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ORIGINAL PAPER

Conservation biogeography of anurans in Brazilian Cerrado

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Abstract The increasing rates of declines in anuran populations worldwide are creating demands for urgent strategies to maximize conservation efforts. This may be critical in regions for which few detailed data on diversity, abundance and distribution are available, such as in the Cerrado of Central Brazil. In this paper, we used a macroecological approach based on the extent of occurrence of 131 species of Anura (Amphibia) in the Cerrado region to design a regional network of potential areas that preserves all anuran species. The final network, obtained using a simulation annealing algorithm based on complementarity, has a total of 17 cells, widely distributed throughout the biome. Minimum costs solutions were obtained in respect to total human population size, soybean production and bovine density, because these are the factors associated with human occupation that historically are more likely to cause broad scale habitat losses. The macro-scale approach used here can provide overall guidelines for conservation and define the focus for more local and effective conservation efforts.

Keywords Anurans · Cerrado · Macroecology · Optimization · Reserve network

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Introduction

Reservation is the main strategy adopted by governments to preserve biodiversity (Margules and Pressey 2000; Aaron et al. 2001). Although this strategy could be effective to diminish habitat loss if the reserves were selected and managed adequately, scientific criterions are hardly taken into account when a reserve is to be established (Possingham et al. 2000; Aaron et al. 2001). Unfortunately, political and economic interests are usually more important than scientific criterions when establishing reserve networks, and many reserves encompass areas of unsuitable habitat for the maintenance of native species, or are defined by cultural or scenic reasons only.

The most important criterion for locating and designing reserve systems should be to achieve maximum representation (or persistence) of biodiversity with the smallest possible cost (Pressey et al. 1997; Margules and Pressey 2000). This optimization involves many different aspects, including spatial distribution of reserves, their connections, overall area, shape and percentage of suitable habitats ensuring species persistence (Possingham et al. 2000; Cabeza and Moilanen 2001; Briers 2002; Lawler et al. 2003; Williams et al. 2004). Also, socio-economic factors associated with the development of human populations at local and regional scales, including population size, growth rate and land use, should be taken into account in the optimization models (Abbitt et al. 2000). This is potentially important because many recent papers found broad-scale correlations between species richness and human population density (Balmford et al. 2001; Araújo 2003; Chown et al. 2003; Luck et al. 2004; Gaston and Evans 2004). These correlations have been interpreted as an indicative that processes driving species richness, mainly related to high ecological productivity and occupation of more suitable habitats, also drive human populations, under the 'more-individuals' energy hypothesis (Balmford et al. 2001). More importantly, because of this positive correlation, a conflict between biodiversity conservation and human development might occur, both because of direct impacts on the environment (i.e., habitat conversion) or because of higher land prices and increase in other associated costs to conserve biodiversity (Luck et al. 2004; but see Faith 2001a, b; Huston 2001; Diniz-Filho et al. 2006).

There is a growing concern about the decline in amphibian populations worldwide (Stuart et al. 2004), creating demands for urgent strategies to maximize conservation efforts for these populations, especially in regions in which few detailed data on diversity, abundance and distribution are available (Young et al. 2000). This is exactly the case of Brazilian Cerrado, one of the global biodiversity hotspots, in which rates of habitat conversion are very high (due to a recent expansion of soybean cultures and cattle ranching (Klink and Machado 2005) and may imply in a quick loss of many endemic and rare species (Sala et al. 2000; Myers et al. 2000; Stuart et al. 2004). Previous attempts to establish conservation priorities in the Cerrado region were usually based on subjective criteria (but see Cavalcanti and Joly 2002). However, lack of detailed data on species distribution and abundance for most groups of organisms constrained many of these previous initiatives. It is also important to note that anurans have the highest level of endemism among vertebrates in Cerrado region (Klink and Machado 2005; Silvano and Segalla 2005), so they may be an important indicator group to establish a network with a relatively high efficiency in terms of preserving more of the biome biodiversity.

In this paper we used macroecological data of geographic distribution (extents of occurrence, following Gaston 1994, 2003) to evaluate spatial patterns in species richness and endemism of anurans in Cerrado. More importantly, we evaluated how these patterns can be optimally represented using complementarity-based and irrepleaceability procedures, defining which regions of the biome are more important to represent total species richness of anurans. We also found which networks represent all Anuran species but, simultaneously, have the minimum amount of human activities (measured as human population and estimates of intensity of soybean cultures and cattle ranching). Although broad-scale approaches are usually considered coarse to establish reserve networks (e.g., Gaston and Rodrigues 2003), they allow an overview of diversity patterns and, thus, can furnish overall guidelines for downscaled conservation strategies and help defining the focus for more local and effective conservation efforts, within the new framework of conservation biogeography (Whittaker et al. 2005). This hierarchical approach may be particularly useful in poorly known and threatened regions of the world, which demands urgent actions due to a combination of high rates of habitat loss and fast human occupation, for instance as the case of Brazilian's Cerrado.

Methods

Geographic distributions, measured as extents of occurrence based on minimum convex polygons (see Gaston 2003), for the 131 species of anurans that can be found in Brazilian Cerrado (e.g., Colli et al. 2002) were mapped with a spatial resolution of 1° grid cell, using as a basis a grid with 181 cells covering the Cerrado Biome (Fig. 1). These 131 species are distributed in 6 families and 29 genera, out of which 47 are endemics to Cerrado region (Table 1). A detailed species list and references are available from the authors upon request (see also Diniz-Filho et al. 2004a, b, 2005, 2006, for a discussions of this dataset).

A binary matrix was constructed by recording the species whose geographic ranges overlap each cell, and species richness was calculated by summing the species present in cells. Total species richness, richness for endemic species and corrected weighted endemism (CWE - given by the average of the inverse of geographic ranges of each species in the Cerrado, for each cell—see Bickford et al. 2004), were also mapped.

Based on the occurrence of the 131 species in the 181 cells of the Cerrado biome, we used an optimization procedure to select the minimum number of cells necessary to represent all species at least once (Church et al. 1996; Possingham et al. 2000; Polasky et al. 2000, 2001; Cabeza and Moilanen 2001). Simulated annealing procedure on Site Selection Mode (SSM) routine of SITES software (Andelman et al. 1999) was used to find these combinations of cells (a network), by performing one hundred runs with 10,000,000 iterations. A relatively high value of penalty for loosing a species was set, so all solutions tended to represent all species with a minimum number of cells.

There are frequently multiple ways (i.e., combination of cells) that satisfy this representation goal, and the solutions were combined to generate a map that gives the relative importance of each cell in these multiple minimum networks, by considering the frequency in which it occurs in the representative combinations of cells or alternative networks. This is an estimate of the irreplaceability of the cell (see Meir et al. 2004), ranging from 0.0 (minimum irreplaceability) to 1.0 (maximum irreplaceability), measuring the likelihood of a given cell to ensure achievement of a set of conservation targets (see also Ferrier et al. 2000).

We also added to SSM a cost for each cell, estimated by different variables expressing human occupation of the Cerrado, and minimized this cost, while representing all species at least once. Some previous studies minimized directly only the total number of people

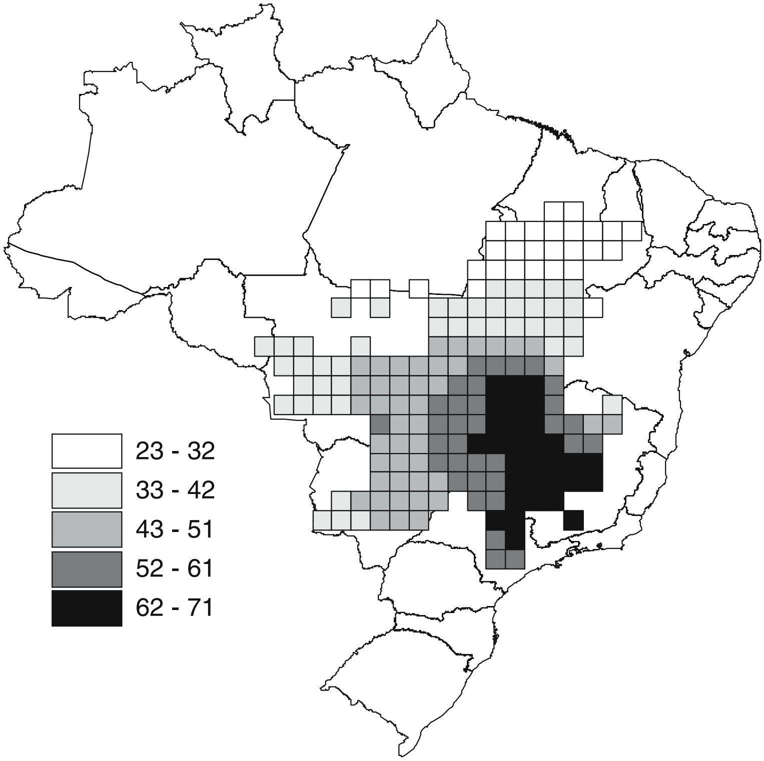

Fig. 1 Spatial patterns of species richness of anurans in the Cerrado region

within the networks (i.e., Chown et al. 2003). However, the recent mode of human occupation in Cerrado is based on a fast expansion of highly technological agriculture and extensive cattle ranching practices (Klink and Machado 2005), which are, in turn, usually weakly correlated with human population density. For example, the Pearson's *r* coefficients of correlation between human population density and soybean productivity and between human population density and bovine herd density were 0.11 and 0.29, respectively. Thus, due to this particularity, we also generate networks with a minimum amount of soybean productivity and density of bovine, as described below.

Data for human population for each cell in the Cerrado region was obtained from the official census of Brazilian population for the year 2000, done by the Brazilian Agency of Geography and Statistics (IBGE) (see www.ibge.gov.br). For each cell covering the Cerrado biome, human population was obtained by summing urban or rural population from 1054 municipalities whose geopolitical limits are within the Cerrado borders. The same procedure was used to obtain the average soybean productivity and bovine density for each cell, based on data of official Brazilian Agricultural Census, from 1996, also from IBGE. These two variables were used as surrogates of occupation by technological agriculture and extensive cattle ranching (see Rangel et al. in press, for a multivariate analysis of socio-economic factors of Cerrado occupation). Thus, amongst many possible solutions that represent all species, we also found a combination of cells in which there is smallest total human occupation, and so may be useful to minimize potential conservation conflicts (Balmford et al. 2001; Diniz-Filho et al. 2006).

Table 1 Families and genera of Anura from Brazilian Cerrado used in the conservation biogeography analyses, with number of species and number of endemic species in each genus

Family	Genus	Number of species	Number of endemic species
Bufonidae	*Bufo*	8	0
Dendrobatidae	*Colostethus*	1	1
	Epipedobates	3	1
Hylidae	*Aplastodiscus*	1	0
	Bokermannohyla	8	4
	Corythomanthis	1	0
	Dendropsophus	13	5
	Hypsiboas	15	7
	Lysapus	2	0
	Phasmahyla	1	1
	Phyllomedusa	4	2
	Pseudis	3	1
	Scinax	13	4
	Trachycephalus	2	0
Leptodactylidae	*Adenomera*	3	1
	Barycholos	1	1
	Crossodactylus	2	0
	Eleutherodactylus	5	2
	Hylodes	1	0
	Leptodactylus	18	7
	Odontophrynus	4	2
	Physalaemus	7	3
	Proceratophrys	2	2
	Pseudopaludicola	5	1
	Thoropa	1	0
Microhylidae	*Chiasmocleis*	3	1
	Dermatonotus	1	0
	Elachistocleis	2	1
Ranidae	*Rana*	1	0

Results

The maximum value for anuran species richness was found in the central-southern region of the Cerrado Biome, decreasing towards northeastern region (Fig. 1). Patterns of richness for endemic species and CWE are also similar, with restricted species more concentrated in the southeastern part of the biome (Fig. 2). This result, as indicated below, will be important to understand the spatial configuration of the reserve network.

The simulated annealing procedure indicated that 17 regions (i.e., cells) must be considered in order to represent all species in the Biome at least once. The combination of solutions with 17 cells provided by SSM (Fig. 3) reveals that the regions must be widely distributed across the entire Cerrado Biome and encompass the states of Goiás, Minas Gerais, Tocantins, Bahia, Maranhão, Mato Grosso, and Mato Grosso do Sul, and cells with maximum irreplaceability (i.e., cells that appear in all 100 solutions) are concentrated in the southeastern part of the Biome. Other cells with high irreplaceability are found close to Pantanal, in the southwestern part of the Cerrado, and a group of cells with moderate irreplaceability is found in the northwest part of the biome. Also, it is important to note that because of the strong spatial autocorrelation in richness and species ranges (see Diniz-Filho et al. 2003, 2004a), these solutions are very similar and congruent across geographic space.

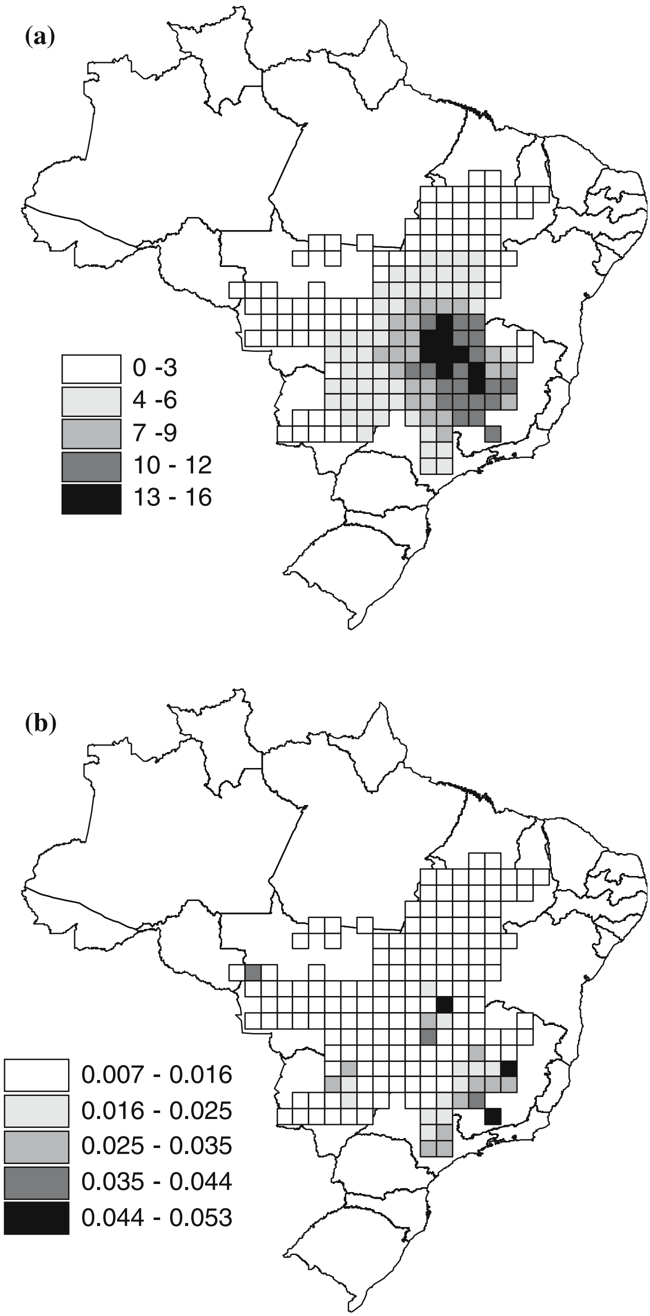

Fig. 2 Spatial patterns of richness for endemic species (**a**) and of endemism (CWE) (**b**)

SSM was also used to represent all species while minimizing the total amount of human population, soybean productivity and bovine density. These three solutions (Fig. 4) are similar, with cells allocated preferentially in the south part of the biome and with a single

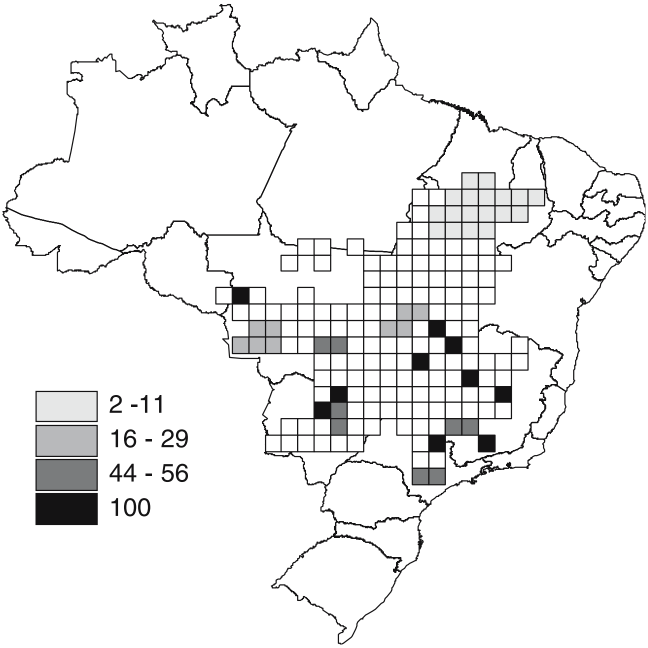

Fig. 3 Sum of the 100 SSM near-optimal solutions with 17 cells (irreplaceability)

cell in the northeastern. For human population size and bovine herd density, SSM found a single minimum solution (Fig. 4a, b), whereas six equivalent minimum solutions were found for soybeans (Fig. 4c). Irreplaceability calculated by combining these six solutions is also higher the southeastern region of the biome, and in a single cell in the extreme west of the Biome.

Discussion

Reserve networks defined by optimal complementarity solutions, based on regional biodiversity analyses, have been successfully implemented or proposed for different parts of the world (Csuti et al. 1997; Araújo 1999; Chown et al. 2003). The analyses performed in this paper showed that conservation efforts for the anurans in Cerrado biome should be concentrated in at least 17 regions (cells) of Central Brazil, covering seven different states (Goiás, Minas Gerais, Tocantins, Bahia, Maranhão, Mato Grosso, and Mato Grosso do Sul). Due to type of data used (i.e., extents of occurrence) and patterns of beta diversity, multiple solutions to represent all species are available, showing a certain level of flexibility in the system, although many areas with maximum irreplaceability are concentrated in the southeastern region of the biome. This is expected since SSM solutions are constrained, in geographical terms, by a number of small-ranged species whose distributions are concentrated in the southeastern of the Biome. Despite this, by considering the Cerrado biome as a whole, it is clearly necessary to establish a national geopolitical coordination in conservation planning to minimize the loss of overall efficiency (see Rodrigues and Gaston 2002).

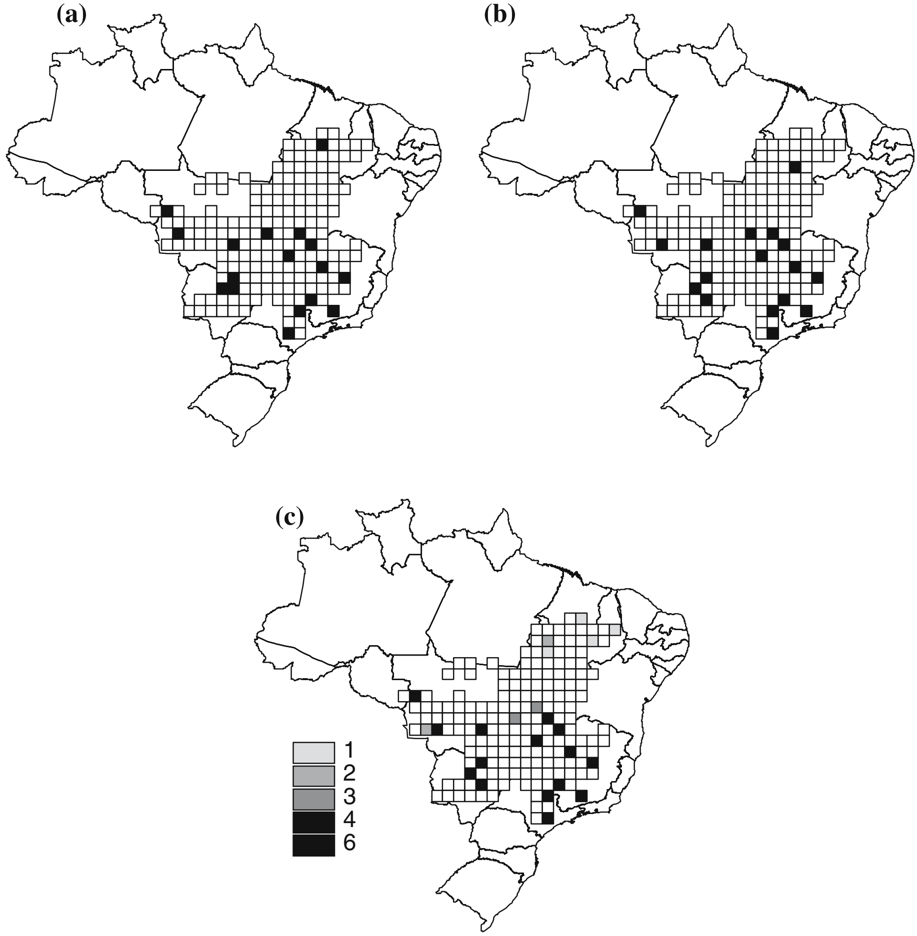

Fig. 4 Minimum solutions of SSM in respect to human population size (**a**) and bovine density (**b**). In (**c**) we show the sum of six optimum solutions minimizing costs related to soybean productivity

A network with 17 select cells represents about 10% of the grid system used to map species‘ ranges (cells with 1° of latitude and longitude), and is similar, both in size and spatial configuration, to a system previously established using a subset of the species used here, a coarsely defined grid and based on a simple heuristic and sequential algorithm of reserve selection (Diniz-Filho et al. 2004b). The 17 cells in the multiple solutions obtained by the simulated annealing algorithm are widely distributed in the space, as expected if beta-diversity increases with increasing geographic distance (see Maurer 1994), and thus encompasses a great amount of the environmental heterogeneity at regional scales, such as different vegetation types (Ratter and Dargie 1992; Ratter et al. 1996; Bridgewater et al. 2004). Also, and more importantly, it is possible to generate networks that contain a smaller amount of human occupation (defined by three different surrogates of these patterns), revealing a possibility to minimize conservation-human development conflicts (sensu Balmford et al. 2001; see also Chown et al. 2003; Diniz-Filho et al. 2006). For modern agricultural spatial patterns, based on soybean cultures, six minimum cost solutions were found, revealing even more flexibility (compared with the single solution provided by minimizing human population and bovine density) to establish a broad-scale conservation system targeted to represent all anuran species. However, most irreplaceable cells are still situated in the south-eastern and central regions of the biome, as a function of endemism of many species, including some recently discovered (Diniz-Filho et al. 2005). The problem is that this region is the one most densely occupied by human populations and their activities, so establishing protected areas becomes both difficult and expensive.

Since there is a strong autocorrelation pattern for grid richness (Diniz-Filho et al. 2003), alternative reserve systems could also work if based on cells close to the ones chosen here, as showed by the multiple solutions obtained by simulated annealing in SSM. This occurs because short distance autocorrelation in species richness is usually a function of range overlap, reflecting low species turnover (Diniz-Filho et al. 2003). These alternative systems would be also important when considering the previous efforts in defining reserves in the Cerrado Biome (e.g. Emas and Chapada dos Veadeiros National Parks, in Goiás State, that are adjacent to some of the cells selected in this paper. Thus, in a context of gap analyses at broad scale (e.g., Rodrigues et al. 2004), these previously established reserves, after a more detailed evaluation of local parameters (see below), could be used as starting points for defining priorities in the allocation of conservation efforts along the entire system. Of course, a better understanding of how the current system of conservation units preserves anuran diversity requires a more detailed study, due to differences in scale focused for each analysis.

Despite the growth of macroecology research program worldwide (see Blackburn and Gaston 2003), macro-scale approaches are obviously considered coarse to establish reserve networks. Although they can provide overall guidelines for conservation and define the focus for more local and effective conservation efforts in Neotropical regions, it is also important to be aware of the limitations of this approach. A first general problem with macro-scale approaches is the definition of the extent of occurrence, based on biogeographical data, which is by definition overestimated (Gaston 2003). Although each region in our study has ca. 12,000 km^2, and probably has at least one population of the species listed (assuming continuous ranges), we cannot ensure that viable population for all species will be found within these regions. More studies are necessary to evaluate these parameters at local scale because, in general, regional patterns of species richness and abundance for Cerrado species are poorly described, with inventories restricted to a few regions in the central and south-eastern part of the biome (Cavalcanti and Joly 2002). In this case, the hierarchical approach suggested here (i.e., defining regions using biogeographic data and only then analysing local areas within regions by local sampling), would be in principle more effective than select reserves based only on spatially restricted and detailed local datasets. Also, this approach can be improved in a near future if a few additional parameters linking species‘ persistence with patterns of regional occurrence and habitat suitability are obtained. This can improve the system by adopting a ‘filtering’ strategy based on extents of occurrence (Araújo and Williams 2000; Williams and Araújo 2000; Araújo et al. 2002). Another possibility is to downscaling data to a finer resolution, based on modeled species distributions, but this procedure still requires relatively high density of local records of occurrence to minimize uncertainness in modeling process (Araújo et al. 2005).

Spatial variation in total species richness and especially in the level of endemism (which possess an important role in establish the networks) may be biased since most sampling efforts have been historically concentrated into the southern and central regions of the Cerrado biome (Diniz-Filho et al. 2005). Suppose, for example, the discovery of new endemic species in the northern part of the biome (e.g. in the Tocantins State), a plausible assumption due to the paucity of faunal inventories in this region. This would increase the relative importance (i.e., the irreplaceability) of those northern regions and, consequently, increase the length of the entire reserve network. Increasing knowledge could also show that geographic distribution of some currently known species could also expand towards these northern regions, and this would counteract this effect of increasing network size due to endemisms. On the other hand, updating data on ranges of known species would even invert the current pattern of the reserves, since species that are today considered endemic to southern would be also preserved in the northern.

Edge effects observed in the network would partially counteract the increase in the number of regions necessary for reservation caused by adding more endemics species in the northern regions, and also change network length in the future (see Diniz-Filho et al. 2005). In a broader scale approach (i.e., analysing the entire country), non-endemic species found only at the margins of the biome would have been previously included in richer regions outside the Cerrado, decreasing the importance of some regions selected in the edge of the biome. Thus, the selected regions in the centre of the biome would be more stable to changes if a national scale planning were implemented (Rodrigues and Gaston 2002). In general, these results indicate how difficult is to predict changes in the network patterns due to the increase in the comprehensiveness in biodiversity data in the entire biome (Diniz-Filho et al. 2005). Anyway, the irreplaceability patterns and reserve networks described here are the best possible conservation bioegeography design based on current knowledge of the anuran species distribution in the Cerrado.

Despite these problems, our analyses revealed general patterns of anuran species richness and endemism in Cerrado biome, which may be important for conservation purposes. The regional system presented here can furnish guidelines for future conservation and research programs, taking into account both patterns of species richness, endemism, human development and land use to define priority regions for conservation. In this context, the next step in this research program is to add habitat suitability dimensions to filter regional occurrence and incorporate issues of increasing species persistence into reserve design.

In addition, at local scales, we suggest an increasing in sampling efforts within the regions identified above with the aim of identify suitable habitats and to estimate population and meta-population parameters. Data gathered in this way will serve to evaluate the validity of areas to maintain viable populations and also to increase our knowledge about patterns of richness and endemism by updating geographic distribution of known and describing new species.

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