Available online at www.sciencedirect.com
ScienceDirect
Applied Geography 27 (2007) 14–27
APPLIED GEOGRAPHY
www.elsevier.com/locate/apgeog

Human development and biodiversity conservation in Brazilian Cerrado

Thiago F.L.V.B. Rangel[a], Luis M. Bini[b,*], José A.F. Diniz-Filho[b], Miriam Plaza Pinto[a], Priscilla Carvalho[c], Rogério P. Bastos[b]

[a] *Pós-Graduação em Ecologia and Evolução, ICB, Universidade Federal de Goiás, Brazil*
[b] *Departamento de Biologia Geral, Instituto de Ciências Biológicas, Universidade Federal de Goiás, Caixa Postal 131, 74001-970, Goiânia GO, Brazil*
[c] *NUPELIA, Universidade Estadual de Maringá, Maringá, PR, Brazil*

Abstract

We evaluated how different variables reflecting human occupation in Brazilian Cerrado are correlated with diversity patterns and which one could be the best indicator of conflicts between biodiversity conservation and socio-economic development across the region. A spatially corrected multiple regression of anuran species richness against axes derived from a principal component analysis summarizing 23 socioeconomic variables was performed. Species richness was positively correlated with the first two principal components, expressing patterns of modern agriculture and cattle ranching, respectively, but not with the third component, expressing human population size. Thus, human population density is not the best indicator of conflicts and, consequently, other socio-economic variables should be considered to minimize costs when establishing regional programs for conservation planning in Brazilian Cerrado.

Keywords: Conservation conflicts; Socioeconomic variables; Human occupation; Cerrado; Species richness; Spatial patterns

*Corresponding author. Fax: +55 62 521 1480.
E-mail address: bini@icb.ufg.br (L.M. Bini).

0143-6228/$ - see front matter
doi:10.1016/j.apgeog.2006.09.009

Introduction

Total monetary cost required to purchasing land that meets a given conservation constraint is often not easily available (McDonnell, Possingham, Ball, & Cousins, 2002). Thus, different variables have been used as a surrogate for monetary costs. Recently, human population density (*H*) has been often used as a criterion to be minimized in reserve design algorithms (Luck, Ricketts, Daily, & Imhoff, 2004) or as an indicative of conflicts between economic/social interests and biological conservation (Araújo, Williams, & Turner, 2002; Balmford et al., 2001; Chown, van Rensburg, Gaston, Rodríguez, & van Jaarsveld, 2003).

Under this reasoning, if one minimizes this surrogate variable *H*, monetary costs will be indirectly minimized. Also, historical and contemporary evidences indicate that, in many situations, this is correct due to the negative effects of human's activities on biodiversity (Cardillo et al., 2004; McKee, Sciulli, Fooce, & Waite, 2004). In addition, a positive relationship between *H* and species richness may be expected because both increase with energy availability (Araújo, 2003; Balmford et al., 2001; Evans & Gaston, 2005; Gaston & Evans, 2004). A high correlation between species richness and *H* is, however, a necessary result for the validity of *H* as a surrogate for costs (but see discussions between Faith, 2001 and Moore et al., 2001). Otherwise, selected areas (any parcel of land that is reserved due to the achievement of some conservation goal) will be still under constant socioeconomic pressure, independently of how populated these areas are.

In some circumstances, human population density may not be the best indicator that an area of interest is under attack or is easily alienated for conservation purposes, because of both historical processes and current patterns of land use and occupation by humans (Faith, 2001; Faith & Walker, 2002). For example, a mining facility, with a small contingent of employees, may stay in a low-populated tropical forest and produce large environmental impacts. Even other forms of resource use done by a small number of people, which are usually considered sustainable, may threat biodiversity at long term (Peres et al., 2003).

In this study, we test and compare the correlation between anuran species richness in Brazilian Cerrado and different socioeconomic indicators, including human population density. By considering the current economic activities and historical process of human colonization in this region, based on highly technological agriculture (Klink & Moreira, 2002), we hypothesize that human population is not the best indicator of conservation conflicts. Thus, if this statement is correct, we should search for other socioeconomic indicators, better correlated with species richness, to be considered as constraints in optimization models of reserve designing in order to minimize possible conflicts between conservation and socioeconomic development.

Methods

Cerrado biome was divided into 181 cells with $1^\circ \times 1^\circ$ (Fig. 1). The geographical ranges (extent of occurrence) of the 131 species of Anura (Amphibia) found in the Cerrado area at Central Brazil, all endemic to South America, were draw on this grid, and the presence of each species in each cell was recorded (see Diniz-Filho et al., 2004, for a detailed description of data sources). Species richness was estimated by counting the overlaps of the geographic ranges of the 131 species, for each of the 181 cells in the Cerrado Biome.

Fig. 1. Distribution of the 181 cells that were used to analyse the spatial variation of anuran species richness in the Cerrado Biome.

Data on social and economic variables that are likely to indicate conservation conflicts were compiled from the site of the Brazilian Institute of Geography and Statistics (IBGE) (see www.ibge.gov.br). Variables analysed (Table 1) were chosen to express both general patterns of human occupation (population size, growth rates, modes of spatial subdivision of agricultural space and size of road network) and variations in agricultural and agro-industrial characteristics, mainly reflecting a contrast between more traditional and more technological agricultural practices.

All variables analysed were strongly correlated to each other (see results). Thus, to avoid multicollinearity problems in our multiple regression model, a varimax rotated factor analysis based on principal components (PCA, Johnson & Wichern, 1992) was used to reduce data dimensionality and to identify a lower number of independent socioeconomic

Table 1
Codes and meaning of socio-economic variables used in this study

Variable/code	Description
Rural pop.	Percentage of rural population
Workers	Number of workers employed at rural establishments
Forests	Percentage of rural areas conserved as natural or recovered forests
Pastures	Percentage of rural areas used as planted pastures
Crops	Percentage of rural areas used as crops
Area100	Percentage of rural establishments with area $\leqslant 100$ ha
Rice	Land productivity of rice in tons
Corn	Land productivity of corn in tons
Soy	Land productivity of soybean in tons
Irrigation	Percentage of irrigated establishments
Bovines	Cattle/ha
VegeSum	Total monetary value of vegetal production
AnimSum	Total monetary value of animal production
Costs	Percentage of costs involved agriculture and cattle ranching
Machines	Density of farming machines (trucks, harvesting machines, tractors and automobiles) per unit of area (ha)
Plague/weed control	Percentage of rural establishments that use any resources against plagues or weeds
Fertilization	Percentage of rural establishments that use any sort of fertilizers
Electric energy	Percentage of rural establishments that use electric power
Erosion control	Percentage of rural establishments that use any measure against erosion
Fecundity	Expected number of children per woman
Roads	Road network size (km)
Income	Income per capita
H2000	Human population in 2000

factors, or axes, that could be related with species richness and, in this way, indicate different forms of conservation conflicts.

We analysed spatial patterns in PCA scores and multiple regression residuals (see below) using spatial correlograms of Moran's I coefficients calculated at 10 geographic distance classes (Diniz-Filho, Bini, & Hawkins, 2003; Legendre & Legendre, 1998). To account for the spatial autocorrelation problems that were detected (see results), before testing the relationship between amphibian species richness and factor scores, we used a relatively new method called eigenvector-based spatial filtering (Borcard & Legendre, 2002; Borcard, Legendre, Avois-Jacquet, & Tuomisto, 2004; Diniz-Filho & Bini, 2005; Griffith, 2003), which is described below.

Geographical coordinates of each cell covering Brazilian Cerrado were used to construct a pairwise matrix of geographical distances among cells (**G**), which was truncated (see below) at distance of 1000 km (truncation distance, D). This truncation distance is important because it gives more weight to short-distance effects, after filtering process. Thus, distances larger than 1000 km were replaced by $4 \times D$ ($= 4000$ km), whereas distances < 1000 km were kept as they were calculated (see Fig. 1 of Borcard & Legendre, 2002). The truncated **G** matrix was then submitted to a principal coordinate analysis (PCORD) (Legendre & Legendre, 1998), which consists in performing an eigenanalysis of the double-centered **G** matrix.

The eigenvectors associated with positive eigenvalues of the double-centered **G** matrix represent the spatial relationship among cells covering Cerrado, at different spatial scales.

The first eigenvectors represent broad-scale variation, whereas eigenvectors derived from small eigenvalues represent fine-scale variation. These vectors are then new orthogonal variables (called filters by Griffith, 2003) that capture, at different scales, the geometry of the grid covering the Cerrado and they can be incorporated into multiple regression approach in different ways, taking into account spatial autocorrelation and allowing an unbiased estimation of regression parameters.

The next step of the analytical protocol discussed here includes the selection of the eigenvectors that should enter as predictors in the model. Borcard and Legendre (2002) suggested testing the significance of all the partial regression coefficients and retaining only the eigenvectors that are significant. Griffith (2003) showed that using all eigenvectors in the analysis might 'overcorrect' for spatial autocorrelation, and propose some strategies to choose some of the vectors. These strategies include (i) maximization of the coefficient of multiple determination (R^2), (ii) minimization of residual spatial autocorrelation, (iii) a significant correlation between the response variable and each selected eigenvector (see Diniz-Filho, De Sant'Ana, & Bini, 1998 for a different approach, based on broken-stick null distribution of eigenvalues), and (iv) using only spatial filters that have significant spatial structure. Detailed methods to select the optimum number of filters that should be used in modelling can be found elsewhere (Diniz-Filho & Bini, 2005; Griffith, 2003). In this paper, we used the fourth method described above, by including the filters with Moran's I coefficients, at the first distance class, higher than 0.1 (see results).

In summary, filters can be considered as different and independent propositions of how cells are geographically related or connected to each other, expressed as new variables derived from geographical distances and indicating the spatial relationships among cells. Mapping and running spatial autocorrelation analysis on filters and residuals of regression models adding filters as predictors can help to interpret which part of spatial structure among cells are captured by each filter. Besides, including filters in statistical models minimize the undesirable effects of subjacent spatial structures that were not captured by the factors (see below). Supposing that the response variable (species richness in our case) is spatially patterned, for example, with low and high values alternating in space, forming patches (e.g. in a fragmented landscape), it is highly probably that one of the filters will account for this complex spatial pattern if no factor does this. Thus, this patchy structure will be not present in the residuals and the regression model will not be biased by spatial autocorrelation. According to Borcard and Legendre (2002), filters are spatial descriptors of the response variable and can be incorporated into analytical frameworks in different ways depending on the context.

The analyses performed above measure conservation conflicts by a correlation between richness and human occupation. However, for applied purposes, conservation actions are not implemented across the entire spatial surface, but instead in specific patches or cells usually defined by complementarity processes (Faith, 2001). Thus, conflicts should be measured within a network of these cells, and not across the entire Cerrado. Based on the presence–absence matrix of species in the cells, we performed a complementarity analysis by using the simulated annealing in the SITES V. 1.0 software program (available in http://www.biogeof.ucsb.edu) with 1,000,000 iterations and ten repeated runs (Possingham, Ball, & Andelman, 2000). The best run was selected. We carried out the complementarity analysis to solve the set-covering problem, i.e., to conserve at least one 'population' (cell) of each species with a minimum total number of cells (the reserve network).

After establishing the optimal reserve network, we applied the randomization procedure proposed by Araújo et al. (2002) and Chown et al. (2003) to evaluate if the sum or the mean of each human occupation variable, expressing the opportunity cost of each cell, within the optimum network, was significantly different from the sum or mean values obtained in randomly generated networks with the same number of cells. We randomly generated 10,000 reserve networks in the Cerrado region, with the same number of cells defined by the simulated annealing procedure, to evaluate the total opportunity cost (e.g. total human population, average bovine density, and so on) in each random network. The observed opportunity cost in the optimal reserve network, for each variable, was then compared with these 10,000 total values derived from randomly generated networks. In the absence of conservation conflicts at the network level, means and sums within the selected cells of the true network should be a random value within the null distribution from randomly generated networks. Otherwise, means and sums in the true network will be significantly higher than the ones obtained by chance alone.

Randomisation was performed in random reserve selection (RRS) software written by one of us (TFLVBR) in Delphi language for IBM-PC compatibles and available from the authors upon request.

Results

Summarizing the spatial patterns in the socioeconomic variables

According to the broken-stick model, three interpretable axes of variation from the socioeconomic metrics were obtained using VARIMAX rotated PCA, which accounted for 60.9% of the variation in these variables. The first axis, accounting for 34% of the total variance, is related to modern agribusiness. It characterizes cells in the Cerrado biome that have, simultaneously, intense use of measures to control arable soil erosion, higher per capita incomes, high investments in plague control, fertilization, farming machinery and other infrastructure facilities (e.g. electric energy), associated with relatively low human population fecundity rates (Table 2). This first group of cells also assembles the largest area of soybean and corn production in Brazil, which are characterized as modern and highly technological agricultural activities, concentrated in the south-south-western region of the biome (Fig. 2A).

The second axis accounts for 14% of the variance and is positively correlated with pastureland area used for cattle ranching, total bovine herd, and negatively correlated with area covered by forests (Table 2). These activities are concentrated in the middle part of the biome (Fig. 2B). The third axis accounts for 12.7% of the variance and indicates patterns of human occupation, in a more demographic sense, with high loadings of total human population, percentage of rural population and high number of farms with area smaller than 100 ha (a surrogate of agricultural landscape fragmentation). High human population density and the other variables correlated with the third axis are scattered in the central part of the biome (near to Goiânia and Brasilia) and in the Eastern border (Fig. 2C).

Spatial patterns and filtering

The peak in anuran species richness was found in the central-southern region of the Cerrado Biome, forming mainly a southeast-northwest gradient (Fig. 3). The spatial

Table 2
Loadings of the indexes of development-opportunities on the first three principal component (PC) axes

Variables	PC1	PC2	PC3	*r*	*P*
Fecundity	−0.68	−0.31	−0.04	−0.53	0.8761
Workers	−0.47	−0.36	0.03	−0.38	0.9138
Forests	−0.26	−0.64	−0.25	−0.54	0.6848
Area100	−0.15	−0.28	0.78	0.01	0.3714
Rural pop.	−0.02	−0.09	0.87	0.16	0.1787
Pastures	−0.01	0.92	−0.14	0.44	0.3854
Rice	0.18	−0.22	−0.10	−0.12	0.7675
Irrigation	0.24	0.35	−0.02	0.46	0.7476
Roads	0.32	0.41	0.50	0.51	0.0502
*H*2000	0.35	0.30	0.73	0.49	0.1511
Bovines	0.38	0.66	0.08	0.57	0.0920
Expenses	0.58	−0.17	−0.12	0.34	0.1507
VegeSum	0.63	0.16	0.06	0.52	0.0425
Machinery	0.67	0.19	0.38	0.62	0.0081
Corn	0.69	−0.08	0.30	0.53	0.6734
Plague/Weed control	0.71	0.54	−0.24	0.66	0.1346
Field crops	0.74	−0.30	0.33	0.34	0.1304
Fertilization	0.76	0.25	0.33	0.80	0.0097
Soy	0.77	−0.08	−0.14	0.48	0.6632
AnimSum	0.80	0.18	0.13	0.63	0.0881
Electric energy	0.80	0.43	0.10	0.69	0.0634
Income	0.83	0.18	−0.31	0.53	0.1367
Erosion control	0.88	0.09	0.08	0.55	0.1352

The column (*r*) indicates the Pearson's correlation between species richness and each index (similar results were obtained when the Spearman's rank correlation was used). The last column (*P*) indicates if the minimum complementary cells represent areas with larger development-opportunities than expected by chance.

correlograms indicated strong spatial structures for species richness and for the first three principal axes scores, with positive significant Moran's *I* coefficients in the first distance classes that decrease toward the largest distance classes (Fig. 4). Thus, nearest cells 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 cells in the grid based on the variables related to these axes. The correlogram of the first and third axes tends to form a more 'clinal' structure beyond this distance, with slightly negative Moran's *I*. The second axis showed a clear 'patchy' structure. Although planted pastures, which support bovine herds (variables related with the second principal component scores), are the most important land use in the Cerrado, their occurrence is not continuous. Instead, areas occupied by planted pastures are intercalated with other land uses (e.g. reserves, crops and other forms of occupation, Fig. 2B).

Out of the 180 eigenvalues extracted from **G** matrix, 92 were positive. The 26 first eigenvectors (principal coordinate scores) with Moran's *I* coefficients higher than 0.10 in the first distance had significant spatial structures (Fig. 5). Thus, these filters contain important and complex spatial patterns of the Cerrado region. Fitting these filters to species richness should, presumably, be enough to remove autocorrelation structure from models of interest and, in this way, allow avoiding undesirable effects of spatial autocorrelation in hypothesis testing and providing unbiased regression coefficients.

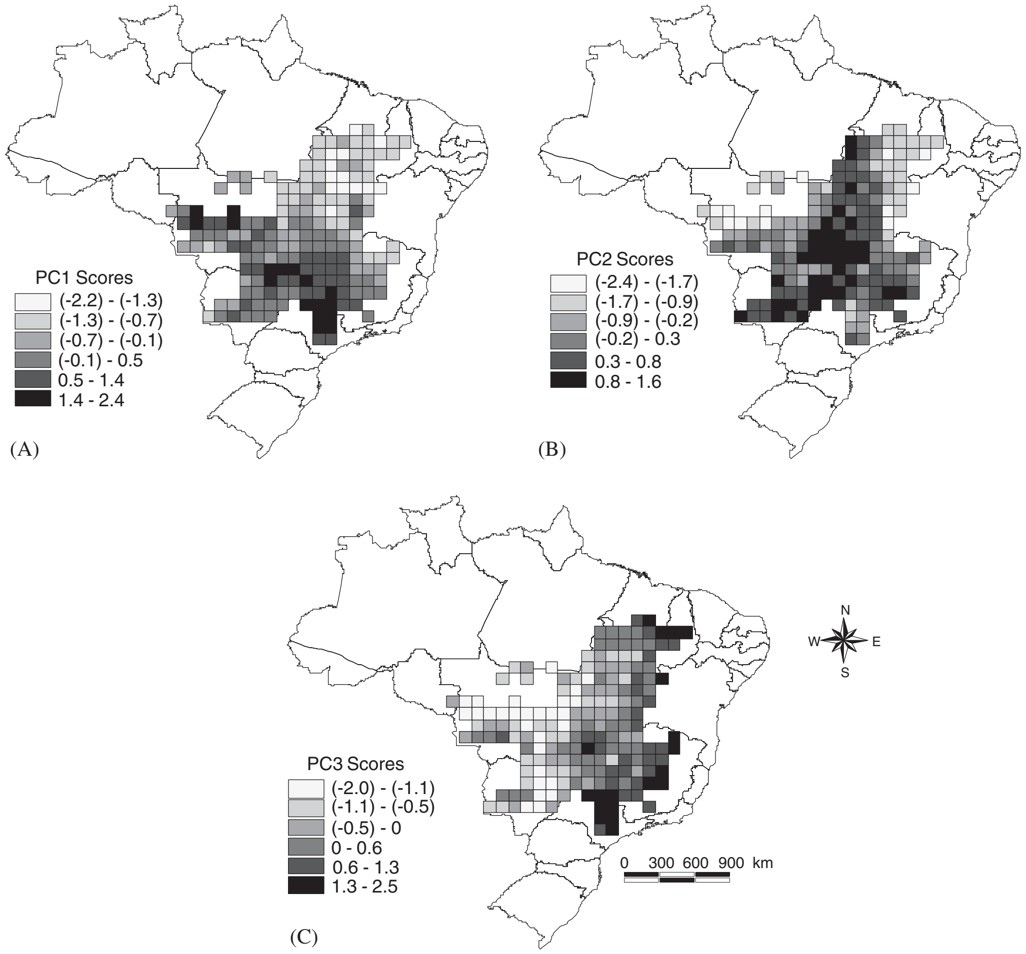

Fig. 2. Geographical variation in the scores of the first three principal component axes. The increasing in the darkness of shading indicates a increasing in values of the variables positively correlated with these axes (see Table 2).

Multiple regression results

Adding both filters and principal component scores as predictors in the multiple regression model furnished an R^2 of 0.97. Partial regression coefficients of the socio-economic variables (summarized by PCA) from the multiple regression model including 26 spatial filters allowed an estimation of which axes were more significantly correlated with amphibian species richness, independently of spatial structures at distinct spatial scales. These coefficients indicated that the first principal component axis was the most important predictor, followed by the second principal component. The relationship between species richness and the third principal component was negative, though non-significant (Table 3).

The spatial correlogram for the residuals indicates that the principal component axes and filters were able to explain most of the spatially structured variation in species richness across the Cerrado biome (Fig. 6). Thus, our results were not influenced by autocorrelation

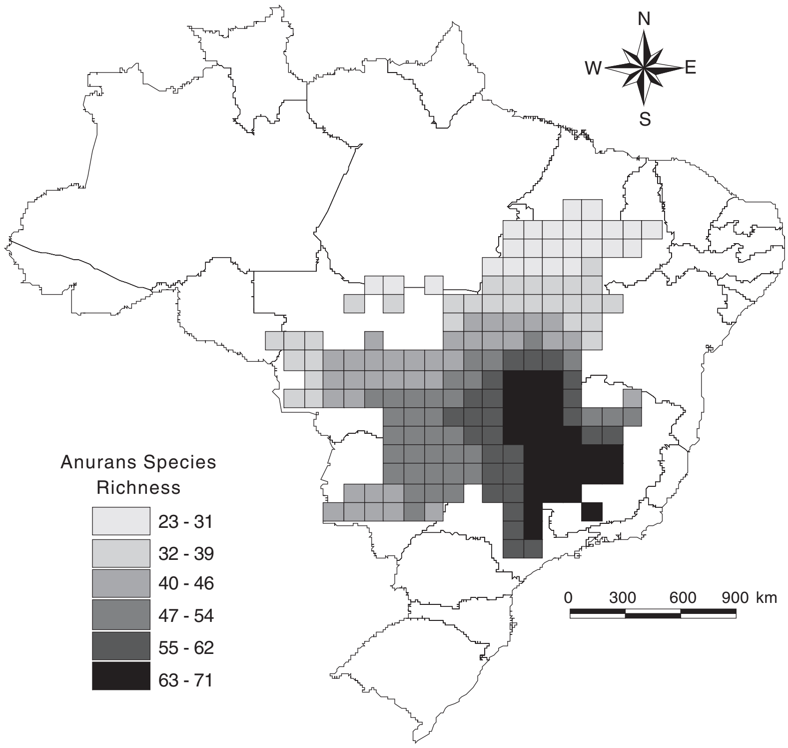

Fig. 3. Anuran species richness variation across the Brazilian Cerrado.

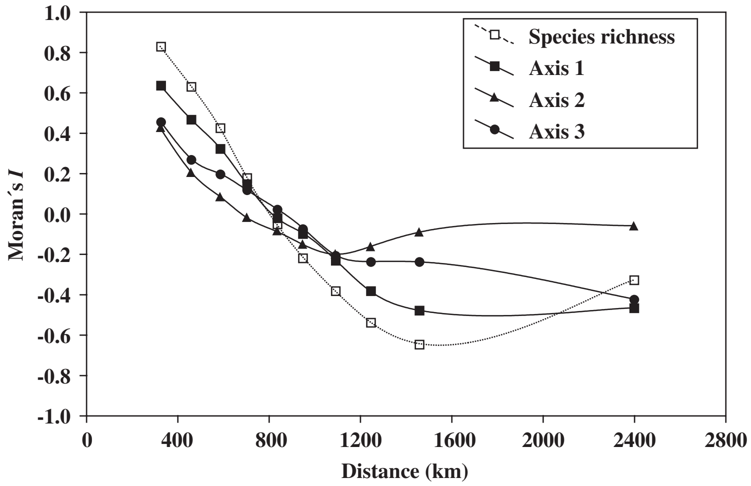

Fig. 4. Moran's *I* correlograms for anuran species richness and for the first three principal components scores.

problems (inflation of type I errors and invalid parameter estimates) (see Diniz-Filho et al., 2003). Simple correlation analyses between species richness and all socio-economic variables independently of each other are also informative to highlight the higher positive

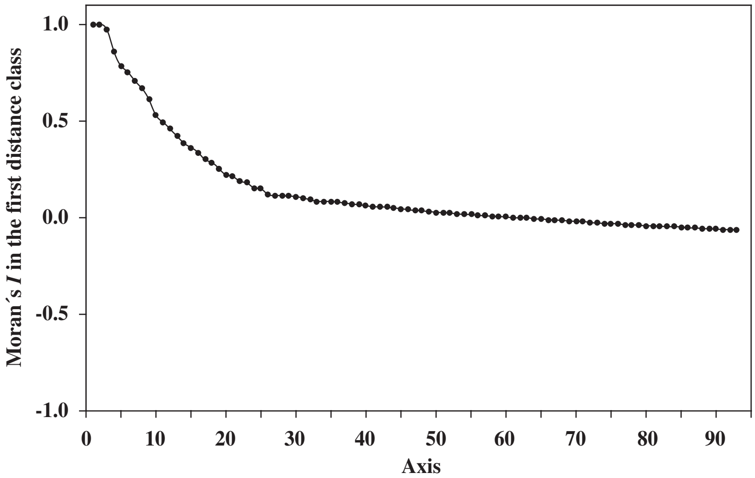

Fig. 5. Moran's *I* coefficients of the first ninety filters estimated at the first distance class.

Table 3
Multiple regression results of the species richness on principal component axes scores and filters (not shown to save space)

Variable	β	SE	t	P
Axis 1	0.16	0.44	4.68	0.000
Axis 2	0.15	0.43	4.51	0.000
Axis 3	−0.02	0.43	−0.53	0.595

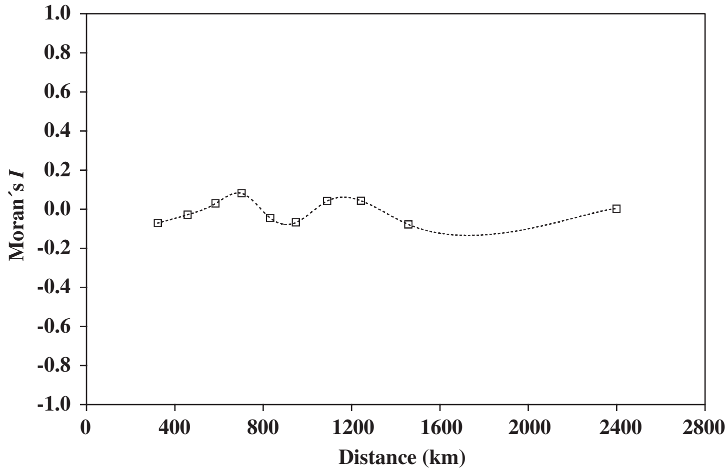

Fig. 6. Moran's *I* correlogram for the residuals of a multiple regression model after regressing species richness on the indexes of development-opportunities (socioeconomic variables) and spatial filters.

correlations of species richness with the variables more associated with the first and second principal component axes (Table 2).

A network with 17 cells was obtained using a simulated annealing procedure to solve a set-covering problem that has at least one occurrence (cell) of each anuran species (Fig. 7). When opportunity cost within this network, for each variable, is compared with null statistical distribution of these costs in 10,000 networks with 17 cells randomly distributed across the Cerrado region, it is possible to observe that high deviations from null expectations (smaller *P*-values, Table 2) were obtained for the variables with the highest correlations with anuran species richness ($r = -0.73$). Thus, conservation conflicts are not only detected for the overall patterns of species richness in the Cerrado, but also within the network of cells that were selected to optimally conserve all species with the minimum effort, taking into account the complementarity patterns of species' geographic distribution. It is also important to note that, as occurred in the correlative analyses, the total human population in the complementarity-based network did not differ significantly from those obtained by chance alone.

Discussion

Modern agriculture activities (mainly soybean) and extensive cattle ranching in the Brazilian Cerrado have been usually considered the main threats to its biodiversity due to the high rates of habitat conversion (Klink & Moreira, 2002; Oliveira-Filho & Ratter, 2002; Ratter, Ribeiro, & Bridgewater, 1997), as occur with other regions of savannas

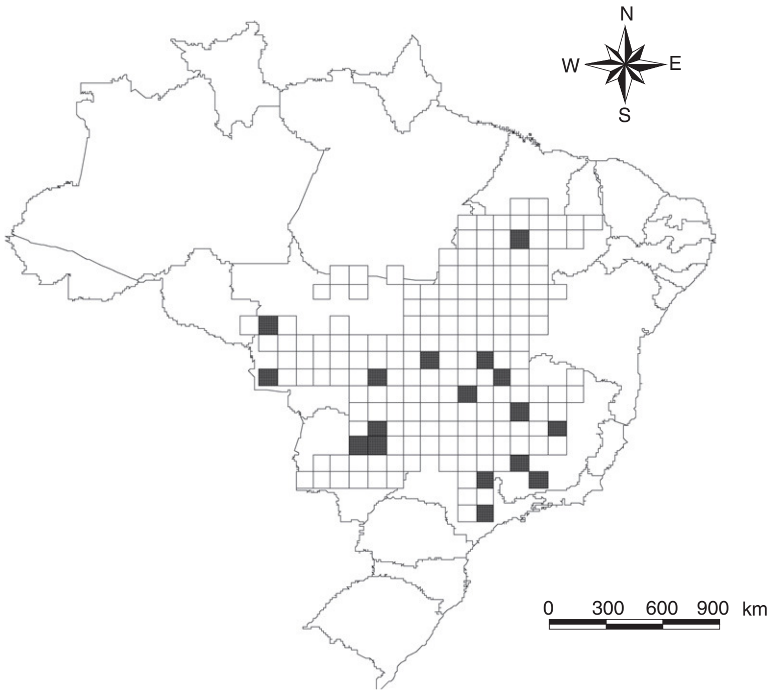

Fig. 7. Map of the Cerrado biome, showing sites selected by simulated annealing algorithm.

worldwide (Sala et al., 2000). Due to these high rates of habitat conversion and elevate plant endemism, the Cerrado was recently considered one of the 25 world hotspots (Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000). Under the 'hotspot' concept (urgent protection of more endangered areas), it is important to identify which are the more appropriate measurements of conservation costs, which should be minimized, in a regional scale, in order to achieve higher conservation targets with smaller costs, minimizing human-development conflicts (Faith, 2001).

Thus, our main purpose in this paper was to quantify and compare the magnitude of the coincidences between different forms of human occupation in the Cerrado region and species richness. Our results were unequivocal. After using a multivariate analysis to summarize information from several socioeconomic variables, we can establish that anuran species richness was indeed more correlated with the axes that summarized modern agriculture and cattle ranching (first and second principal components, respectively). In addition, the weakest relationship was found with the axis indicating human population density. These results are not biased by autocorrelation effects, which were controlled by the set of 26 eigenvector-based spatial filters (Diniz-Filho & Bini, 2005; Griffith, 2003). Also, similar results appear when dealing with a complementarity-based network of cells designed to optimally conserve all species with minimum effort, where threats to biodiversity related to modern agriculture are concentrated in regions that are also important for conservation. Indeed, human population is highly concentrated into a few large urban centres in south and south-eastern region of Cerrado (such as Brasilia, Goiânia and a few cells in the extreme south-east of the biome, in São Paulo State), whereas the first two PCA scores are more widely distributed, with patterns more similar to the one observed for anuran species richness.

A positive relationship between species richness and human population density is usually expected to rise due to a shared response to energy availability (Chown et al., 2003; Gaston & Evans, 2004). Regardless of the mechanism underlying the positive relationship between richness and human population density (see Araújo, 2003), several studies assume that the best strategy is based on the search for reserve networks that solves a determined conservation goal (e.g. represent each species at least once in the minimum set of regions) and, simultaneously, assign for each cell an acquisition cost proportional to its human population density, reducing total conservation costs and reducing potential conservation-development conflicts (Balmford et al., 2001). However, our analyses also showed that, even if one considers that it is the complementarity, not species richness, that is important (see Faith, 2001; Moore et al., 2001 for a debate about this issue), the problem still persists if human population is used as a surrogate for costs, simply because total human population within the network is a value that can be obtained by chance alone in random samples, with the same area, in the Cerrado. The same does not occur with other socioeconomic variables related to modern agriculture.

At a worldwide scale, hotspots can be identified or ranked according to biodiversity and the level of threats. Thus, a country with high diversity and under a strong level of threat should be ranked higher than a country with similar biodiversity but less threat (Veech, 2003). At a regional scale, we strongly agree with the current idea of minimizing conflicts in conservation planning by adding surrogates for costs in reserve network design. However, our main message is that there is a probable flaw in the use of human population density as a surrogate for conservation conflict, at least at this regional scale in the Cerrado biome. The low correlation with human population can be understood by considering the recent process of human occupation of Brazilian Cerrado, characterized by successive wave fronts of colonization coming from the south and south-eastern parts of the country since the 18th century. However, only after the 1950s the human population started to grow in a few localized regions (see Klink & Moreira, 2002). At the same time, southern and southwest regions of the biome were quickly dominated by highly technological agricultural and agro-industrial activities, usually at low human population densities. These more complex patterns of human occupation tend to be spatially distributed in a southeast–northwest trend, and thus are more associated with anuran species richness. Thus, other socioeconomic variables, reflecting the advance of highly technological agriculture and cattle ranching in the region, should replace human population as surrogates of conservation cost and to be minimized in regional conservation planning in Cerrado. This may be particularly important for anurans, since there is a growing concern about the decline in their populations worldwide (Stuart et al., 2004; Young et al., 2001) creating demands for urgent strategies to maximize conservation efforts.

Acknowledgements

Financial support for this study came from a PRONEX program of CNPq and SECTEC-GO (proc. 23234156). Work by JAFDF, LMB and RPB were also partially supported by other CNPq projects (procs. ns. 300762/94-1, 300367/96-1; 400381-97.4). CAPES and FUNAPE-UFG have also continuously supported our research program in macroecology and biodiversity.

References

Araújo, M. B. (2003). The coincidence of people and biodiversity in Europe. *Global Ecology and Biogeography*, *12*, 5–12.

Araújo, M. B., Williams, P. H., & Turner, A. (2002). A sequential approach to minimize threats within selected conservation areas. *Biodiversity and Conservation*, *11*, 1011–1024.

Balmford, A., Moore, J. L., Brooks, T., Burgess, N., Hansen, L. A., Williams, P., et al. (2001). Conservation conflicts across Africa. *Science*, *291*, 2616–2619.

Borcard, D., & Legendre, P. (2002). All-scale spatial analysis of ecological data by means of principal coordinates of neighbour matrices. *Ecological Modelling*, *153*, 51–68.

Borcard, D., Legendre, P., Avois-Jacquet, C., & Tuomisto, H. (2004). Dissecting the spatial structure of ecological data at multiple scales. *Ecology*, *85*, 1826–1832.

Cardillo, M., Purvis, A., Sechrest, W., Gittleman, J. L., Bielby, J., & Mace, G. M. (2004). Human population density and extinction risk in the world's carnivores. *PLOS Biology*, *2*, 909–914.

Chown, S. L., van Rensburg, B. J., Gaston, K. J., Rodríguez, A. S. L., & van Jaarsveld, A. S. (2003). Energy, species richness, and human population size: Conservation implications at a national scale. *Ecological Applications*, *13*, 1233–1241.

Diniz-Filho, J. A. F., & Bini, L. M. (2005). Modelling geographical patterns in species richness using eigenvector-based spatial filters. *Global Ecology and Biogeography*, *14*, 177–185.

Diniz-Filho, J. A. F., Bini, L. M., & Hawkins, B. A. (2003). Spatial autocorrelation and red herrings in geographical ecology. *Global Ecology and Biogeography*, *12*, 53–64.

Diniz-Filho, J. A. F., Bini, L. M., Vieira, C. M., Souza, M. C., Bastos, R. P., Brandão, D., et al. (2004). Spatial patterns in species richness and priority areas for conservation of anurans in the Cerrado region, Central Brazil. *Amphibia-Reptilia*, *5*, 63–75.

Diniz-Filho, J. A. F., De Sant'Ana, C. E. R., & Bini, L. M. (1998). An eigenvector method for estimating phylogenetic inertia. *Evolution*, *52*, 1247–1262.

Evans, K. L., & Gaston, K. J. (2005). People, energy and avian species richness. *Global Ecology & Biogeography*, *14*, 187–196.

Faith, D. P. (2001). Overlap of species richness and development-opportunity does not imply conflict. *Science*, *293*, 1591–1592.

Faith, D. P., & Walker, P. A. (2002). The role of trade-offs in biodiversity conservation planning: Linking local management, regional planning and global conservation efforts. *Journal of Biosciences*, *27*, 393–407.

Gaston, K. J., & Evans, K. L. (2004). Birds and people in Europe. *Proceedings of the Royal Society of London Series B—Biological Sciences*, *271*, 1649–1655.

Griffith, D. A. (2003). *Spatial autocorrelation and spatial filtering. Gaining understanding through theory and visualization*. Berlin: Springer.

Johnson, R. A., & Wichern, D. W. (1992). *Applied multivariate statistical analysis*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Klink, C. A., & Moreira, A. G. (2002). Past and current human occupation, and land use. In P. S. Oliveira, & R. J. Marquis (Eds.), *The Cerrados of Brazil. Ecology and natural history of a Neotropical savanna* (pp. 69–88). New York: Columbia University Press.

Legendre, P., & Legendre, L. (1998). *Numerical ecology*. Amsterdam: Elsevier.

Luck, G. W., Ricketts, T. H., Daily, G. C., & Imhoff, M. (2004). Alleviating spatial conflict between people and biodiversity. *Proceedings of the National Academy of Sciences of the United States of America*, *101*, 182–186.

McDonnell, M. D., Possingham, H. P., Ball, I. R., & Cousins, E. A. (2002). Mathematical methods for spatially cohesive reserve design. *Environmental Modeling & Assessment*, *7*, 107–114.

McKee, J. K., Sciulli, P. W., Fooce, C. D., & Waite, T. A. (2004). Forecasting global biodiversity threats associated with human population growth. *Biological Conservation*, *115*, 161–164.

Moore, J., Balmford, A., Brooks, T., Burgess, N., Folkmann, M., Hansen, L. A., et al. (2001). Complementarity analyses reveal extent of conservation conflict in Africa. *Science*, *293*, 1591–1592.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*, 853–858.

Oliveira-Filho, A. T., & Ratter, J. A. (2002). Vegetation physiognomies and wood flora of the Cerrado Biome. In P. S. Oliveira, & R. J. Marquis (Eds.), *The Cerrados of Brazil. Ecology and natural history of a Neotropical savanna* (pp. 91–120). New York: Columbia University Press.

Peres, C. A., Baider, C., Zuidema, P. A., Wadt, L. H. O., Kainer, K. A., Gomes-Silva, D. A. P., et al. (2003). Demographic threats to the sustainability of Brazil nut exploitation. *Science*, *302*, 2112–2114.

Possingham, H., Ball, I., & Andelman, S. (2000). Mathematical methods for identifying representative reserve networks. In S. Ferson, & M. Burgman (Eds.), *Quantitative methods for conservation biology* (pp. 291–306). New York: Springer.

Ratter, J. A., Ribeiro, J. F., & Bridgewater, S. (1997). The Brazilian Cerrado vegetation and threats to its biodiversity. *Annals of Botany*, *80*, 223–230.

Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., et al. (2000). Biodiversity—Global biodiversity scenarios for the year 2100. *Science*, *287*, 1770–1774.

Stuart, S. N., Chanson, J. S., Cox, N. A., Young, B. E., Rodrigues, A. S. L., Fischman, D. L., et al. (2004). Status and trends of amphibian declines and extinctions worldwide. *Science*, *306*, 1783–1786.

Veech, J. A. (2003). Incorporating socioeconomic factors into de analysis of biodiversity hotspots. *Applied Geography*, *23*, 73–88.

Young, B. E., Lips, K. R., Reaser, J. K., Ibanez, R., Salas, A. W., Cedeno, J. R., et al. (2001). Population declines and priorities for amphibian conservation in Latin America. *Conservation Biology*, *15*, 1213–1223.