12 endemic species for A5_2, including three species from the solution of consensus area A4_4 (Table 1).

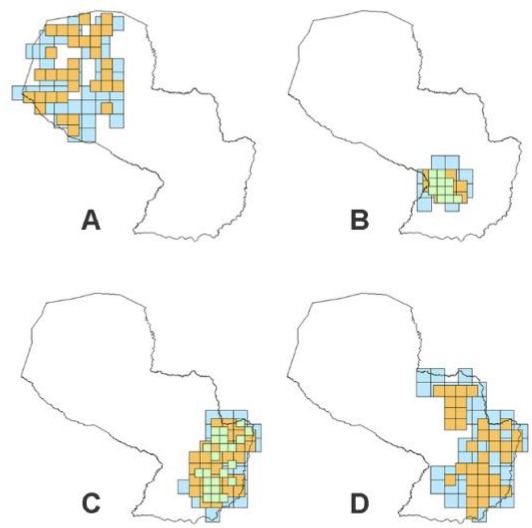

Figure 3. A. Overlapping of consensus areas: 4_4 (orange) and 5_2 (light blue). B. Overlapping of consensus areas: 3_3 (green), 4_3 (orange) and 5_4 (light blue). C. Overlapping of consensus areas: 3_2 (green), 4_2 (orange), 5_3 (light blue). D. Overlapping of consensus areas: 4_1 (orange), 5_1, 5_5 and 5_6 (light blue).

Dinerstein et al. (1995) identified three ecoregions in western Paraguay: The Humid Chaco, which surpasses the boundaries of the Paraguay River and enters the Eastern Region; the Dry Chaco and a narrow margin running parallel to the Paraguay River; and the Pantanal ecoregion in Eastern Chaco (Figure 1). In this study, only the Chaco Seco showed areas of endemism, making it an important area for conservation policies in this sense. Most of the protected wild areas are located north of this region, sustaining a good system of protected areas that continues with the system of protected wild areas in southern Bolivia.

The remaining areas of endemism are found to the east of the Paraguay River plateau forming three groups of sympatric areas in each grid size (Figures 3B, 3C, and 3D), making all these areas of endemism well supported. One of these areas coincides with the Asunción Rift (Figure 3B), through which the Cordillera de Los Altos and associated valleys run and in which Lake Ypacarai is located. This area, which corresponds to the center of the country, is the most inhabited area in Paraguay and, therefore, has been heavily impacted by humans. There are also no consolidated protected wildlife areas in this zone, which makes it a high priority for biodiversity conservation. The endemic area is supported by all six species, all of which were found in A5_4, while five were found in A4_3, and four were found in A3_3 (Table 1).

The other two areas are not only sympatric at different grid sizes but are also partially sympatric within the same grid size—one of them (corresponding to solution D5_1 of Figure 2) covers all other consensus areas at all three study scales. Szumik et al. (2019) argued that the idea that endemism areas cannot be sympatric stems from the belief that they are only produced by vicariant events. However, because spatial patterns are caused by historical and/or ecological factors, when a certain region is affected by a causal factor, some species may be modified in their distribution ranges, while others are not (or they are affected in different ways). Thus, the distribution pattern of each is modified, which explains why areas of endemism may overlap. This is a real and natural phenomenon, Noguera-Urbano and Escalante (2015) called these areas of overlap “unions” or “transitions” obtaining patterns with multiple or diffuse boundaries. This is consistent with the concept of biogeographic transition zones, which are defined as geographical areas of overlap with a gradient of substitution and partial segregation between biotic components (Ferro and Morrone 2014). In ecological terms, transition zones are equivalent to ecotones or ecotonal zones (Acha et al. 2015), where ecological interactions and historical relationships of biota are shared with the zone (Brown et al. 1996, Noguera-Urbano and Escalante 2015, Yackulic and Ginsberg 2016).

These overlapping endemic areas are consistent with the hypothesis of Mereles et al. (2013), who observed that the Eastern Region is a phytogeographic zone influenced by different plant formations originating in Brazil and Argentina, making the region a large ecotonal zone. Similarly, Spichiger et al. (2006) considered the entire phytogeographic region corresponding to the flooded valley of the Paraguay River as ecotonal zones, thus making this area transitional. Prado, Darién E; Gibbs (1993) and Oakley and Prado (2011), who studied the Neotropical Seasonal Dry Forest Domain, concluded that this area’s flora extends along the left bank of the Paraguay River and part of the Upper Paraná from Mato Grosso do Sul in Brazil. This flora is particularly distinctive of the Cerrado but also has an important presence in the Humid Chaco and in the hills that run north-south through the center of the Eastern Region, providing further evidence of the ecotonal and transitional character of eastern Paraguay.

In this context, C3_2, C4_2, and C5_3 (Figure 3C) are sympatric and share 8 species (Table 1), and the other sympatric group, D3_1, D4_1, and D5_1 (Figure 3D), shares 15 species (Table 1).

Morrone (2014) argues that the origins or causes of areas of endemism result from barriers that arise due to historical or ecological factors. These barriers lead to the isolation of specific biotas over time. Consequently, when two or more species share congruent distribution areas, even if they are not phylogenetically related, it can indicate common factors that shape speciation and the distribution of different groups. This agreement in distribution delineates areas of endemism (Szumik et al. 2012, Noguera-Urbano and Escalante 2015, Noguera-Urbano 2016). Recognizing the importance of conserving these areas becomes paramount, as they represent unique and irreplaceable reservoirs of biodiversity.

Table 1. Species found at consensus areas.

Species	A4_4	A5_2	B3_3	B4_3	B5_4	C3_2	C4_2	C5_3	D3_1	D4_1	D5_1	Taxon
Acacia praecox	X	X										Plant
Shinopsis lorentzii	X	X										Plant
Aspidosperma quebracho-blanco	X	X										Plant
Buddleja tubiflora			X	X	X							Plant
Vernonia brasiliana			X	X	X							Plant
Veronia chamaedrys				X	X							Plant
Melabophriniscus paraguayensis			X	X	X							Amphibian
Tropidurus guarani			X	X	X							Reptile
Inga laurina							X	X				Plant
Alchornea triplinervia							X	X				Plant
Cupania vernalis						X	X	X				Plant
Allophylus edulis						X	X	X				Plant
Guarea kunthiana						X	X	X				Plant
Bastardipsis densiflora							X	X				Plant
Cabralea canjerana						X	X	X				Plant
Piculus aurulentus							X	X				Bird
Eugenia uniflora										X	X	Plant
Nectandra megapotamica										X	X	Plant
Sorocea bonplandii									X	X	X	Plant
Plinia rivularis									X	X	X	Plant
Helietta apiculata									X	X	X	Plant
Chrysophyllum gonocarpum										X	X	Plant
Lochocarpus campestris									X	X	X	Plant
Diatenopteryx sorbifolia									X	X	X	Plant
Machaerium paraguariensis									X	X	X	Plant
Cordia trichotoma										X	X	Plant
Campomanesia xanthocarpa									X	X	X	Plant
Cordia ecalyculata									X	X	X	Plant
Trichilia catigua										X	X	Plant
Banara arguta										X	X	Plant
Maclura tinctoria										X	X	Plant

CONCLUSIONS

We found 129 areas of endemism, summarized in 13 consensus areas. Three areas in a multiscale analysis formed three sympatric endemism area solutions. Among them was the group of consensus areas located in the center of the country, where the Cordillera de los Altos hills range is located. This area was identified as a priority hot spot for conservation purposes, mainly because there are no protected wild areas of adequate size or conservation management. This is also the region where the highest percentage of Paraguay's population lives.

Two other groups of endemism areas were identified. Almost half of the surface of the one in the dry Chaco ecoregion (in the north and northwest of the country) is protected wild areas. The other one, which is located in the Eastern Region of Paraguay, is where most of Paraguay's intensive agriculture is located, although there are areas of different sizes in some categories of protection. In this context, this work provides valuable information for the prioritization of biological corridors between these protected areas in areas of high endemism.

We hope this study will be useful for better planning efforts to collect wild species and provide better prioritization policies for protected wilderness areas and legal reserves in productive areas of Paraguay.

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