Spatial patterns in species richness and priority areas for conservation of anurans in the Cerrado region, Central Brazil

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Abstract. Declines in anuran populations worldwide are increasingly creating demands for quick and urgent strategies to maximize efforts to conserve amphibian populations, especially in areas in which few detailed data on diversity, abundance and distribution are available, such as the Cerrado of Central Brazil. We used extent of occurrence of 105 species of Anura (Amphibia) in the Cerrado region to establish a regional system of potential areas that preserves all anuran species in the region, at a macroecological scale. The final network, obtained using a simple "greedy" algorithm based on complementarity, has a total of 10 regions, widely distributed in the biome. These areas were also evaluated in terms of their human demographic parameters (human population size and growth rate). Strong spatial autocorrelation in species richness indicates that alternative systems based on pre-existing conservation units will also be efficient in terms of biodiversity conservation. Although macro-scale approaches are usually coarse, they can provide overall guidelines for conservation and define the focus for more local and effective conservation efforts, which is particularly important when dealing with a taxonomic group such as anurans for which quick and drastic population declines have been reported in many regions of the world.

Introduction

There is a growing concern about the decline in amphibian populations worldwide (Pechmann et al., 1991; Tyler, 1991; Crump et al., 1992; Blaustein and Wake, 1995; Marsh, 2001), and a list of possible causative factors includes habitat loss, habitat fragmentation, species introduction, pollutants and climate change (Alford and Richards, 1999). These declines are increasingly creating demands for quick and urgent strategies to maximize conservation efforts for amphibian populations, especially in regions in which few detailed

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data on diversity, abundance and distribution are available, such as in the Cerrado of Central Brazil (Young et al., 2001).

Despite high rates of habitat destruction in this region (Sala et al., 2000; Myers et al., 2000), previous attempts to establish conservation priorities in the Cerrado area were usually based on subjective criteria, such as prioritizing regions of presumed high species richness or simply regions in which the fauna was little known (see Colli et al., 2002; Oliveira and Marques, 2002). This was because few detailed data on species distribution and abundance were available. The lack of information was especially of concern for anuran species.

The definition of conservation units (reserves) is the main strategy adopted by the governments to preserve biodiversity, despite many criticisms (Margules and Pressey, 2000; Aaron et al., 2001). Although this strategy could be effective to diminish habitat loss if the reserves were selected adequately, these criteria are hardly taken into account when a reserve is to be established (Possingham et al., 2000). Unfortunately, political and economic interests are usually more important than scientific criteria.

A group of reserves (i.e., reserve system) is usually not defined to meet specific biodiversity objectives (Possingham et al., 2000). Many reserves encompass areas of unsuitable habitat for the maintenance of native species, or are defined by cultural or scenic reasons. The most important criterion to define the reserve system should be to achieve maximum representation of biodiversity for the smallest possible cost. This optimization involves many different aspects, including spatial distribution of reserves, their connections, overall area, shape and percentage of suitable habitats (Cabeza and Moilanen, 2001). When the conservation strategy is focused on a single species, population dynamics parameters linked to minimum viable population size must be considered (Possingham et al., 2000). Also, socio-economic factors associated with the development of human populations at local and regional scales, including population size, growth rate and land use, must be taken into account (Abbitt et al., 2000). These human development parameters, associated with data on endemism, were recently used to define priority areas for conservation at a global scale (the so-called hotspots; Myers et al., 2000).

Many algorithms have been developed to create a reserve system that maximizes the representation of biodiversity in a region (see Cabeza and Moilanen, 2001, for a recent review). These methods can be based on occurrence data for a group of species (Church et al., 1996; Pressey et al., 1997; Araújo and Williams, 2000; Polasky et al., 2000; Briers, 2002) and, more recently, optimization of other "measures" of diversity, such as phylogenetic diversity (Polasky et al., 2001; Rodrigues and Gaston, 2002a; Sechrest et al., 2002).

In this paper we used macro-scale biogeographical data (extent of occurrence, sensu Gaston, 1994) to define sequentially the most important regions that should be included in a reserve system to protect all species of anurans, including an analysis of human population parameters (population size and growth rate) in each region. Because the grid-diversity data based on extents of occurrence are usually autocorrelated (Diniz-Filho and Telles, 2002;

Diniz-Filho et al., 2003), we also performed spatial analyses to define patch size around each region. Although macro-scale approaches are usually coarse, they can provide overall guidelines for conservation and define the focus for more local and effective conservation efforts in the Neotropical region (Young et al., 2001). This hierarchical approach is a starting point to prioritize conservation efforts in a Biome where political decisions are usually not based on science, and hopefully will help to conserve anuran diversity.

Methods

We limited our analyses to 105 species of Anura (Amphibia) that can be found in the Cerrado area at Central Brazil (fig. 1), all endemic to South America. Species whose taxonomic status was undefined or that probably constitute groups of species (i.e., *Scinax* gr. *ruber* or *Bufo* gr. *granulosus*) were excluded from our dataset. The occurrence of these species in South America was registered on a standardized map of South America (Azimuthal projection, scale 1:40,000,000) covered by a grid with 780 quadrats of approximately 135 km side length (Bini et al., 2000; Diniz-Filho et al., 2002), based on extensive literature data and on records of the Museu Nacional (Universidade Federal do Rio de Janeiro). Cerrado Biome in this grid was then defined based on a map provided by the Brazilian Institute of Geography and Statistics (IBGE) (see www.ibge.gov.br) and UNESCO (1981) (fig. 1). Extent of occurrence was defined based on minimum convex polygons defined using data on occurrence of each species in South America (Gaston, 1994). For most species, more than 10 records in different points of the continent were available to establish geographic ranges. A complete species list and associated sources for defining geographic ranges are available from the authors upon request.

Species richness was estimated by counting the overlaps of the geographic ranges of the 105 species, for each of the 82 quadrats in the Cerrado Biome. In this paper, each quadrate will be considered as a "region" that encompasses many local areas (that in turn hopefully support minimum viable populations for the species).

Grid data for species richness are usually strongly autocorrelated (see Jetz and Rahbek, 2001; Diniz-Filho et al., 2002, 2003). We estimated autocorrelation patterns in species richness using spatial correlograms constructed using Moran's I coefficients estimated at distinct distance classes. Moran's I coefficient is given by

$$I = \left(\frac{n}{C}\right)\left[\frac{\sum_i \sum_j (y_i - \bar{y})(y_j - \bar{y})w_{ij}}{\sum_i (y_i - \bar{y})^2}\right]$$

where n is the number of points in the grid, y_i and y_j are the values of the variable (i.e., species richness) in the quadrats i and j, $\bar{y}$ is the average of y, w_{ij} is the element of the matrix $\mathbf{W}$, that assumes a value of one if the pair i, j of points is within the geographic distance class interval and zero otherwise. C is given by the count of these connections among points in $\mathbf{W}$, for each class interval. In this study, 10 geographic distance classes were used. The value expected under the null hypothesis of absence of autocorrelation is given as $-1/(n-1)$. Detailed computations of the coefficient and of its standard error are given in Legendre and Legendre (1998). Autocorrelation analyses were performed using the Spatial Autocorrelation Analysis Program (SAAP), version 4.3 (Wartenberg, 1989).

Based on the occurrence of the 105 species in the 82 quadrats of the Cerrado biome, we used the "greedy" algorithm to select the most representative regions for conserving all species with a minimum cost (Possingham et al., 2000; Polasky et al., 2001). This algorithm is very simple, and starts by picking up the region with most species. Then, it sequentially searches for the next region that adds species that were not found in the previous region. The final purpose is to define a network with a small number of sites (regions) in which all species are represented at least once (the set covering problem) (Church et al., 1996). The ties in region selection, at each step of the algorithm, were solved by adding the richest site (increasing the representativity of the species in the final network) (see also Briers, 2002). The number of new species added to the system can be monitored and the curve can be use to define a minimum cut-off level. Although there are now more sophisticated methods to optimize the solution (i.e., "greedy" algorithms usually provide slightly sub-optimal solutions, with 5% to 10% more sites than optimal solutions — Pressey et al., 1997; Possingham et al., 2000), its advantage is the ability to deal with very large data matrices relatively easily (Csuti et al., 1997, but see Rodrigues and Gaston, 2002a). Although sequential algorithms are sub-optimal, they permit the establishment of a priority rank for the different areas, which can be useful when dealing with constraints in financial resources to establish new conservation units.

In order to establish the relative efficiency of the network found under the greedy process, we also selected quadrats at random in the Cerrado region and calculated the species richness preserved for the same number of quadrats defined using the greedy algorithm described above, and repeated this procedure 250 times.

For each region selected, we also searched for the larger municipality inside the quadrat, to give a proximate reference for human population parameters (human population size and growth rate from 1996 to 2000) (IBGE, 2000).

We also discuss that the presence of large conservation units in the region that, due to strong autocorrelation patterns in species richness, could be used as more effective local conservation units within the defined regions.

Results

The peak in species richness for Anuran species was found in the central-southern region of the Cerrado Biome, as shown by mapping the grid richness based on the extents of occurrence (fig. 1). The correlogram (fig. 2) indicated a strong spatial structure in species richness, with positive significant Moran's I coefficients in the first distance classes that decrease toward the largest distance classes. Thus, nearest quadrats in the grid are more similar than expected by chance alone, and this similarity decreases up to around 1200 km. After that distance class, it is not possible to predict relationships among quadrats in the grid based on species richness. The x-intercept of the correlogram, indicating the distance up to which quadrats can be considered independent (Moran's I not statistically different from zero), is around 600 km. This is expected by considering that geographic range sizes of most species are usually small (less than around 900 km of side, for circular ranges, corresponding to 50 quadrats) (fig. 3A) and that many of them possess only a small portion of their ranges (less than 30%) in the Cerrado Biome (fig. 3B).

The application of the "greedy" algorithm to the occurrence matrix indicated that 10 regions must be preserved in order to retain all richness in the biome (table 1). The regions are 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 (fig. 4; table 1). The curve of proportion of the species pool added in relation to sequential introduction of regions in the network system indicates that preservation of the first region alone (region of Alto Paraíso, Goiás State, with 62 species), will maintain around 60% of the overall species pool. After increasing the size of the network system to 6 regions, 95% of the pool will be retained. The number of Cerrado endemics preserved in the system follows the same pattern, with around 40% of endemics being preserved in the first region only (table 1).

It is also interesting to note that, although the purpose of the algorithm is to find a small number of sites (regions) for which all species are represented at least once, by considering the statistical distribution of extents of occurrence in the area (fig. 3A) it is possible to check for representation of each species in the established network with 10 regions (fig. 5).

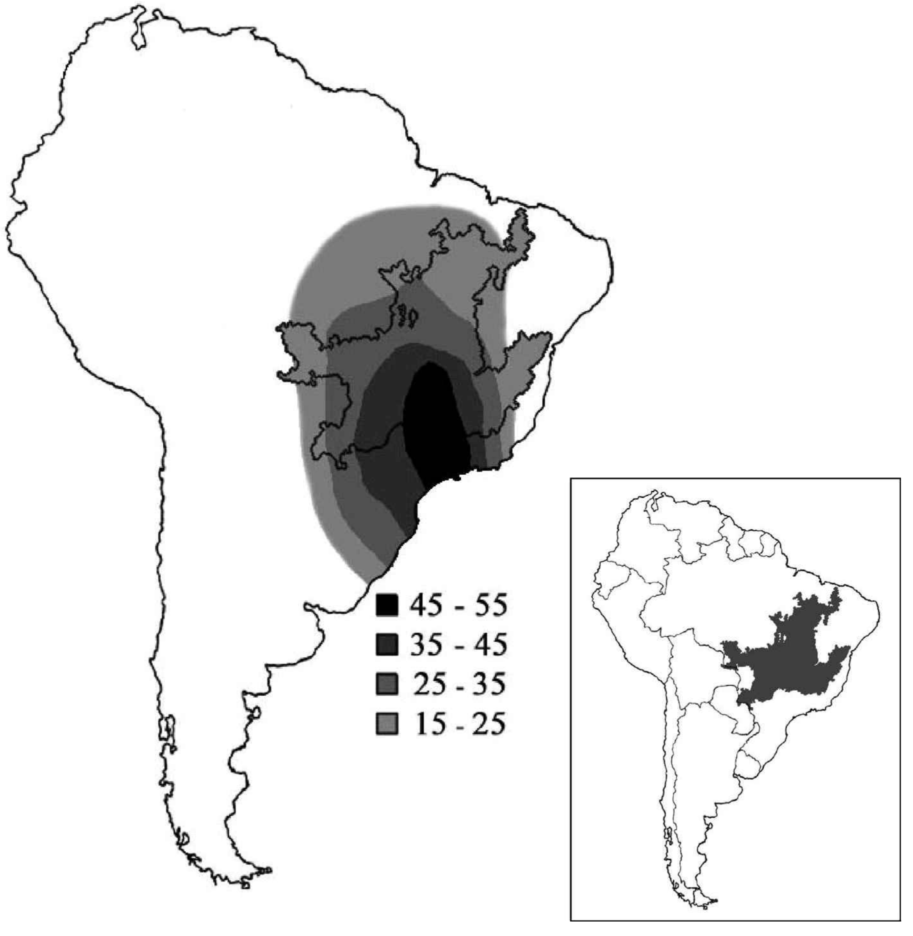

Figure 1. Spatial patterns of species richness in 105 species of Anura from the Cerrado Biome, interpolated using a distance weighted least-squares (DWLS) algorithm.

In fact, 67.6% of the species were represented more than once in the network with 10 regions. Only 32.4% of the species occur in single regions, while 12.4% are represented in all 10 regions.

Selecting at random (250 replications), 10 regions in the Cerrado grid would protect, on average, 74 species (standard deviation of 7 species), with a maximum of 94 and a minimum of 56 species preserved (fig. 6). In none of the simulations the total number of species was preserved by these random networks.

Human population parameters in the municipalities representative of the 10 regions indicate a coherent structure if one adopts the “hotspot” criterion (see Myers et al., 2000). The population sizes in the center of the region (and also in the surrounding areas) are

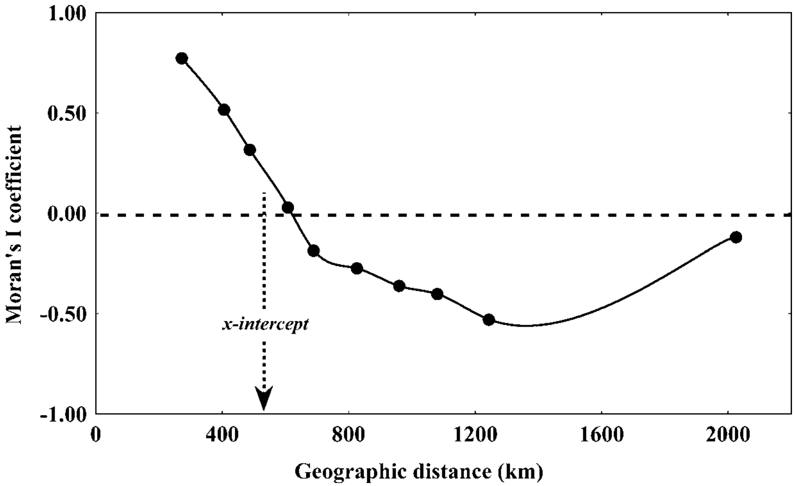

Figure 2. Spatial correlogram, containing the relationship between Moran's I autocorrelation coefficient and geographic distance class. The dashed line indicates the expected Moran's I under the null hypothesis of no autocorrelation, and the intercept is the distance at which samples (quadrats) are expected to be independent for species richness (see Bini et al., 2000; Diniz-Filho and Telles, 2002, for detail).

Table 1. Data for the 10 quadrats defined as priority areas for conserving Anuran species, including priority (q), overall species richness in the quadrat (S), added species richness after incorporating the previous quadrat (S_A), number of endemic species present in each quadrat (S_E)*, closest city (municipality), state, latitude and longitude of the center of the quadrat, human population size in the year 2000 (N) and intrinsic growth rate [$r(\%)$, for human population in the period 1991-2000]. All latitudes are South and all longitudes are West.

q	S	S_A	S_E	Closest city	State	Latitude	Longitude	N	$r(\%)$
1	62	62	8	Alto Paraíso	GO	14°20′	47°30′	6173	3.33
2	60	21	4	Lassance	MG	18°00′	44°30′	6491	0.94
3	42	10	4	Pedro Gomes	MS	18°00′	54°30′	8540	0.88
4	55	3	4	Três Marias	MG	18°00′	45°00′	23539	−0.60
5	48	2	2	Palmeirópolis	TO	13°00′	48°30′	7096	−1.13
6	36	2	0	Correntina	BA	13°00′	45°00′	30580	0.73
7	25	2	0	Fortaleza das Nogueiras	MA	6°20′	46°00′	11264	2.49
8	47	1	1	Santa Helena de Goiás	GO	18°00′	50°30′	34523	1.15
9	40	1	2	Diamantino	MT	16°30′	53°25′	18457	4.65
10	39	1	0	Coluna	MG	18°00′	43°00′	9993	3.72

* The sum of the endemic species is higher than the actual number (equal to 19 species) because some endemic species will occur in two or more quadrats.

usually low (maximum 35.000 persons), since these areas are distant from large urban centers of Central Brazil, such as Goiânia, Campo Grande and Brasilia. However, there are very high growth rates, such as 4.65 % year^{-1} in Diamantino (Mato Grosso State). The municipality in the first selected region, Alto Paraíso (Goiás State), has the third largest growth rate (3.33% year^{-1}).

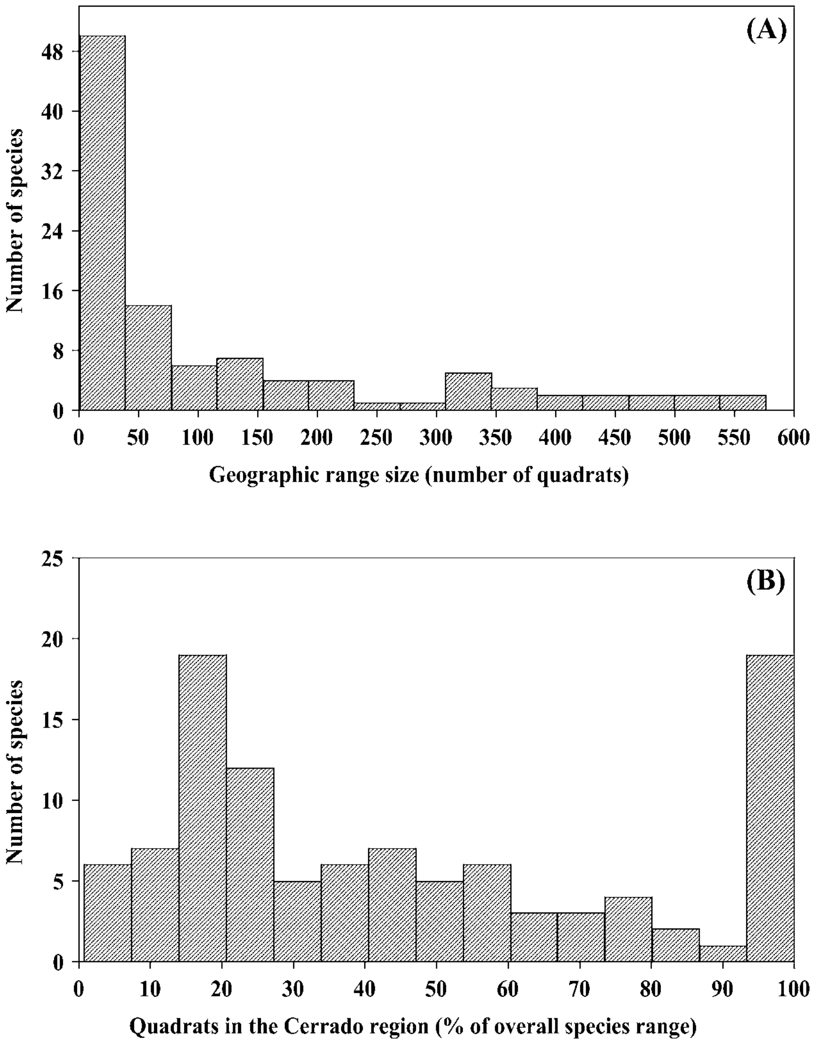

Figure 3. (A) Distribution of geographic range size for the 105 species studied and; (B) the percentage of the range encompassing the Cerrado Biome.

Discussion

Conservation netwoks defined by optimal or sub-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, 2000). The analyses performed here show that conservation efforts for the anurans in Cerrado biome should be concentrated at least in 10 different regions of Central Brazil, in seven different states (Goiás, Minas Gerais, Tocantins, Bahia, Maranhão, Mato Grosso, and Mato Grosso do Sul). These

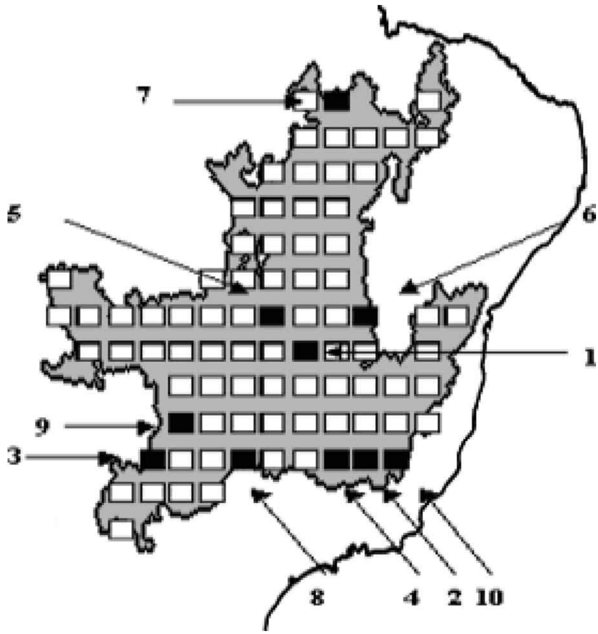

Figure 4. The spatial distribution of the 10 regions selected based on complementarity of Anura, in which number indicate priority for conservation (see table 1 for detailed description of each region). Quadrats were shown as discontinuous just for visualization purposes.

regions are widely distributed in the space, as expected if beta-diversity increases with increasing geographic distance (see Maurer, 1994). The exceptions are the three areas in the south-eastern region of the Cerrado Biome. Anyway, the network system suggested by our analysis encompasses a great part of the environmental heterogeneity in the Cerrado Biome, including vegetation types, micro-climatic and relief variation (Ratter and Dargie, 1992; Ratter et al., 1996).

Since there is a strong autocorrelation pattern for grid richness, alternative reserve systems could also work if based on quadrats close to the ones chosen here. This occurs because short distance autocorrelation in species richness is usually a function of range overlap and reflect low species turnover (Diniz-Filho et al., 2003). Thus, at least in principle, autocorrelation analysis furnishes an initial criterion for irreplaceability mediated by geographic distance (sensu Margules and Pressey, 2000) and taking into account the distribution of the representation of each species in the network proposed (see fig. 5). These alternative systems would be important when considering the previous efforts in defining conservation units in the Cerrado Biome. For example, in the first region selected, there is already a conservation unit (a National Park, the “Parque Nacional das Chapadas dos Veadeiros”). Also, the Mirador National Park is located approximately 200 km of the selected region 7, in the northern part of the biome, whereas the third selected

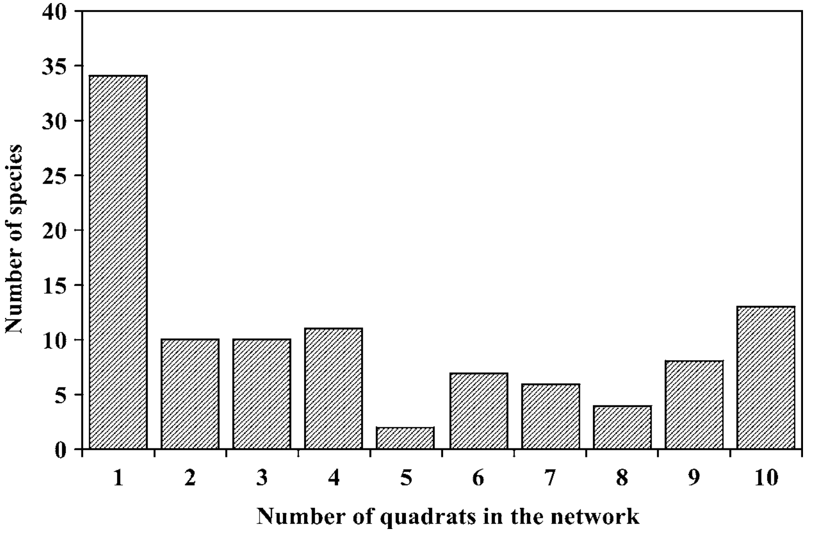

Figure 5. Species representation, in terms of number of regions in which they occur in the final network with 10 regions.

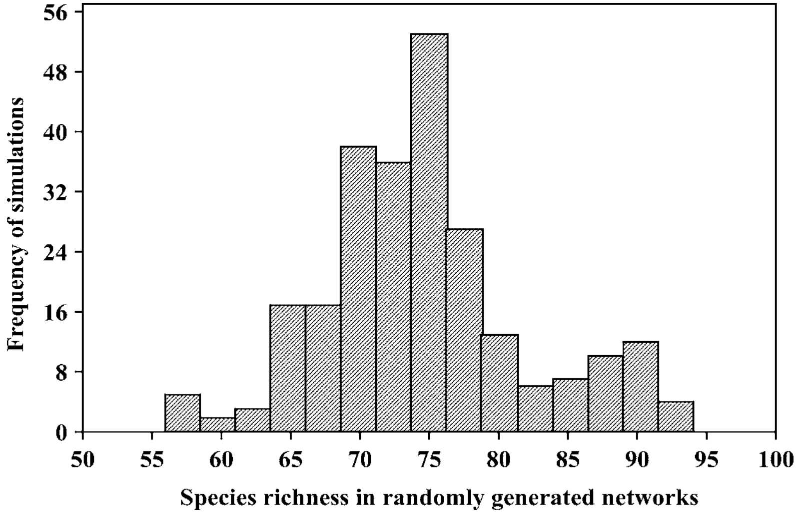

Figure 6. Number of species preserved in 250 networks established by randomly sampling 10 quadrats from the Cerrado grid. Note that in none of the simulated networks the total number of species (105) was preserved.

region (around the municipality of Pedro Gomes), is situated close to the corridor Cerrado-Pantanal, now under scientific evaluation by "Conservation International (CI)" (Silveira, pers. comun.). Thus, these previously established units, 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 (see below).

Macro-scale approaches can provide overall guidelines for conservation and define the focus for more local and effective conservation efforts in Neotropical regions. This is especially important when dealing with a taxonomic group, such as anurans, for which rapid and drastic population declines have been reported all around the world (Alford and Richards, 1999; Sala et al., 2000) and in Latin America (Young et al., 2001). On the other hand, these macro-scale approaches are usually coarse and can be considered only as a starting point for more detailed strategies at a local scale.

A first general problem with macro-scale approaches is the definition of the extent of occurrence, based on biogeographical data, that is by definition overestimated in relation to the occurrence of the species at a more local scale (Gaston, 1994). Although each region in our study has more than 18,000 km^2, and probably has at least one population of the species listed, we cannot ensure that viable population for all species will be found.

It is also important to remember that local species lists may be subject to problems in the definition of suitable habitats, sampling designs, and efforts, especially for some cryptic species of anurans. In this case, the hierarchical approach adopted here (i.e., defining regions using biogeographic data and only then analysing local areas within regions by local sampling), would be more effective. In any case, at local scale, it would be important to choose, within regions, distinct areas of suitable habitats that could maintain minimum viable populations for all species. More probably, as a simple consequence of species-area relationship, many local areas within region should be preserved in order to include, in combination, a higher number of species.

Also, the overall richness patterns may be biased since most sampling efforts have been concentrated into the southern and central regions of the biome, which may create a taxonomic problem across the entire Cerrado Biome. Adding more endemic species to regions in Tocantins State would change the guidelines presented here and will increase the representation of those regions and, consequently, increase the size of the entire reserve network. Although further studies could try to measure variations in sampling efforts across the Cerrado and take this into account when designing the reserve network, recent studies suggest that methods based on complementarity are potentially valuable tools for reserve selection in regions for which biological data are poor (Gaston and Rodrigues, 2003). Anyway, the network proposed here is based on current knowledge of the anuran species distribution in the Cerrado.

On the other hand, it is also interesting to note that because of the relatively low endemism of species in the Cerrado (Colli et al., 2002), edge effects observed in the network showed here would partially counteract the increase caused by adding more endemic species in the northern regions, and also change network length. This would occur because, 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, such as 1 and 5, would be more stable to changes in the scale, when considering only the Cerrado biome. In short, a reserve network depends on scale and its properties derive from the delimitation of the entire area of interest, which is usually defined by political and social economic motivations and not necessarily by biogeographical boundaries and ecological discontinuities. This delimitation defines the statistical distribution of geographic ranges inside and outside the target areas, changing then the spatial distribution of reserves and the network length (Rodrigues and Gaston, 2002b).

Despite these problems, our analyses revealed general patterns of species richness of Anuran species in Cerrado Biome, which are important for conservation purposes. The regional system presented here, based on current knowledge of species distributions, can furnish guidelines for future conservation programs, taking into account both patterns of species richness and endemism and human development and land use to define priority regions for conservation. In this context, the next step in this program is a more intensive and detailed local sampling effort within each region, defining local areas of suitable habitat and estimating population and meta population parameters for the species found.

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