

# Priorities for Conservation of the Evolutionary History of Amphibians in the Cerrado

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**Abstract** Population declines and species extinction can be abated through the establishment of effective conservation policies. Actions and policies towards biodiversity conservation must be well planned and priorities must be set. Besides the widely recognized principles of systematic conservation planning, it is also important to consider species attributes, such as their evolutionary distinctiveness (ED) and distribution pattern. In this study we did a gap analysis to evaluate protection status of anuran species endemic to the Brazilian Cerrado. We then selected priority areas for conservation in this biome based on a systematic conservation planning framework, also including species attributes as prioritization criteria. We found 65 gap species, for which less than 20 % of their conservation targets are met by the current network of protected areas, and 39 of them are not protected at all. Priority areas are located in the central portion of the Cerrado, and include river valleys and mountaintops. Mountains in southeastern and central Cerrado are especially rich in endemic and range-restricted species, resulting in higher priority values for these areas. Priority areas selected here are also the richest regions and have greater Total Evolutionary Distinctiveness than the rest of the biome, demonstrating their high potential for conserving evolutionary history of anuran lineages in the Cerrado. Despite their great importance for biodiversity, areas that have higher richness of endemic species are also those that suffered from more severe loss of habitat, which reinforces the urgency for effective actions towards species conservation.

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## Introduction

Declines and extinctions of species often occur simply because many countries do not have an effective conservation policy. These declines are creating a demand for rapid and urgent strategies to maximize conservation efforts, especially in regions where there is little data on diversity, abundance and distribution of species, such as in Brazil (Young et al. 2001). Amphibians are perhaps the most threatened group of organisms at global scale (Wake and Vredenburg 2008; see Youssefou and Davies chapter “[Reconsidering the Loss of Evolutionary History: How Does Non-random Extinction Prune the Tree-of-Life?](#)”), with rapidly declining populations throughout the world (Stuart et al. 2004; Becker et al. 2007) and a significant concentration in the Neotropics (Becker and Loyola 2008). Brazil is the world leader in amphibian diversity. In spite of that, there is not yet a specific agenda for their conservation. There are some important initiatives undertaken by the government, such as lists of endangered species and the selection of priority areas for conservation (Silvano and Segalla 2005). However, these initiatives are quite general and often use subjective criteria.

Other initiatives are being conducted by the academic community, such as the Action Plan for Amphibian Conservation in Brazil (Verdade et al. 2012). Among the proposals outlined in this Action Plan for Amphibian Conservation, there is an indication of priority areas for their conservation (Verdade et al. 2012). To make this effective, it is recommended that they follow the same principles of systematic conservation planning (SCP) (Margules and Pressey 2000). SCP aims at a cost efficient protected areas network with the help of purposely built computer software that takes advantage of optimization algorithms. These criteria are essential to define the smallest set of areas necessary to achieve preset conservation goals (see Arponen and Zupan chapter “[Representing Hotspots of Evolutionary History in Systematic Conservation Planning for European Mammals](#)”). Since there are no resources neither enough time to conserve species one by one, we need to maximize the return on investment in conservation (Margules and Pressey 2000).

For conservation to be effective, in addition to the basic principles related to systematic conservation planning, it is necessary to consider certain attributes of the target species. Among these characteristics, we highlight Evolutionary Distinctiveness (ED) (Isaac et al. 2007) and their range size. The ED and range size should be considered independently for each species. The ED is a measure of species’ relative contributions to the total diversity in a phylogenetic tree (Isaac et al. 2007). In this framework more relictual species (i.e. those that belong to ancient

clades, with few species) should be prioritized by the unique evolutionary history they represent (Posadas et al. 2001). Similarly, species that have restricted distribution (e.g. endemic to Espinhaço range) require further attention over those widely distributed, since the species' range size is the most important predictor for the risk of extinction (Purvis et al. 2000a, b). This approach allows for preserving evolutionary history within a taxonomic group, providing more alternatives for responding to possible future environmental changes (Vazquez and Gittleman 1998; Avise 2005; Becker et al. 2010, and see Faith chapter “[The PD Phylogenetic Diversity Framework: Linking Evolutionary History to Feature Diversity for Biodiversity Conservation](#)”).

Since half of the over 200 anuran species that occur in the Cerrado are endemic to this domain (Valdujo et al. 2012), it is critical that conservation strategies are outlined specifically to this region. Cerrado is one of 34 priority areas for conservation on the planet (Biodiversity Hotspots – Mittermeier et al. 2004), due to high levels of endemism of fauna and flora and the high rates of habitat destruction. However, few conservation actions are being carried out there. Currently, less than 2 % of the Cerrado range is under strict protection (CNUC 2010). This percentage is low for a region with high heterogeneity of vegetation and topography, and because the main threat to amphibian conservation in the Cerrado is the destruction of their habitats due to deforestation, expansion of agriculture, mining, fire and infrastructure development (Silvano and Segalla 2005). Therefore, strengthening and expanding the network of protected areas should be prioritized as an important conservation strategy, which could maximize the return on investment in conservation (Margules and Pressey 2000).

In spite of the recognized importance of including information on historical and evolutionary studies to define conservation priorities, in the Cerrado, just few and recent papers consider this information (e.g. Carvalho et al. 2010). The papers published over the last decade involving the prioritization of areas for anurans conservation in the Cerrado were based just on the species' extent of occurrence and richness, in a complementarity approach (e.g. Diniz-Filho et al. 2004, 2007, 2009). In order to contribute to enlarge this perspective, we conducted a gap analysis to check the conservation status of amphibian species endemic to the Cerrado and performed an exercise in prioritization of additional conservation areas needed for their protection. Information related to geographical distribution and evolutionary distinctiveness were considered in setting conservation goals for each species. Thus, we have prioritized the most relictual species, because they are phylogenetically rare, and the species of more restricted distribution, because restricted distribution ranges are associated with higher vulnerability to extinction in cases where habitat destruction pop up simultaneously in several points of the landscape. This study contributes to the proposed priority areas already published for the Cerrado through the inclusion of relevant evolutionary information and the use a more refined and complete database.

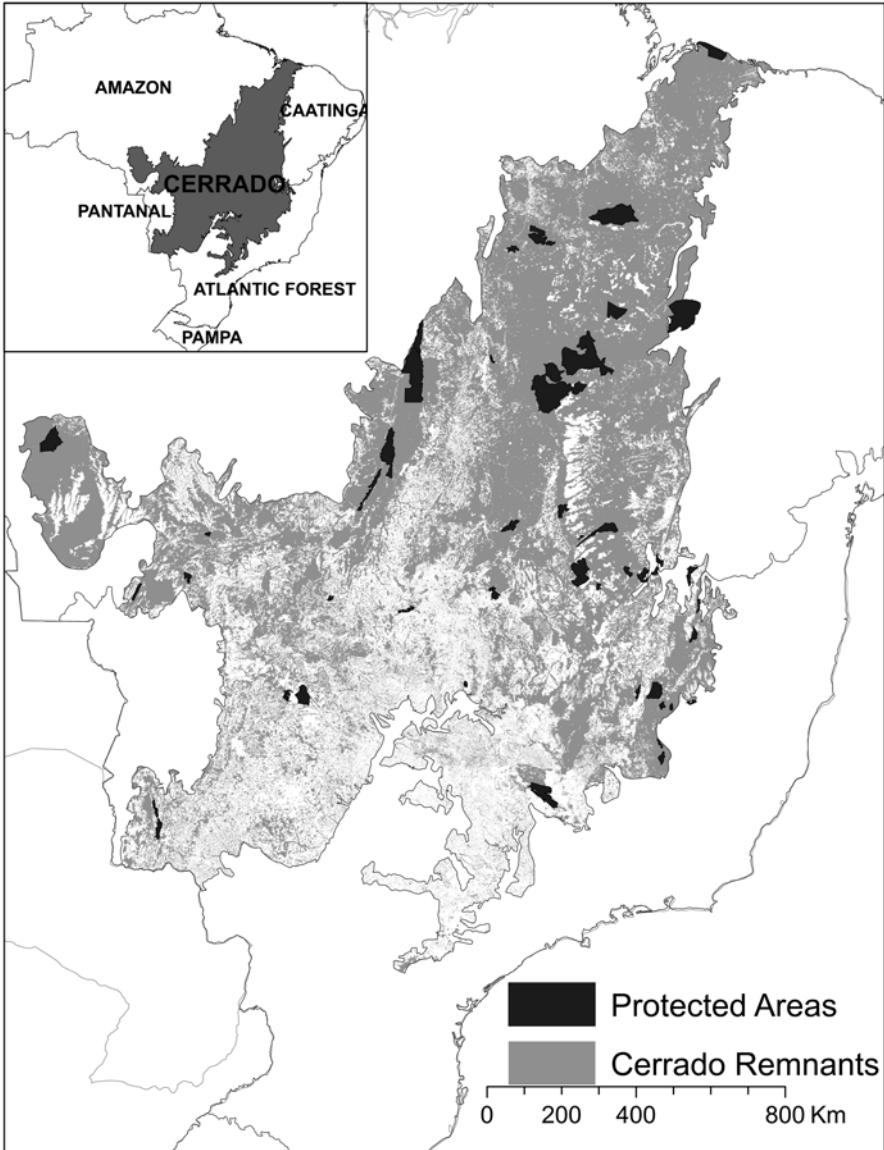
## Methods

### *Study Area*

The Cerrado is located in central-eastern South America. It is covered by a heterogeneous mosaic of savannic and forest vegetation, including grasslands, shrublands and riverine forests, consisting of a gradient of altitude and vegetation density (Eiten 1972, 1982). Covering over 2.5 million km<sup>2</sup>, the Cerrado is renowned for its high species richness and endemism that places it as the planet's most diverse savannah. However, during the past 40 years their land has been converted mainly into crops and pastures, leading to an intense process of destruction and fragmentation of the vegetation (Klink and Machado 2005). Currently, the widest remnants of natural vegetation are mainly concentrated in the northern portion (Fig. 1). According to recent estimates, there are only 34 % of the original vegetation left and this is expected to disappear in 30 years if current rates of deforestation are maintained in the region, where traditional cultures are giving place to modern mechanized crops such as soybeans, cotton, corn, sorghum and sunflower (Machado et al. 2004). There is not a consensus about the delimitation of the Cerrado. However, since one of the main objectives of this study is to provide tools for decision-making related to conservation, we chose here to use the biome boundaries that are also adopted by the federal government's policies (IBGE 2004).

### *Data Used and Pre-processing*

**Planning Units** Planning units (PUs) are subdivisions of the study area into small spatially explicit units. Among many possible ways of obtaining PUs, we used a hydrosheds arrangement built from SRTM (Shuttle Radar Topography Mission; Hydrosheds, <http://hydrosheds.cr.usgs.gov/index.php>). This is the same database used by Brazilian government to set priority areas for conservation in Cerrado and Pantanal Biomes (MMA 2012, unpublished data). The use of sub basins as PUs has many advantages over other arrangements such as grids or hexagons: firstly, they have natural and biogeographically meaningful limits; secondly, they allow an hierarchical structure of basins within basins, which is very useful to switch scales and adjust data and results to different needs. To account for the complementarity principle of systematic conservation planning, strictly protected areas (IUCN categories I to IV) were included as PUs, using their actual boundaries regardless of the basin subdivision to design PUs. We only included protected areas wider than 350 km<sup>2</sup> to keep PUs sizes compatible with the scale of study and compatible to the official map of priority areas for conservation of the Cerrado, published by the Ministry of Environment. Twenty-three out of 108 protected areas were considered in the gap analysis, covering 50,640 out of 56,223 km<sup>2</sup> of IUCN categories I-IV protected areas



**Fig. 1** The Cerrado and its relation with other biomes (*inset*). Distribution of the Cerrado vegetation remnants (*gray*) and Protected Areas (PAs) greater than 350 km<sup>2</sup> (*black*)

in the Brazilian Cerrado. To define the area available within each PU, we overlaid the official map of extent of natural vegetation in the Cerrado in 2010 with PUs (data available from <http://siscom.ibama.gov.br/monitorabiomas/cerrado/index.htm>), and excluded any PU having no remnants of natural vegetation.

**Conservation Cost** The cost for each PU was obtained from WWF (Soares et al. 2012). The database was built by the Conservation Science Team based on potential future deforestation, using Land Change Modeler module of Idrisi Selva. Distance to roads, to cities, to infrastructure and to previously deforested areas were included as driver to changes in land cover from 2002 to 2010, and then applied to 2010 natural vegetation map to predict which areas are more likely to be deforested in the next 10 years.

**Focal Species** Eighty-two out of 209 amphibian species known to occur in the Cerrado (Valdujo et al. 2012) were selected as focal species. The criteria were based on endemism, range size (both obtained from Valdujo et al. 2012) and level of tolerance to anthropogenic alterations in habitat quality (two classes: tolerant and not-tolerant; species were classified based in our field experience, so that species commonly seen in disturbed areas were considered as tolerant). We used both endemism and extent of distribution as independent criteria because some species are endemic to the Cerrado but have a wide range within this biome, whereas some other species are range restricted (e.g. <60,000 km<sup>2</sup>) but occur in a transition zone between Cerrado and Atlantic Forest, and so they are not endemic to the Cerrado (Valdujo et al. 2012). Since we were prioritizing among natural areas within the Cerrado, widespread species do not add to the final solution, and neither do species that can tolerate habitat degradation.

**Species Distribution Models** We prepared geographic distribution maps for all 82 species, using distribution models constructed through the Maximum Entropy algorithm – MAXENT (Elith et al. 2006; Phillips and Dudik 2008). We included as predictors elevation and all 19 bioclimatic variables with a 10 arc-min spatial resolution provided by Worldclim (Hijmans et al. 2005). For each species we used the mean model of 20 runs and converted probabilistic models to binary models using the 10 percentile training presence logistic threshold. Distribution maps were lately validated by a group of experts during a workshop organized by the Ministry of Environment and WWF aiming to identify priority areas for biodiversity conservation in the Cerrado, in 2011, following the procedure recommended by Graham and Hijmans (2006). The distribution map for each species was superimposed onto the PUs' map in order to calculate how much of its distribution area is contained in each PU. All distribution maps were overlaid to obtain the richness surface of endemic species of amphibians in the Cerrado.

**Evolutionary History Prioritization** In some cases the outcome of area prioritization through SCP analyses fails to meet all targets. To ensure that at least the most important species meet their targets, it is possible to set a penalty factor (SPF) for each species that penalizes solutions more heavily when not achieving these targets. We assigned SPF based on both threat and phylogeny, using ED scores (Evolutionarily Distinctiveness) obtained from Isaac et al. (2012), ranging from 4669 to 17,903.

**Mapping Total Evolutionary Distinctiveness** We calculate the total ED of each PU by summing the value of all species occurring in it. As ED is highly correlated with richness, here we used a weighted value, obtained by dividing summed ED by richness in each PU.

**Table 1** Criteria for the definition of quantitative targets (percentage of range size already under legal protection), according to species range size

Species range size	Quantitative target
<60,000 km <sup>2</sup>	80 %
60,000–350,000 km <sup>2</sup>	50 %
>350,000 km <sup>2</sup>	20 %

**Table 2** Gap category, according to the percentage of quantitative target reached

Percentage of quantitative target reached	Gap category
<20 %	Gap species
20–90 %	Partial gap
>90 %	Covered

## Analysis

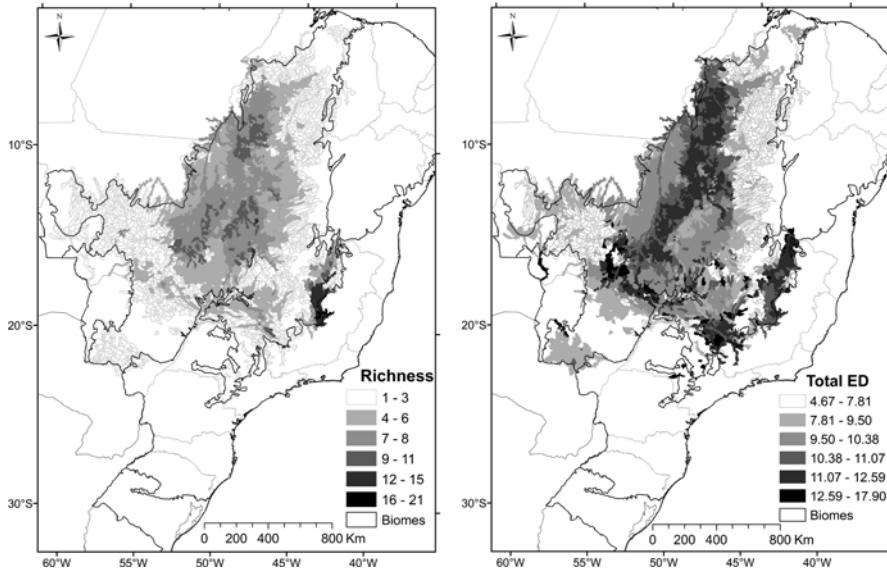
**Gap Analysis** To evaluate the conservation status of each of the focal species we performed a gap analysis (Rodrigues et al. 2003, 2004). This analysis consists of overlaying species distribution maps and protected areas to calculate how much of the quantitative target set for each species is already under legal protection. Spatial data for Brazilian protected areas were obtained from the Ministry of Environment website (<http://mapas.mma.gov.br/i3geo/mma/openlayers.htm?u3n6kqkh7ajn4igbe5jilhka56>). Targets were set to 20–80 % according to range size (Table 1). Those for which only up to 20 % of its conservation goal has been reached were considered “gap species”. The reaching from 20 to 90 % of the target were considered “partial gaps”, and above 90 % the species was considered “covered” (Rodrigues et al. 2003, 2004) (Table 2).

To select areas and define a conservation scenario for Cerrado amphibians we used the conservation planning software Marxan available online (<http://www.uq.edu.au/marxan/index.html>; Ball and Possingham 2000). Marxan uses a simulated annealing optimization algorithm for minimizing costs of achieving conservation targets. Planning units defined by protected areas were assigned to status 2, “reserved”. We set to 10,000 runs with 1 million iterations each run, temperature decreases = 10,000, and boundary modifier = 0.2. The identification of priorities for expanding the current network of protected areas was based on measures of “biological significance” (irreplaceability) of each PU within the study area.

Only to assist the identification of some areas within the basins we used geomorphological units denominations (IBGE 2011).

## Results

Species richness of amphibians endemic to the Cerrado varied between 0 and 21 species per PU (Fig. 2). Species are concentrated in the center of the biome, in its northwestern portion in the contact zone with the Amazon, and in the extreme



**Fig. 2** Species richness and total evolutionary distinctiveness of amphibian endemic to Cerrado per Planning Units (PUs)

southeastern region of the Espinhaço in the contact zone with the Atlantic Forest. The northeastern, southern and western Cerrado portions have low endemism, not exceeding four focal-species (Fig. 2). Total Evolutionary distinctiveness is also concentrated at the center, but with highest values at the Atlantic Forest contact zone (Espinhaço range), in the central western portion (Caiapônia plateau) and in some points at contact zone with Pantanal (Fig. 2).

Among the 82 species examined, over 80 % (66 species) have restricted distribution ranges (<6 million ha) and only 11 % (9 species) are widely distributed across the domain (>35 million ha). Sixty-five (79 %) have less than 20 % of its conservation target achieved being thus classified as gap species. Thirty-nine of these species are completely out of Protected Areas, all of them are restricted range species (<1.5 million ha) (Among the later, some more relictual species are also included, such as *Chiasmocleis mehelyi*, *Oreobates heterodactylus*, *O. remotus*, *Odontophrynus salvatori*, *Proceratophrys moratoi* e *P. cururu*). Only four species endemic to the Cerrado were considered covered (*Leptodactylus tapiti*, *Crossodactylus sp.*, *Bokermannohyla ibitiguara* and *Phyllomedusa ayeaye*). All of these covered species have restricted ranges (<0.25 million ha) with most of their distribution in protected areas, and 13 species can be considered as partial gaps, presenting between 23 and 57 % of their conservation goal achieved (Table 3).

In the conservation prioritization analysis the “best solution” (lower cost and higher efficiency) offered by Marxan selected 742 PUs (18.6 % of the biome area)



**Table 3** Focal species evolutionary distinctiveness (ED), distribution area (million hectares), conservation goals, percentage of conservation goal achieved (area of distribution contained in protected areas), classified according to the percentage of goal achieved

Species	ED	Total area	Goal %	Goal area	Area in PAs	% achieved	Classification
<b>Aromobatidae</b>							
<i>Allobates brunneus</i>	5.1	0.202	80	0.162	0.000	0.0	Gap
<i>Allobates goianus</i>	5.1	0.160	80	0.128	0.000	0.0	Gap
<i>Allobates sp.</i>	5.1	0.284	80	0.228	0.000	0.0	Gap
<b>Bufonidae</b>							
<i>Melanophryniscus fulvoguttatus</i>	9.05	4.984	80	3.988	0.077	1.9	Gap
<i>Rhinella cerradensis</i>	4.67	35.147	10	3.515	0.699	19.9	Gap
<i>Rhinella ocellata</i>	4.67	98.528	10	9.853	3.953	40.1	Partial gap
<i>Rhinella scitula</i>	4.67	0.082	80	0.066	0.000	0.0	Gap
<i>Rhinella sp.</i>	4.67	0.118	80	0.095	0.000	0.0	Gap
<i>Rhinella veredas</i>	4.67	17.550	50	8.775	1.273	14.5	Gap
<b>Craugastoridae</b>							
<i>Barycholos ternetzi</i>	16.47	75.998	10	7.600	2.140	28.2	Partial gap
<i>Pristimantis dundeei</i>	11.38	0.952	80	0.762	0.042	5.5	Gap
<i>Oreobates crepitans</i>	11.38	0.238	80	0.190	0.000	0.0	Gap
<i>Oreobates heterodactylus</i>	15.68	0.339	80	0.271	0.000	0.0	Gap
<i>Oreobates remotus</i>	15.68	0.378	80	0.302	0.056	18.7	Gap
<b>Cycloramphidae</b>							
<i>Thoropa megalotypanum</i>	13.5	5.359	80	4.287	0.280	6.5	Gap
<b>Dendrobatidae</b>							
<i>Ameerega berohoka</i>	5.44	0.430	80	0.344	0.000	0.0	Gap
<i>Ameerega braccata</i>	5.44	0.238	80	0.190	0.000	0.0	Gap
<i>Ameerega flavopicta</i>	5.44	27.314	50	13.657	0.336	2.5	Gap
<i>Ameerega picta</i>	5.44	0.082	80	0.066	0.000	0.0	Gap
<b>Hylidae</b>							
<i>Aplastodiscus sp.</i>	13.82	0.222	80	0.178	0.000	0.0	Gap
<i>Bokermannohyla alvarengai</i>	11.74	5.118	80	4.095	0.231	5.6	Gap
<i>Bokermannohyla ibitiçuara</i>	11.74	0.250	80	0.200	0.198	98.9	Covered
<i>Bokermannohyla izecksohni</i>	10.65	0.040	80	0.032	0.000	0.0	Gap
<i>Bokermannohyla nanuzae</i>	10.65	2.297	80	1.838	0.196	10.7	Gap
<i>Bokermannohyla pseudopseudis</i>	11.74	9.042	50	4.521	0.105	2.3	Gap
<i>Bokermannohyla ravida</i>	10.65	0.246	80	0.197	0.000	0.0	Gap

(continued)

**Table 3** (continued)

Species	ED	Total area	Goal %	Goal area	Area in PAs	% achieved	Classification
<i>Bokermannohyla saxicola</i>	11.74	5.098	80	4.079	0.266	6.5	Gap
<i>Bokermannohyla sazimai</i>	10.65	2.482	80	1.985	0.198	10.0	Gap
<i>Dendropsophus anataliasiasi</i>	9.36	42.393	10	4.239	1.196	28.2	Partial gap
<i>Dendropsophus araguaya</i>	9.36	0.181	80	0.145	0.000	0.0	Gap
<i>Dendropsophus cerradensis</i>	9.36	0.036	80	0.029	0.000	0.0	Gap
<i>Dendropsophus cruzi</i>	9.36	108.799	10	10.880	3.599	33.1	Partial gap
<i>Dendropsophus jimi</i>	9.36	0.589	80	0.472	0.133	28.1	Partial gap
<i>Dendropsophus rhea</i>	9.36	0.225	80	0.180	0.000	0.0	Gap
<i>Dendropsophus tritaeniatus</i>	9.36	1.158	80	0.926	0.000	0.0	Gap
<i>Hypsiboas botumirim</i>	9.67	0.030	80	0.024	0.000	0.0	Gap
<i>Hypsiboas buriti</i>	9.67	0.565	80	0.452	0.000	0.0	Gap
<i>Hypsiboas cipoensis</i>	9.67	3.334	80	2.667	0.244	9.1	Gap
<i>Hypsiboas ericae</i>	9.67	0.149	80	0.119	0.000	0.0	Gap
<i>Hypsiboas goianus</i>	9.67	1.553	80	1.242	0.000	0.0	Gap
<i>Hypsiboas jaguariaivensis</i>	9.67	0.057	80	0.046	0.000	0.0	Gap
<i>Hypsiboas phaeopleura</i>	9.67	0.059	80	0.047	0.000	0.0	Gap
<i>Hypsiboas stenocephalus</i>	9.67	0.433	80	0.347	0.198	57.1	Partial gap
<i>Hypsiboas sp.</i>	11.19	22.337	50	11.169	0.971	8.7	Gap
<i>Lysapsus caraya</i>	12.6	0.129	80	0.104	0.000	0.0	Gap
<i>Phasmahyla jandaia</i>	12.19	0.169	80	0.135	0.032	23.4	Partial gap
<i>Phyllomedusa ayeaye</i>	10.77	0.257	80	0.206	0.198	96.2	Covered
<i>Phyllomedusa centralis</i>	10.77	0.195	80	0.156	0.000	0.0	Gap
<i>Phyllomedusa megacephala</i>	10.77	6.057	50	3.029	0.280	9.2	Gap
<i>Phyllomedusa oreades</i>	10.77	0.583	80	0.466	0.000	0.0	Gap
<i>Pseudis tocantins</i>	11.89	36.514	10	3.651	1.204	33.0	Partial gap
<i>Scinax cabralensis</i>	8.94	0.161	80	0.129	0.022	17.2	Gap
<i>Scinax canastrensis</i>	9.64	0.623	80	0.498	0.198	39.7	Partial gap
<i>Scinax centralis</i>	9.64	0.619	80	0.495	0.000	0.0	Gap
<i>Scinax constrictus</i>	8.94	88.952	10	8.895	3.562	40.0	Partial gap

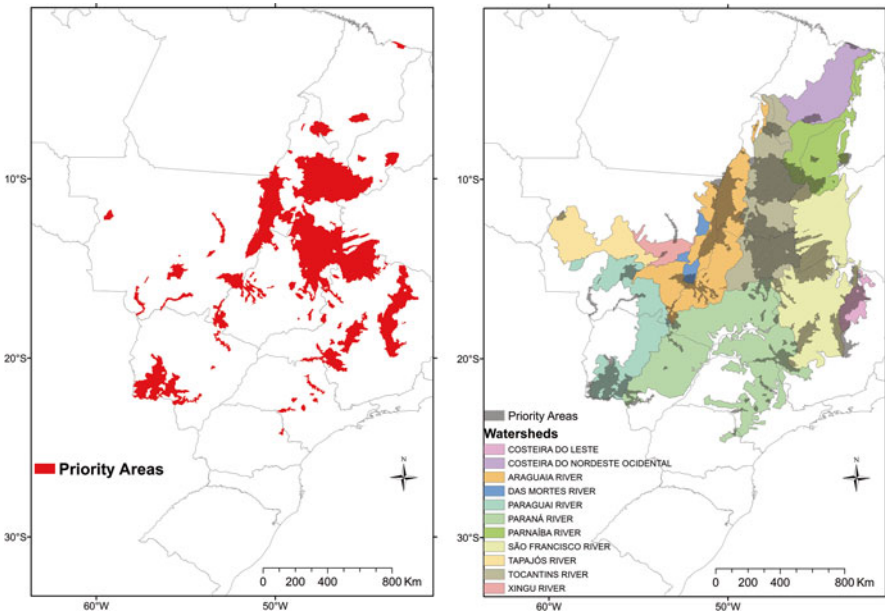
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**Table 3** (continued)

Species	ED	Total area	Goal %	Goal area	Area in PAs	% achieved	Classification
<i>Scinax curucica</i>	8.94	1.787	80	1.430	0.196	13.7	Gap
<i>Scinax lutzorum</i>	8.94	0.039	80	0.032	0.000	0.0	Gap
<i>Scinax machadoi</i>	9.64	0.777	80	0.622	0.042	6.8	Gap
<i>Scinax maracaya</i>	8.94	0.622	80	0.498	0.198	39.7	Partial gap
<i>Scinax pinima</i>	8.94	0.100	80	0.080	0.000	0.0	Gap
<i>Scinax rogerioi</i>	8.94	0.200	80	0.160	0.000	0.0	Gap
<i>Scinax skaios</i>	9.64	0.886	80	0.709	0.000	0.0	Gap
<i>Scinax sp.</i>	9.64	0.563	80	0.451	0.011	2.4	Gap
<i>Scinax tigrinus</i>	8.94	0.332	80	0.265	0.000	0.0	Gap
<i>Trachycephalus mambaiensis</i>	10.23	0.180	80	0.144	0.000	0.0	Gap
<b>Hylodidae</b>							
<i>Crossodactylus bokermanni</i>	11.61	2.508	80	2.006	0.196	9.8	Gap
<i>Crossodactylus sp.</i>	13.05	0.243	80	0.194	0.198	101.7	Covered
<i>Crossodactylus trachystomus</i>	13.05	6.242	50	3.121	0.336	10.8	Gap
<i>Hylodes otavioi</i>	10.22	0.296	80	0.237	0.032	13.4	Gap
<b>Leptodactylidae</b>							
<i>Leptodactylus camaquara</i>	11.85	3.296	80	2.637	0.218	8.3	Gap
<i>Leptodactylus cunicularius</i>	11.85	11.644	50	5.822	0.478	8.2	Gap
<i>Leptodactylus pustulatus</i>	14.26	50.906	10	5.091	1.196	23.5	Partial gap
<i>Leptodactylus tapiti</i>	11.85	0.065	80	0.052	0.065	125.0	Covered
<i>Physalaemus deimaticus</i>	13.22	0.207	80	0.166	0.000	0.0	Gap
<i>Physalaemus evangelistai</i>	12.49	1.366	80	1.093	0.061	5.6	Gap
<i>Pleurodema fuscomaculatum</i>	12.74	0.339	80	0.271	0.000	0.0	Gap
<i>Pseudopaludicola mineira</i>	13.52	0.623	80	0.499	0.000	0.0	Gap
<b>Microhylidae</b>							
<i>Chiasmocleis mehelyi</i>	17.9	0.216	80	0.173	0.000	0.0	Gap
<b>Odontophrynidae</b>							
<i>Odontophrynus salvatori</i>	14.97	0.657	80	0.526	0.000	0.0	Gap
<i>Proceratophrys cururu</i>	14.13	0.511	80	0.409	0.055	13.4	Gap
<i>Proceratophrys goyana</i>	14.13	47.302	10	4.730	2.084	44.1	Partial gap
<i>Proceratophrys moratoi</i>	14.13	0.323	80	0.259	0.000	0.0	Gap

**Table 4** Category (frequency of selection) of the Planning Units (PU), number of PUs, area (million ha) and percentage of Cerrado corresponding to each category of PUs in the best solution of priority areas for Cerrado endemic species of anurans conservation

Category	Number of PUs	Area	% Cerrado
Very high conservation value (10,000)	153	10.49	4.39
High conservation value (7501–9999)	232	13.63	5.71
Intermediate conservation value (5001–7500)	167	10.26	4.30
Low conservation value (1–5000)	190	10.02	4.20
Protected	50	5.87	2.46
Total selected	792	50.27	21.06
Not selected	3760	188.43	78.94
Total	4552	238.7	100



**Fig. 3** Priority areas for the conservation of amphibians species endemic from Cerrado in 11 basins

as priorities. Among them, 153 PUs have a very high conservation value (selected in all 10,000 rounds) and 232 have high conservation value, matching 4.4 and 5.7 % of the biome area, respectively (Table 4). In contrast, 3760 PUs were not selected, representing 78.9 % of the Cerrado.

The selected areas, here termed as priorities for conservation of amphibian species endemic to the Cerrado, mostly occupy the central portion of the biome, following a northwest-southeast diagonal (Fig. 3). Some sparse areas can also be found at the contact with Pantanal biome. This set of areas is of fundamental importance

**Table 5** Richness and endemism of amphibians in major Cerrado basins. Cerrado endemic amphibians species richness, amphibians unique to each basin (Endemism) species richness, and geomorphological units, which concentrate priority areas

Basin	Richness	Endemism	Geomorphological units
São Francisco River	45	3	São Francisco baseline and tableland; Tocantins baseline; Espinhaço mountains
Paraná River	36	6	Canastra and Brazilian central uplands
Tocantins River	28	5	Tocantins and Araguaia rivers depressions and uplands; Brazilian central upland
Araguaia River	21	3	Araguaia, Tocantins and Pantanal rivers depressions
Costeira do Leste	21	1	Espinhaço mountains; Jequitinhonha and Pardo rivers uplands
Paraguai River	18	9	Paraguai and Guaporé rivers depressions and uplands; Guimarães upland
Mortes River	12	0	Tocantins and Araguaia rivers depressions
Parnaíba River	9	0	Meio Norte tableland and depressions
Xingu River	7	0	
Tapajós River	6	0	
Costeira do Nordeste Ocidental	4	0	Meio Norte tablelands

for achieving the conservation goals established. The prioritization analysis selected areas both in river valleys regions (below 400 m altitude), as well as elevated areas (above 1300 m). The selected areas include the depressions of the Araguaia, Tocantins and Paraguay rivers; the uplands in the São Francisco River, in western Bahia; the northern portion of the Central upland, and Canastra and Espinhaço uplands (Fig. 3, Table 5).

The priority areas are mainly concentrated in the Tocantins, Araguaia, São Francisco and Paraguay river basins and on the Costeira do Leste basin (Fig. 3). The São Francisco river basin has the largest number of frog species endemic to the Cerrado (45 species – Fig. 3, Table 5). Among them *Bokermannohyla raveda*, *Scinax cabralensis* and *S. pinima* occurs exclusively in this basin. The Paraná river basin is the second highest in richness, with 36 endemic amphibian species and is home to 6 species that occurs exclusively in this basin (*Bokermannohyla izecksohni*, *Dendropsophus cerradensis*, *D. rhea*, *Hypsiboas jaguaraiensis*, *Proceratophrys morato* and *Scinax centralis*). This basin is followed by the Tocantins river with 28 Cerrado endemic species and 5 species endemic to this basin (*Allobates* sp., *Hypsiboas ericae*, *H. phaeopleura*, *Leptodactylus tapiti* and *Trachycephalus mambaiensis*). The Paraguay river basin has the highest endemism with nine species that occur exclusively there (*Allobates bruneus*, *Ameerega braccata*, *A. picta*, *Chiasmocleis mehelyi*, *Oreobates heterodactylus*, *Phyllomedusa centralis*, *pleurodema fuscomaculatum*, *Oreobates crepitans* and *Rhinella scitula*). Another three species are endemic to the Araguaia river basin (*Dendropsophus araguaya*, *Lysapsus caraya* and *Scinax lutzorum*) and *Hypsiboas botumirim* is endemic to the Costeira do Leste basin.

## Discussion

Given the low number of protected areas and high species richness of amphibians with restricted range in the Cerrado, it was expected that most of the species were not adequately protected and that a large area of biome would be of high conservation value, as demonstrated by the results presented here. An aggravating fact is the greatest richness and total ED of endemic species associated with the central and southeastern regions of the biome. As shown in Fig. 1, these are the areas that suffered the greatest habitat destruction and where remnants are scarce. Forecasts of future habitat degradation also indicate that these areas will suffer further habitat loss if the current economic and political scenarios remain unchanged (see Silvano 2011).

The fact that 39 endemic and restricted range species of amphibians from the Cerrado are completely unprotected is alarming. Several studies have shown that limited range species are more prone to extinction (e.g. Purvis et al. 2000a, b; Cooper et al. 2008). This can happen simply because environmental change can affect all or most of their narrow distributions (Cooper et al. 2008). Most of these species are habitat specialists, and more susceptible to environmental changes (Hero et al. 2005). Moreover, many species occur in low abundance, and also have low reproductive success, and are subject to demographic stochasticity and inbreeding (O'Grady et al. 2006). Among these species are *Proceratophrys moratoii*, an example of threatened restricted range species, which occurs in small populations in extremely degraded grassland areas in the state of São Paulo (Carvalho-Jr et al. 2010; Rolim et al. 2010; Maffei et al. 2011).

More relictual species, such as *Chiasmocleis mehelyi*, *Oreobates heterodactylus*, and *Odontophrynus salvatori*, are completely unprotected and all of them are restricted range species. *Proceratophrys moratoii*, although currently detected within a protected area in São Paulo state, is also considered a gap-species because only a very small proportion of its limited range is actually protected. Others, like *Pristimantis dundeei* and *Oreobates crepitans* are restricted to the region of the cities of Cuiabá and Chapada dos Guimarães at Mato Grosso state. Recent studies indicate that these species are not closely related to others of the same genus, because of their low number of chromosomes and ecological characteristics (Siqueira et al. 2009), which makes them even more unique.

The areas of greatest conservation value for endemic amphibians species are concentrated in the central portion of the biome on a northwest-southeast diagonal, and represent 18.6 % of the Cerrado area. In recent studies, in order to define important areas for inclusion in an efficient network of protected areas for the conservation of all species of Cerrado frogs, 17 priority areas were defined, based on distribution maps (minimum convex polygons) for 131 species (Diniz-Filho et al. 2007, 2009). The results were very similar to those found in a previous study (Diniz-Filho et al. 2004), with the same purpose but using a shorter list of species, different algorithms and a grid of cells of different sizes. These results indicate priority regions for conservation of anurans distributed widely in the biome, but the most

important areas of concentration (“irreplaceable”) in the southeast part. Some of these areas are coincident with those found here and others are very different, as the northern portion of the biome, indicated by these studies as a priority and not selected here. The differences in results should be linked to the fact that (1) our study was based on a more complete database (see Valdujo et al. 2012), (2) we used modeled distribution maps based on topographic and climatic species requirements and (3) we included evolutionary characteristics.

The selection of areas along the elevation gradient, including both lowlands and river valleys as uplands and mountains, is related to the fact that endemic species have different habitat requirements (Valdujo et al. 2012). The São Francisco River basin has the highest species richness, certainly due to the high richness of endemic and restricted range species in the Espinhaço complex (see review in Leite et al. 2008). Other high elevation areas where endemic species have high richness are the Guimarães, Canasta and Central Brazil uplands (Valdujo et al. 2012).

The priority areas for achieving conservation goals established in this study seem to coincide with areas of high species richness and greater Total ED of amphibians in the Cerrado. According to our data, these areas incorporate most of the evolutionary history of Cerrado amphibians. The evolutionary history may be more important for maintaining ecosystem services than simply species richness (Cadotte et al. 2008). Conserving this diversity, we are also conserving the genotypic, phenotypic and functional diversity, giving more chances for ecosystems to respond appropriately to future changes (Cadotte and Davies 2010). In an assessment of the effects of climate change and habitat degradation on endemic amphibian species to the Cerrado, Silvano (2011) found that future scenarios are extremely unfavorable to the occurrence of these species. Thus, conservation strategies that consider the evolutionary diversity are mandatory tools for the future.

Since the resources available for conservation are limited and it is not possible to preserve the entire area due to conflicts with other social and especially economic interests, it is expected that the selection of these areas act as a starting point for decision makers. The areas considered here as priorities for the conservation of endemic Cerrado frogs should be investigated and appropriate plans for the conservation, management and control of these areas should be developed and implemented to ensure the existence of these species in the future.

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