Ariane Lima Xavier

Influência de fatores ambientais na distribuição espacial de uma comunidade de anuros em área de altitude no domínio das caatingas

Orientador: Dr. Marcelo Felgueiras Napoli

Dissertação apresentada ao Programa de Pós-Graduação em Ecologia e Biomonitoramento da Universidade Federal da Bahia como parte dos requisitos necessários à obtenção do título de mestre em Ecologia e Biomonitoramento.

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Prof. Dr. Marcelo Felgueiras Napoli (Orientador)

Para aqueles que
me fizeram acreditar
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Sumário

I INTRODUÇÃO GERAL

nunidades são moldadas por interações bióticas (Pianka 1973) e podem responder de maneira independente aos mesmos fatores ambientais (Homes et al. 1986). A identificação das funções que tais fatores desempenham na determinação dos padrões de distribuição e abundância das espécies é o primeiro passo para a compreensão dos processos de inter-relação das espécies com o ambiente (Underwood et al. 2000).[AMP1]

Os padrões de organização das comunidades refletem predisposição social (Ricklefs 2001), requerimentos específicos de hábitats (Pianka 1967; Willson 1974), distribuição de recursos (Duellman 1990; Mesquita et al. 2006) e magnitudes das interações sociais (Sredl 1992; Eterovick 2003), sendo que muitas vezes estas ações agem em conjunto, o que dificulta o estabelecimento de relações de causalidade (Begon 2006). Entretanto, a existência ou a aparente falta de padrões na estrutura das comunidades pode refletir condições históricas que atuaram no passado e que não agem mais nos dias atuais (Inger 1969; Connell 1980).

Nenhum sistema ecológico pode ser estudado isoladamente do ambiente no qual está inserido (Begon et al. 2006). A heterogeneidade estrutural do ambiente é um dos fatores que tem sido reconhecido por apresentar associação com a riqueza de espécies em diferentes grupos zoológicos (MacArthur & MacArthur 1961; Parris 2004). É esperado que em áreas com maior disponibilidade de microambientes e nichos ecológicos ocorra maior riqueza de espécies (Putman 1996), já que estes ambientes permitiriam a coexistência de um número maior de espécies, quando comparados a ambientes mais homogêneos (Cardoso et al. 1989; Gascon 1991). No entanto, a dependerdeve-se ponderar que o efeito da heterogeneidade ambiental pode variar consideravelmente dependendo do que é reconhecido como hábitat para o táxon estudado (Tews 2004).

A interação fisiológica dos anfíbios com seu ambiente é um sistema complexo e dinâmico de processos relacionados (Duellman & Trueb 1986), difíceis de serem isolados. Essa estreita relação faz os anfíbios serem considerados bioindicadores de variação nas condições ambientais, uma vez que suas características ecofisiológicas (p. ex. pele permeável e ciclo de vida bifásico) possibilitam marcada suscetibilidade a alterações de parâmetros físico-químicos da água, bem como da estrutura da vegetação que os circundam (Vitt et al. 1990; Wake 1991).

Abordagens descritivas ainda representam grande parte do esforço em trabalhos de pesquisa com anuros (p.ex. Duellman 1988; Feio & Ferreira 2005; Uetanabaro 2007; Vieira et al. 2007) e as relações investigadas entre a estrutura da comunidade e as variáveis do ambiente muitas vezes limitam-se a associações com temperatura (p.ex. Bertoluci 1998), pluviosidade (p.ex. Rossa-Feres et al. 1999; Bernarde 2007; Bernarde & Kokubum 1999) ou a ambas (p.ex. Pombal Jr. 1997; Conte & Machado 2005; Zina et al. 2007). Poucos são os estudos que buscaram relacionar os padrões de distribuição das espécies e os fatores ambientais que os influenciam. Associações positivas da complexidade estrutural da vegetação com a riqueza, diversidade ou composição de espécies foram encontradas por Parris & McCarthy (1999), Vallan (2002), Krishnamurthy (2003), Parris (2004) e Bastazini et al. (2007), embora em Santos et al.

(2007) o hidroperíodo tenha sido considerado dentre os descritores de complexidade estrutural o que melhor representou a riqueza registrada nos ambientes estudados.

O domínio morfoclimático das caatingas (ver Ab'Sáber 1977 para definição dos domínios morfoclimáticos) é um dos domínios brasileiros menos investigados para os anuros (Rodrigues 2003). Estudos ecológicos que versem especificamente sobre estrutura de comunidades de anfíbios no domínio das caatingas são escassos, pontuais e, por vezes, limitam-se a monografias, dissertações e teses não publicadas (p. ex. Cascon 1987; Lima 1999). Isso é consistente para o Parque Estadual das Sete Passagens (PESP), localizado na Serra de Jacobina, designação regional da Serra do Espinhaço, representando a vertente norte da Ecorregião "Complexo da Chapada Diamantina" (ver Velloso et al. 2002 para caracterização das Ecorregiões do bioma Caatinga). A Serra de Jacobina foi definida pelo Ministério do Meio Ambiente (Rodrigues et al. 2004) como área prioritária para conservação por apresentar "informação insuficiente". O conhecimento proporcionado pela elaboração do Plano de Manejo do PESP (MF Napoli comunicação pessoal) ao qual esteve associada a execução desta dissertação, subsidiou alteração na categorização destas prioridades. A Serra de Jacobina (incluindo aí o PESP) foi definida pelo MMA (2007) como área com relevância extremamente alta para conservação devido à diversidade de fisionomias e registros de espécies novas, endêmicas, restritas e ameaçadas. O PESP está inserido em uma das áreas consideradas como zona de exceção do domínio das caatingas (ver Ab'Sáber 1977 para definição de zona de exceção), caracterizado pela presença de maciços montanhosos que podem ultrapassar 2000m de altitude e condições de temperatura e umidade que proporcionam a ocorrência de ecossistemas singulares, como os campos rupestres, as matas estacionais deciduais e as semi-deciduais montanas. Ambientes de altas elevações (>700m), montanhosos e acidentados, como os encontrados no PESP, propiciam barreiras à dispersão de diversos grupos filogenéticos (Naniwadekar & Vasudevan 2007), apresentando localmente condições climáticas e geográficas que, refletidas na vegetação, justificam a presença de espécies singulares. O presente trabalho é o primeiro a investigar as relações entre a composição da comunidade de anuros e a estrutura do hábitat para a Ecorregião “Complexo da Chapada Diamantina”.

Diante da insuficiência de dados para o domínio das caatingas e do crescente consenso sobre o declínio nas populações de anfíbios no mundo (Crump et al. 1992; Marsh 2001; Funk & Mills 2003; Beebee & Griffiths 2005), há uma clara necessidade de estudos que além de descreverem a diversidade de espécies de ambientes desconhecidos para a ciência, procurem estabelecer as relações que estruturam estas comunidades bióticas. Os resultados obtidos nestes estudos podem subsidiar ações de manejo a serem adotadas por gestores ambientais e dar suporte a estratégias regionais de conservação em áreas prioritárias do bioma Caatinga, especialmente em regiões onde a disponibilidade de dados sobre diversidade e distribuição é incipiente.

A presente pesquisa tem como objetivos (1) determinar a composição e a distribuição espacial de uma comunidade de anuros em área montanhosa coberta por campos rupestres e florestas decíduas e semi-decíduas no domínio das caatingas e (2) buscar por variáveis ambientais que sejam capazes de explicar o padrão de distribuição espacial desta comunidade.

II MANUSCRITO PARA APRECIAÇÃO

Este capítulo apresenta o manuscrito intitulado **“Influência de fatores ambientais na distribuição espacial de uma comunidade de anuros em área de altitude no domínio das caatingas”**, que se destina à submissão para publicação no periódico científico BIODIVERSITY AND CONSERVATION. Os resultados aqui discorridos, assim como a discussão e conclusões derivadas, decorrem do desenvolvimento da presente dissertação. Os critérios de redação e formatação seguem as normas deste periódico, as quais se encontram disponíveis na integra no ANEXO desta dissertação.

Running head: **Environmental Variables vs. Anurans Composition**

Influence of environmental variables to the spatial distribution of an anuran community in a exception area within the Caatinga Domain

Ariane Lima Xavier · Marcelo F. Napoli

Ariane Lima Xavier
Programa de Pós-Graduação em Ecologia e Biomonitoramento, Instituto de Biologia, Universidade Federal da Bahia, Rua Barão de Geremoabo 147, Campus Universitário de Ondina, 40170-290 Salvador, Bahia, Brazil
Phone: +55 71 3283-6562, Fax: +55 71 3283-6511, e-mail: arianelx@yahoo.com.br

Marcelo F. Napoli
Museu de Zoologia, Departamento de Zoologia, Instituto de Biologia, Universidade Federal da Bahia, Rua Barão de Geremoabo 147, Campus Universitário de Ondina, 40170-290 Salvador, Bahia, Brazil
Phone: +55 71 3283-6562, Fax: +55 71 3283-6511, e-mail: napoli@ufba.br

Abstract The present study searched for associations between an anuran community composition and environment variables to test which variable would better explain spatial patterns of anurans within a mountain environment covered by semidecidual forests and rocky mountain fields. The study area was a State Park in the Municipality of Miguel Calmon, Bahia State, Brazil, an area comprised in the Caatinga Morphoclimatic Domain. We sampled 20 plots by active method during two rainy seasons, and measured 13 environment variables. The environment matrix was reduced to four synthetic axes by the principal component analysis (PCA), and anuran community (abundance matrix) was reduced to a single synthetic axis by the nonmetric multidimensional scaling method (NMS). We tested the absence of association between environment axes (PCA) and community composition (NMS axis) by multiple regression analysis. The PC1 (40%) was the only axis significantly associated to anuran composition, in which variables with major contributions were directly related to the vegetation structure. The anuran community was ordered along an environment gradient, from open areas featured by rocky mountain fields ("Campo Rupestre") to primary semidecidual mountain forest patches. Anuran composition in Sete Passagens State Park is very distinct from those in Caatinga, which denotes the importance in considering both phytophysiognomies to create protection areas in the Brazilian semi-arid.

Keywords Anuran community structure · Brazilian semi-arid · Campo Rupestre · Chapada Diamantina · Habitat gradient · Landscape context · Semideciduous forest

Abreviations

PESP	Sete Passagens State Park
SU	Sample Unit
NMS	Nonmetric Multidimensional Scaling
PCA	Principals Components Analysis

Introduction

The identification of factors that regulate spatial distribution patterns and abundance of species is an important step to realize the processes that determine the communities' biologic diversity (Magurran 1988; Norton 1991; Underwood et al. 2000). Such patterns come from different processes, reflecting specific requirements of habitats (Pianka 1973; Sredl 1992), resources distribution (Duellmann 1990; Mesquita et al. 2006), and extension of the social interactions (Connell 1980; Eterovick 2003).

Regardless of the importance on conduct researches to find the structural processes that shape the biotic communities, descriptive approaches still represent a huge part of the effort in research works on anurans in Brazil (e.g. Feio and Ferreira 2005; Santos et al. 2005; Uetanabaro 2007). Several studies related community structure to environmental variables and indicated associations with temperature (e.g. Bertoluci 1998), rainfall (e.g. Bernarde and Kokubum 1999; Rossa-Feres et al. 1999; Bernarde 2007), or both (e.g. Pombal Jr. 1997; Conte and Machado 2005; Zina et al. 2007).

However, these studies did not provide general explanations for the organization patterns found at anuran communities. In Brazil, only few studies on these communities searched for relationships between patterns of species distribution and environmental variables (e.g. Giaretta 1999; Bastazini et al. 2007; Afonso and Eterovick 2007). Such studies were carried out mainly to the Atlantic Forest Biome and studies focusing on anuran communities in the Brazilian semi-arid are still rare (e.g. Arzabe et al. 1998).

The Caatinga Morphoclimatic Domain (see Ab'Sáber 1977 for definition of Morphoclimatic Domain), comprised within the Brazilian semi-arid, is highlighted as the most unknown area regarding its taxa composition, turning more difficult the development of ecological studies. The exception zones distributed within this domain (see Ab'Sáber 2003 for definition of exception zones) are known as areas of extremely high relevance for conservation due to their singular physiographic features, climate, and association with endemic, threatened, and/or new species. Up till now, there are no studies conducted in a landscape of the ecoregion Chapada Diamantina Complex (see Velloso et al. 2002 for definition of the ecoregions from Brazilian Caatinga), an exception area, focusing on the landscape context of spatial distribution of anuran communities.

Ecological investigations on spatial distribution of anurans, and the understanding of how environmental variables influence the anuran community allows to know of main ecological demands for the species survival. In this scope, the results obtained here can help finding management actions, and to support regional strategies of conservation in priority areas of the Caatinga biome, especially in regions where there is a poor availability of data about diversity and distribution.

The aims of the present research are: (1) to analyze the composition and spatial distribution of an anuran community in an exception area known as “Campo Rupestre” (a rocky mountain area, characterized by stony fields and Deciduous and Semideciduous Forests) in the Caatinga Morphoclimatic Domain, and (2) to search for environmental variables able to explain the spatial distribution pattern of this community.

Material and methods

Study area

The present study was carried out at the Sete Passagens State Park (Parque Estadual das Sete Passagens – PESP; 11°26'S, 40°33'W), in the Municipality of Miguel Calmon, State of Bahia, Brazil (Fig. 1). This park is placed in the ecoregion Chapada Diamantina Complex (Velloso et al. 2002), comprised in the Caatinga Morphoclimatic Domain (Ab’Sáber 1977), the latter with vegetation morphologically and physiologically adapted to semiarid conditions. At the PESP, elevations ranged from approximately 800 m to 1300 m, with an estimated area of 2821 ha, being part of the residual group of mountains named Serra de Jacobina, a regional designation of the northern portion of the Serra do Espinhaço mountain range (see Davis et al. 1997 for characterization of the Serra do Espinhaço mountain range). The topography is represented by a sequence of edges and aligned bars, with deep kerfs, steep cliffs, short flat peaks, and canyons. This topography is classified as extremely unstable with medium slopes ranging from 30^{o} to 45^{o}, excepting for the tops. Almost all rivers surrounding the Park have their headsprings inside its boundaries. In accordance to Köppen classification, the weather is of the BSwh type, semi-arid, rainy in summer and dry in winter. The rainy period is from October to April, and the rainiest months are November to January. Due to the complex geomorphology and its elevated altitudes, PESP temperature reaches less than 14^{o} C in winter, establishing a difference with its surroundings, where the minimum temperature recorded is 20^{o} C. Such characteristics are reflected in the plant cover, composed by seasonal Semideciduous Forests and mountains immersed in a matrix of Campo Rupestre (the same of Campos Rupestres Montane Savanna of WWF 2008; see also Rizzini 1979 for the characterization of the Brazilian Campo Rupestre), which contrast with lowland areas (up to ca. 500 m de altitude) surrounding the Park that present shallow soils covered by a typical Caatinga landscape (see Ab'Sáber 2003 for the characterization of the Caatinga landscape).

Sampling methods

The sample design followed Bastazini et. al. (2007). We distributed 20 sample units (SUs) (plots: P1–P20), measuring 60 x 25 m each, within the overall landscape of the PESP, composed by areas of Campo Rupestre and patches of seasonal Semideciduous Forests (Fig. 1). The sample units were placed along existing trails, as the extremely hilly topography led to access difficulties, mainly at night, preventing the equivalence between the amount of plots distributed in forest patches and areas of Campo Rupestre. Yet, as plots were placed with a minimum arbitrary distance of 300 m to avoid violation of the premise of plots independence, the available sampling area for each main phytophysiognomy was reduced. To control for sampling biases in searching for relationships among SUs, we categorized each plot by its main microhabitat features only after statistical analyses.

We sampled SUs in two periods of consecutive rainy seasons, as follows: 10 SUs from 18–22 November 2006 (P1–P10), and 10 SUs from 16–20 January 2007 (P11–P20). Each sampling period lasted for five days. To control for temporal biases in the characterization of the main landscape units (forested areas vs. rocky open areas), in each sampling occasion we distributed 40% of the SUs in open areas and 60% in forested areas. Therefore, environmental temporal variation will affect the sampling of the two main physiognomies similarly, and habitat or microhabitat effects will not be confused with time variation. We looked for anurans in each SU during 40 min a day, after the 1800 h, totalling 6 h and 40 min of active search per day (total effort of 66 h and 40 min considering all SUs and both sampling periods). We covered the SUs with homogeneous effort with a team of three pairs of researches, which were not changed during the study. These pairs of observers and the sequence of visitations to SUs were changed randomly during the sampling period.

We measured 13 environmental variables in each SU. (1) Air moisture and (2) air temperature, both measured every night in each SU before the 40 minutes of active search, using a thermo-hygrometer Minipa MT 242. (3) Estimated percentage of water cover in the SU. (4) Type of water body in the SU: we calculated the average velocity achieved by a matchstick (0.082 g and 3.5 cm long) through 1 m of water course for three consecutive times, and then the arithmetic mean; the same matchstick and chronometer were used for this measurement in all SUs with water bodies. (5)

Maximum depth and (6) width of the water body. (7) Number of terrestrial and (8) epiphytic bromeliads. The next five environmental variables were taken from 10 points chosen at random in the SU, following a point map used for all SUs (Fig. 2); points were not changed during the study. A circle of 3 m diameter was drawn around each point, and the following variables were measured. (9) Soil moisture: 10 soil samples were taken from the SU, one per point; samples were mixed and sealed in a plastic bag. Moisture was measured by the “Moisture at 65° C” analysis (Embrapa 1997). (10) Percentage of leaf litter and (11) percentage of understory, shrub, and herb layers (covering of forest layers between canopy and litter layers); ordinal variables ranging from 0 to 4: 0 (0%), 1 (1–25%), 2 (25–50%), 3 (50–75%), and 4 (75–100%). (12) Canopy height, ordinal variable, ranging from 0 to 4: 1 (1–5 m), 2 (5–10 m), 3 (10–15 m), and 4 (>15 m). (13) Density of trees (point-quarter method; Krebs 1999).

In order to search for differences in anuran composition and species richness between the Sete Passagens State Park ─ PESP (an exception area) and the nearby Caatinga landscapes (xeric plant cover), we surveyed for anurans within adjacent and contiguous areas in the Municipality of Miguel Calmon, Bahia State, in 09–11 October 2006 and 17–19 February 2007. In addition, we obtained data on a collection of anurans from another contiguous area to PESP, with the same plant cover type (Municipality of Jacobina, Itaitu, 11°19'S, 40°28'W; ca. 570 m altitude, 18–20 April 2003, by M. F. Napoli), deposited in the Amphibians’ Collection of the Museu de Zoologia da Universidade Federal da Bahia (UFBA).

The specimens captured were deposited in the Amphibians’ Collection of the Museu de Zoologia da Universidade Federal da Bahia (UFBA). Names of the taxa followed

Faivovich et al. (2005), Frost et al. (2006), Grant et al. (2006), Chaparro et al. (2007), and Hedges et al. (2008).

Data analyses

For the purpose of analysis, we considered only SUs with the presence of anurans (*n* = 16; P7–P9 and P19 were discarded). We produced four data matrices: (A) a matrix of 16 SUs (plots) vs. 15 anuran species (attributes), representing the dependent variable of the study, namely community composition. We used the ‘‘concrete community’’ concept of McCune and Grace (2002), which is characterized as the collection of organisms found at a specific place and time. In the matrix, each cell corresponded to the number of specimens of the species in the SU. (B) A matrix with relative abundances, calculated from the matrix A by dividing each cell by the line sum to reduce differences in weight of sample units in analyses. (C) A second matrix of relative abundances, calculated from the matrix A by dividing each cell by the column sum to reduce differences in weight of species in the analysis. (D) A matrix with 16 SUs vs. 13 environmental variables, representing the independent variable in the analysis. We considered the relative number of specimens collected per species as an adequate comparative index of plot composition, since the sample effort was the same in the sample units.

We used the Nonmetric Multidimensional Scaling method (NMS), an ordination technique, to seek and display the strongest anuran community structure using only the anuran species data set (matrix B) (McCune and Grace 2002). We selected only one dimension (ordination axis) to the NMS solution, and used the Bray-Curtis distance measure. To avoid the local minima problem, we made 50 starting configurations, using as stability criteria the instability value of 0.0005, 20 iterations to evaluate the stability of the solution, and 500 as the maximum number of iterations. The Monte Carlo test (a randomization test) was used to evaluate whether the NMS extracted a stronger axis than expected by chance (500 iterations for the randomized results). The proportion of variance represented by the NMS axis, based on the correlation between distance in the ordination space (Euclidian distance) and distance in the original space (Sorensen distance), was obtained by a standardized Mantel test (r). We removed *Ischnocnema* aff. *ramagii* from the analysis because this species turned the test unfeasible (its inclusion led to a high final stress in the NMS solution). This taxon was represented in all 16 SUs considered for the analysis, showing a high abundance in forested areas, as well as in Campo Rupestre. As the final stress of the NMS ordination depends on the quantity of objects used (plots) and variables (species), very abundant species regularly distributed within almost all replicas can influence the quality of ordination and, therefore, the final stress. We followed McCune and Grace (2002) in removing this taxon from the analysis, as the removal of species occurring in more than half SUs leads to a lower final stress. The quality of the indirect ordination of the anuran community obtained from the NMS solution was represented in a composite graph (Fig. 3), using projections of the relative abundances of each species vs. the NMS axis (plots) (matrix C).

The null hypothesis of absence of association between the community composition (NMS axis) and the spatial distribution of SUs was tested by the Spatial Autocorrelation Analysis (Sokal and Oden 1978). A spatial correlogram was constructed using Moran’s I coefficients in four distance classes, whose upper bound limits (in km) were: 1.3, 2.1, 3.1, and 6.4. These limits were chosen irregularly, but in a way that each distance class contained approximately the same number of distance pairs of SUs. For each distance class we computed a correlation coefficient, and the statistical significance of the overall correlogram was tested by the Bonferroni criterion, in which a correlogram is considered significant if at least one of its Moran's I is significant at $P \leq 0.05/k$, where "k" is the number of distance classes. Significant and positive Moran's I coefficients indicate that plots a given distance apart are similar for the variable under analysis (NMS axis: community composition), while significant and negative Moran's I values indicate dissimilar plots for that variable at this distance (Diniz-Filho et al. 2000). The result of the spatial autocorrelation analysis was graphically represented by a spatial correlogram, where the values of the Moran's I coefficient were plotted vs. a horizontal axis representing the geographical distance classes among SUs.

We used the Principals Components Analysis (PCA) to reduce the environmental data set (matrix D) to a smaller number of orthogonal synthetic variables that represent most of the original information. The principal components were obtained from a correlation matrix, and those with eigenvalues ≥ 1 were rotated to a new Varimax solution (McCune and Grace 2002).

The null hypothesis of absence of association between the environmental data set (principal components) and the anuran community composition (NMS axis) was tested by multiple regression analysis. The significance value adopted was of $P \leq 0.05$. In cases with multiple comparisons, working with the same set of data, the P critic value was corrected by the Bonferroni method (Bland 2004).

Results

Composition and Structure of the Anuran Community

We sampled in the PESP 567 anurans belonging to 5 families, 9 genera, and 15 species. The family with the highest amount of specimens was Hylidae, followed by Brachycephalidae. The five most abundant species were *Ischnocnema* aff. *ramagii* (44.8%), *Ischnocnema* sp. (16.6%), *Bokermannohyla oxente* (14.5%), *Scinax* sp. (6.3%), and *Proceratophrys* aff. *cristiceps* (4.4%), corresponding together to 86.6% of the total sampled individuals. Out of nine SUs located at Campo Rupestre, only five presented anurans, which were distributed within six species (40% of the species in PESP). Anurans occurred in all forested SUs. *Scinax pachycrus* was the only species not found in forested areas, and *Bokermannohyla* cf. *circumdata*, *Proceratophrys* aff. *cristiceps*, *Rhinella crucifer*, *Scinax eurydice*, *S.* aff. *catharinae*, and *Trachycephalus* aff. *mesophaeus* were restricted to forested areas. *Bokermannohyla oxente*, *Scinax* sp., and *Ischnocnema* sp. were the most widespread species in PESP, the former two mainly associated to forested environments, while the latter to Campo Rupestre.

Comparisons of species richness and composition of anurans between the PESP and adjacent areas covered by Caatinga vegetation evidenced very distinctive anuran communities (Table 1). The only species in common were *S. pachycrus*, *Hypsiboas crepitans*, *H. faber*, and *Phyllomedusa bahiana*, all usually related to forest borders and/or open habitats with lentic water bodies.

The NMS axis was able to express structure in the anuran community of the PESP (Fig. 3). Although stress associated with NMS axis was high (24.5), it is not implied that the obtained stress leads to a low level of interpretation. According to McCune and Grace (2002), an increase in sample units leads to a rise in stress (>15%), which does not interfere with the results interpretation. The variance represented by the NMS axis explained 68% of the variance in the original multidimensional space (Mantel test: r = 0.81, $P \leq 0.001$). The Monte Carlo test resulted in a probability of 0.02, indicating that the NMS extracted a stronger axis than expected by chance. The NMS axis ordered the anuran community through an environmental gradient that reflects six main landscape categories. Category 1 (P20): Campo Rupestre, mostly (80%) an open area, marked by sparse treelets and shrubs with thick bark, and also with a patch of Deciduous Forest (20%), with shallow ground and a narrow and deep water well. Category 2 (P10, P16, P17, and P18): similar to the former category, but without water bodies on the ground. *Scinax pachycrus* was exclusive to the former two categories, in which *Ischnocnema* sp. reached its highest abundance values. Category 3 (P6 and P13): hybrid areas, characterized by mixing features of open areas (herbaceous vegetation and bare rocks) and riparian forests, not dense, with understory layer and water bodies on the ground. *Hypsiboas crepitans*, *H. faber*, *Scinax* sp., *Phyllomedusa bahiana*, and *Proceratophrys* aff. *cristiceps* were associated to this landscape category, often captured inside forested areas, but also in forest edges and open areas. The forest cover of categories 3 and 4 (see below) suffered different degrees of deforestation by human activities in the last 20 years, and is at present in an initial stage of natural forest recovery. Category 4 (P3 and P4): forest areas without water bodies on the ground, with many epiphytic bromeliads, herbaceous vegetation, and bryophytes. *Strabomantis aramunha* was restricted to plots of this landscape category, but also captured from open areas external to the sampled plots in cavities under rocks on the side of a stream. Categories 5 (P1, P5, P14, P15, and P11) and 6 (P2 and P12): include the largest forest patches in the PESP covered by dense vegetation. These areas are somewhat inaccessible for human activities due to their long trails in hard topographies, which are represented by a sequence of edges and aligned bars, with deep kerfs, steep cliffs, short flat peaks, and canyons. Category 5 differs from category 6 by the presence of water bodies on the ground, absent in the latter. *Bokermannohyla* cf. c*ircumdata*, *Rhinella crucifer*, and *Scinax* aff. *catharinae* were restricted to these latter two categories.

Environmental Variables

The PCA applied to 13 environmental variables generated four principal components with eigenvalues larger than 1.0 (Table 2). They represented 84.7% of the entire variance after the varimax solution. The first principal component accounted for 40.0% of the total variance, and presented high loadings (≥ 0.7) on variables related to the vegetation structure; in decreasing order: (1) percentage of leaf litter, (2) density of trees, and (3) canopy height; (4) soil moisture (loadings =0.68). In the second axis (19.5%), the variables that mostly contributed were associated to water bodies on the ground, as follows: (1) maximum width of the water body, (2) maximum depth of the water body, (3) estimated percentage of water cover in the SU, and (4) type of body of water in the SU. In the third axis (14.8%), out of three most important variables, two were related to atmospheric features: (1) air temperature, (2) air moisture, and (3) number of epiphytic bromeliads. The fourth axis (9.6%) was strongly and positively related to the number of terrestrial bromeliads.

The projection of PC1 on PC2 discriminated three groups of SUs (Fig. 4): (1) SUs with water bodies on the ground (P1, P5, P6, P11, P13–P15, P20); (2) SUs without water bodies on the ground in open areas (P10, P16–P18); and (3) SUs without water bodies on the ground in forested or transitional areas (P2–P4, P12). Within areas without water bodies on the ground, the ordination of SUs followed a plant cover gradient throughout PC1, with moderately forested SUs (P3 and P4) placed between non forested (P10, P16–P18) and forested plots (P2 and P12). A similar plant cover gradient was observed for SUs with water bodies on the ground: .(1) open areas: 80% of the SU covered by a matrix of Campo Rupestre (P20); (2) transitional areas: riparian forest (55% of the SU) along with a matrix of Campo Rupestre (45% of the SU), the latter covered by herbaceous vegetation (P13) or by rocks and bromeliads (P6), being that P13 with greater forest layering than P6; (3) forested areas (P1, P5, P11, P14–A15): with the highest density of trees, diameter at breast height reaching 40 cm, and canopy reaching 15 m high

Anuran Community vs. Environmental Variables

We tested the null hypothesis of association absence between the environmental data set (independent variables: principal components with eigenvalues ≥1.0) and anuran community composition (dependent variable: NMS axis) using a multiple regression analysis, which was strongly significant ($P < 0.0001$). However, out of four possible partial regressions, only PC1 vs. the NMS axis was significant ($P < 0.0004$, Bonferroni corrected). The other three partial plots showed no regression pattern. The partial regression plot of PC1 on the NMS axis (Fig. 5) accounted for 82% of the variation and reflected an environmental gradient, that is, from open areas of Campo Rupestre to forest environments. Considering only the forested areas, there is a environmental gradient from hybrid areas (P6, P13) to full forested areas (P1–P5, P11–P12, P14–P15), determined by gradual increase of leaf litter, density of trees, and canopy height, and gradual decrease of understory, shrub, and herb layers.

The distribution pattern of the anuran community (NMS axis) was not related to the spatial distribution of SUs, as none of the four Moran’s I coefficients calculated for the dataset (community composition; 1 variable vs. 4 distance classes) were significant at the 5% level or less, as well as the overall correlogram ($P > 0.15$), and therefore not rejecting the null hypothesis of absence of spatial autocorrelation among the SUs.

Discussion

Habitat Structure and Composition of the Anuran Community

The variables that markedly related to the spatial distribution of anuran species in the Sete Passagens State Park were primary associated to the vegetation structure, describing an environmental gradient from open areas of Campo Rupestre to forested areas. Forest patches presented greater species richness than those with direct sunlight, probably due to the structural complexity granted by forests, which provide more predictable (Colwell 1974), complex (Putman 1994), and heterogeneous habitats than shrubby environments (see Tews 2004 for a brief review on the relation between species diversity and habitat heterogeneity).

Similar results were found by other studies that searched for environmental variables to explain richness, diversity or species composition in anuran communities (e.g. Parris and McCarthy 1999; Atauri and Lucio 2001; Vallan 2002; Bastazini et al. 2007). On the other hand, Vasconcelos and Rossa-Feres (2005), studying an anuran community from an anthropized area originally covered by seasonal forests in the State of São Paulo, Brazil, did not find association of anuran species richness with habitat heterogeneity, but found with air temperature and air moisture; Santos et al. (2007), analysing a similar area of Vasconcelos and Rossa-Feres (2005), stated that the hydroperiod was the environmental variable that better explained the anuran species richness. Nevertheless, these estudies were done in highly anthropized habitats, i.e. small secondary forest patches surrounded by pastures. Moreover, the environmental variables used to describe the habitat heterogeneity were associated only to water bodies on the ground, as inner vegetation, marginal vegetation, and vegetation surrounding water bodies, clearly denoting the lack of complex forest stratification (e.g. litter, herb, shrub, understory, and canopy layers).

In the Campo Rupestre almost all anurans were captured in terrestrial bromeliads. Bromeliads are considered in the literature important ecological units, as they provide moisture, shelter, and breeding sites, mainly in environments with high air temperatures, low soil and air moistures, and absence of water bodies on the ground (Dejean and Olmsted 1997; Richardson 1999; Shineider and Teixeira 2001; Teixeira et al. 2002).

However, terrestrial bromeliads were not able to explain the anurans spatial distribution in the studied area. This result could be due to the homogeneous distribution of these plants along the SUs, without leading to a gradient or a clear cut distribution pattern among SUs, as that encountered by Bastazini et. al. (2007). These authors studied an anuran community in a Brazilian Restinga (see Suguio and Tessler 1984 for a brief characterization of the Restinga environment), and found a clear cut pattern in the spatial distribution of terrestrial bromeliads among SUs (few terrestrial bromeliads per SU in forested areas, and more than a hundred in open areas of sand dunes habitats). For the Restinga landscape, terrestrial bromeliads were among the environmental variables that most explained the changes in anuran composition.

Most investigations on anuran communities are usually limited to water bodies on the ground, such as breeding ponds and streams (e.g. Arzabe et al. 1998; Arzabe 1999; Vasconcelos and Rossa-Feres 2005; Zina et al. 2007), mainly because water is conventionally considered the most important factor in shaping the spatial distribution of the anuran fauna. Nevertheless, this relation has been scarcely tested (e.g. Zimmerman and Bierregaard 1986; Eterovick 2003; Afonso and Eterovick 2007; Bastazini et al. 2007). In the present study, variables associated to water reservoirs on the ground (represented by PC2) were not associated to the spatial distribution of the anuran fauna. Despite of the anurans’ dependence on water bodies that function as breeding sites for many species, environments with more diversified vegetal stratification lead to low direct sunstroke, high availability of microhabitats, and wet soils with high accumulation of organic materials, which together provide environmental conditions of moisture and temperature that are sufficient to support a large variety of adult forms of anurans. The anuran spatial distribution therefore were not regulated only by the presence of water bodies, though many species need to reach them over a period of their life cycles to deposit their egg clutches, but mainly by the degree of vegetal layering of that habitat. This statement is supported by the results of Bastazini et al. (2007), in which change in plant communities was the most important environmental factor acting on the structure of an anuran community of a Restinga habitat.

Anuran Conservation

The anuran species richness of the Sete Passagens State Park (PESP) (15 species) is similar to other mountain regions in the Caatinga Domain (12–18 species; Azarbe 1999; Borges-Nojosa and Cascon 2005; Vieira 2007). On the other hand, its richness is noticeably smaller than the overall Chapada Diamantina Complex (44 species; Juncá 2005), once the latter includes a larger amount of distinct landscapes (e.g. Caatinga, Campo Rupestre, Cerrado, and Deciduous and Semideciduous Forests).

The Chapada Diamantina region is one of the five biogeographic sub-regions of endemism proposed by Galindo-Leal and Câmara (2005) for the Tropical Atlantic Forest (based on birds, primates, and butterflies). The PESP is placed in the Bahia's north-western limit of the original Tropical Atlantic Forest covering, but its anurans composition is related to a mixture of distinct phytophysiognomies. *Scinax pachycrus* and *Hypsiboas crepitans* are common species to xeric environments of the Caatinga Domain, while *Bokermannohyla* cf. *circumdata*, *Hypsiboas faber*, *Ischnocnema* aff. *ramagii*, *Phyllomedusa bahiana*, *Scinax* aff. *catharinae*, *Scinax eurydice*, and *Rhinella* *crucifer* are related to the Atlantic Forest Domain (Fig. 5). One particular record deserves to be highlighted. The record of *Bokermannohyla* cf. *circumdata* represents the northernmost limit of the *B. circumdata* species group, which is distributed mainly over mountain stream habitats in the Atlantic Tropical Forests, occurring over 350 m (Napoli and Caramaschi 2004). Species of the group are also observed inhabiting gallery forests within high elevation fields in the Caatinga, Cerrado, and Tropical Atlantic Forest domains (e.g. *B. diamantina*, *B. circumdata*, *B. feioi*, *B. ibitipoca*, *B. nanuzae*, *B. ravida*, and *B. sazimai*) (Napoli and Juncá 2006). Up till now, *B. diamantina* was the only species of the group known for the Brazilian semi-arid (type-locality Serra do Barbado, Chapada Diamantina, Bahia State). The occurrence of *B.* cf. *circumdata* at the Serra de Jacobina mountain encloses an important biogeographical and conservational value, since the presence of this taxon points to a relict of the original Atlantic Forest range, and also set the northern limits of the *B. circumdata* species group. Napoli and Juncá (2006) had already stated that the occurrence of species of the *B. circumdata* group in Cerrado and Caatinga domains is due to the presence of gallery forests, which provide, in some degree, environmental conditions similar to the Atlantic Tropical Forests from coastal Brazil, and therefore these species should not be considered as characteristic taxa of Cerrado and Caatinga biomes.

The anuran species composition of the PESP, when compared to the anuran fauna of the surrounding open area covered by xeric vegetation (Caatinga plant cover) (Table 3), places the former almost as a forest island in the Caatinga landscape (see Vanzolini 1981 for an interesting discussion of the current mesic enclaves found in northeastern Brazil). Almost all anuran species from the surrounding open area are inhabitants of permanent and temporary ponds, sometimes invading forest edges, while anurans from the PESP are usually related to forests. Five species were common to both areas, all of them related to open or transitional areas with or without lenthic environments (*B. oxente*, *Scinax pachycrus*, *Hypsiboas crepitans*, *H. faber*, and *Phyllomedusa bahiana*). *Corythomantis grenningi*, a hylid tree frog widespread in the Caatinga Domain, was only found in a patch of forested area out of the PESP limits, bordering its base, and contiguous to the surrounding xeric Caatinga plant cover. These dry forest patches are physiognomically different from the mountain forests within the PESP, but is not under protection, as usually occurs for non mountainous landscapes in the Caatinga Domain. The PESP should not be understood as an isolated unit, but instead as ecologically and historically related to the adjacent Caatinga plant cover, lowland areas, and dry forests, which points out to the importance to include these different, but contiguous, phytophysiognomies within new environmental protection areas in the Brazilian semi-arid.

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Figure Legends

Fig. 1 Distribution map of the 20 sample units within the limits of the Sete Passagens State Park (PESP), Municipality of Miguel Calmon, State of Bahia, Brazil. **(a)** South America; in gray, Brazil; in black, Bahia State; white circle, geographical position of the PESP headquarters. **(b)** Topographic map of the State of Bahia, highlighting PESP's position in the Ecoregion of the Chapada Diamantina Complex. **(c)** PESP's polygon, highlighting its vegetation, hydrography, sample units (circles), and State Park headquarters (square). The Capão Forest is a forest patch inside an open area due to natural causes or to human activities, a name commonly used for this type of physiognomy by native inhabitants of the studied area

Fig. 2 Distribution map of 10 environmental sampling points chosen at random within a hypothetical sampling unit. Five environmental variables were taken following this map: soil moisture, percentage of leaf litter, canopy height, density of trees, and percentage of understory, shrub, and herb layers

Fig. 3 Composite graph of the anuran community structure from the Sete Passagens State Park based on weighted averaging from the NMS ordination. X-axis, sample units; Y-axis, relative abundances (in percentage) of an anuran species per sample unit (matrix C). Arabic numerals represent environmental categories: 1, Campo Rupestre with water bodies on the ground; 2, Campo Rupestre without water bodies on the ground; 3, hybrid habitat (mix of forest patch with streams and open areas of Campo Rupestre); 4, forest patches without water bodies on the ground, but of elevated air moisture and high density of epiphytes and herbaceous vegetation; 5, dense forests with water bodies on the ground; 6, dense forests without water bodies on the ground. See text for a more detailed description of each category

Fig. 4 (a) Projection of individual scores resulting from the principal component analysis for 13 environmental variables of the combined 16 sample units (SUs) used in the account in the space of the first with the second axis. **(b)** Partial regression plot of the first principal component axis (PC1; environmental variables) on the nonmetric multidimensional scaling axis (NMS; anuran species composition). Regression was significant ($P < 0.0004$, Bonferroni corrected). Symbols represent types of environment: open and closed symbols, SUs without and with water bodies on the ground, respectively; asterisk, hybrid habitat (see legend of Fig. 3); circle, Campo Rupestre; square, dense forest; triangle, forest patch with many epiphytic bromeliads, herbaceous vegetation, and bryophytes

Fig. 5 Anurans from the Sete Passagens State Park. **(a)** *Bokermannohyla* cf. *circumdata*; **(b)** *B. oxente*; **(c)** *Hypsiboas crepitans*; **(d)** *H. faber*; **(e)** *Scinax eurydice*; **(f)** *S.* aff. *catharinae*; **(g)** *Scinax* sp.; **(h)** *S. pachycrus*; **(i)** *Phyllomedusa bahiana*; **(j)** *Trachycephalus* aff. *mesophaeus*; **(l)** *Strabomantis aramunha*; **(m)** *Ischnocnema* aff. *ramagii*; **(n)** *Ischnocnema* sp.; **(o)** *Proceratophrys* sp.; **(p)** *Rhinella crucifer*

Table 1 Abundances of anuran species in the Sete Passagens State Park (PESP), and within its surrounding area (xeric plant cover). Prevailing physiognomies of the PESP are ordered following PC1 ordination scores of 16 sample units used in the account, and species based on weighted averaging from NMS ordination (except for *Ischnocnema* aff. *ramagii*, which was not included in the analysis). Abundances from outside limits of the PESP are not given due to distinct sample efforts; species unique to this are alphabetically ordered. A hybrid habitat is a mix of forest patch with streams and open areas of Campo Rupestre. CAA: Caatinga plant cover; DAM, human-made barrier within a stream, the latter characterized by slow backwaters that almost seem like a lentic system; LEN, lentic environment; LFP, lowland forest patches outside the PESP limits; LOT, lotic environment, characterized by springs and streams of noticeably flowing waters; WWA, areas without water bodies on the ground. Acronyms in parentheses indicate anuran families: BR, Brachycephalidae; BU, Bufonidae; CY, Cycloramphidae; HY, Hylidae; LE, Leptodactylidae; LP, Leiuperidae; ST, Strabomantidae

Species (Family)	Surrounding area		Sete Passagens State Park						
			Campo Rupestre		Hybrid habitat		Semideciduous Forest patches		
	CAA	LFP	LEN	WWA	LOT	DAM	WWA	LOT	WWA
Sample units	—	—	P20	P10, P16–18	P6	P13	P3–4	P1, P5, P11, P14–15	P2, P12
Ischnocnema aff. *ramagii* (BR)			33	69	6	8	65	87	19
Corythomantis grenningi (HY)		●							
Dendropsophus branneri (HY)	●								
Dendropsophus minutus (HY)	●								
Dendropsophus oliveirai (HY)	●								
Leptodactylus fuscus (LE)	●								
Leptodactylus ocellatus (LE)	●								
Leptodactylus vastus(LE)	●								
Odontophrynus sp. (CY)	●								
Phyllomedusa nordestina (HY)	●								
Physalaemus aff. *kroyeri* (LP)	●								
Procerathophrys sp. (CY)	●								
Pseudopaludicola sp. (LP)	●								
Rhinella granulosa (BU)	●								

Rhinella jimi (BU)	●								
Scinax pachycrus (HY)	●			2					
Ischnocnema sp. (BR)			12	52	20	1	9	12	
Phyllomedusa bahiana (HY)	●		2			2		1	
Scinax sp. (HY)			5	10	5	15		6	
Strabomantis aramunha (BR)							2		
Hypsiboas crepitans (HY)	●					1			
Hypsiboas faber (HY)	●		1	1				1	
Proceratophrys aff. *cristiceps* (CY)					7	1	1	15	1
Trachycephalus aff. *mesophaeus* (HY)							1	3	
Bokermannohyla oxente (HY)		●	1	5	6	7	5	49	10
Scinax eurydice (HY)							1		3
Scinax aff. *catharinae* (HY)								2	
Bokermannohyla cf. *circumdata* (HY)								1	
Rhinella crucifer (BU)								1	1
Total number of species	17	2	6	6	5	7	7	11	5

Table 2 Loadings from Principal Components Analysis (after Varimax rotation) for 13 environmental variables of 16 combined sample units from the Sete Passagens State Park, Municipality of Miguel Calmon, State of Bahia, Brazil. Projection of component scores are in Fig. 4a

Environmental variables	PC1	PC2	PC3	PC4
Air temperature	0.30	0.23	–0.83	–0.06
Air moisture	0.31	–0.06	0.81	0.29
Number of epiphytic bromeliads	0.25	0.41	0.70	–0.14
Number of terrestrial bromeliads	–0.05	–0.14	0.15	0.89
Canopy height	0.80	0.22	0.14	–0.08
Density of trees	0.82	0.09	–0.28	0.01
Maximum width of the water body	0.20	0.88	0.03	–0.07
Maximum depth of the water body	–0.10	0.86	–0.25	0.16
Soil moisture	0.68	0.57	0.37	0.03
Type of water body in the SU	0.28	0.77	0.30	–0.28
Percentage of understory, shrub, and herb layers	0.65	0.21	0.01	0.67
Estimated percentage of water cover in the SU	0.25	0.84	–0.13	–0.01
Percentage of leaf litter	0.93	0.08	0.12	0.06
Eigenvalues	5.21	2.54	1.93	1.25
% Total variance	40.0	19.51	14.88	9.61

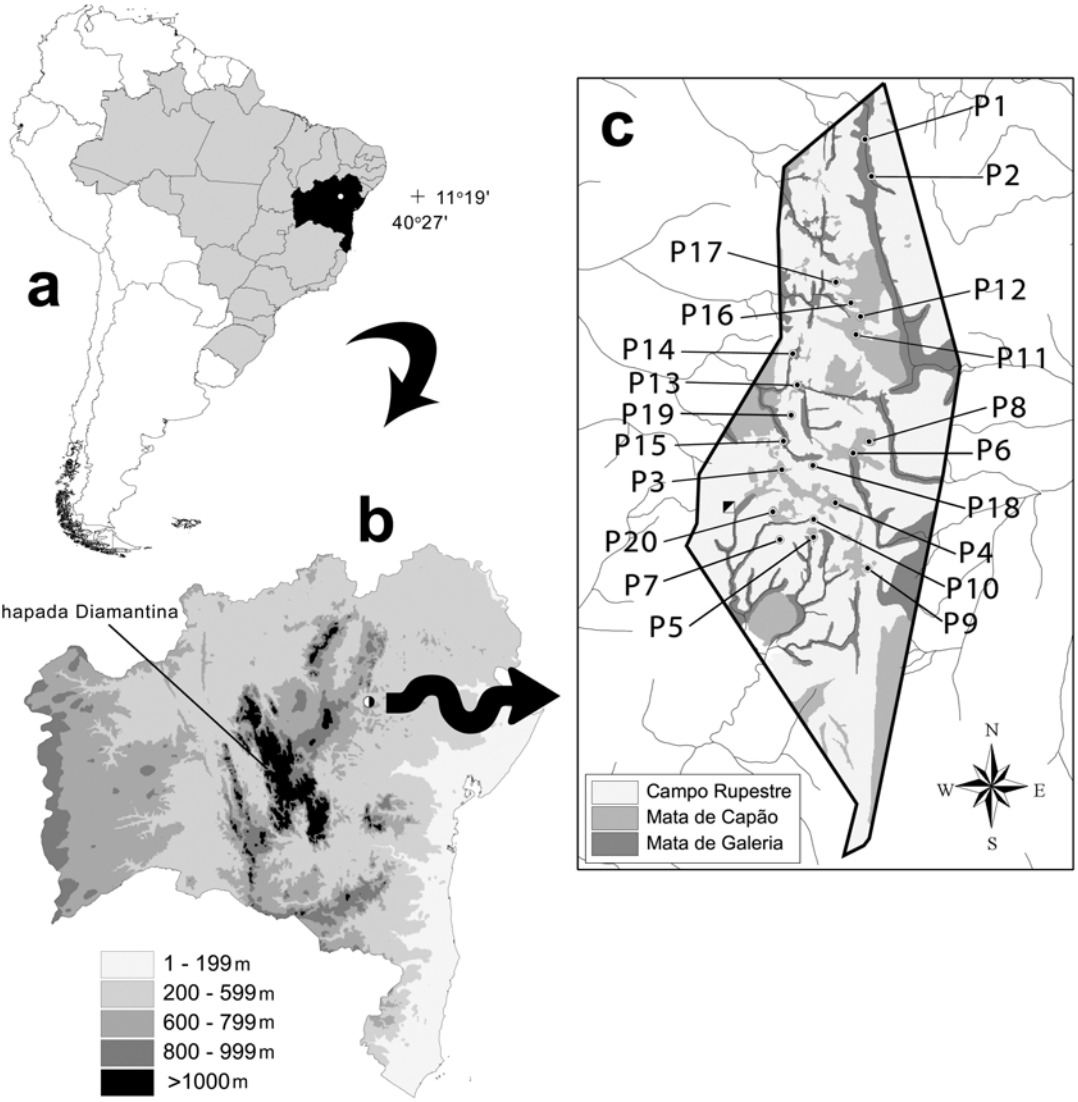
a
+ 11°19'
40°27'
b
Chapada Diamantina
1 - 199m
200 - 599m
600 - 799m
800 - 999m
>1000m
c
P1
P2
P17
P12
P16
P14
P11
P13
P8
P19
P15
P6
P3
P18
P20
P4
P7
P10
P5
P9
Campo Rupestre
Mata de Capão
Mata de Galeria
N
W
E
S

FIG. 1

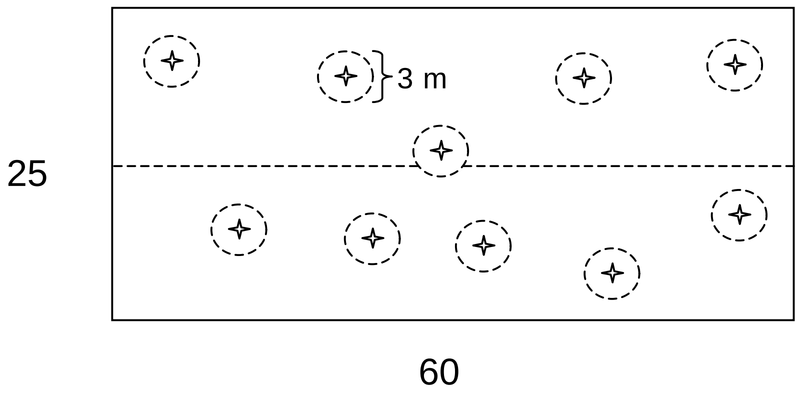

FIG. 2

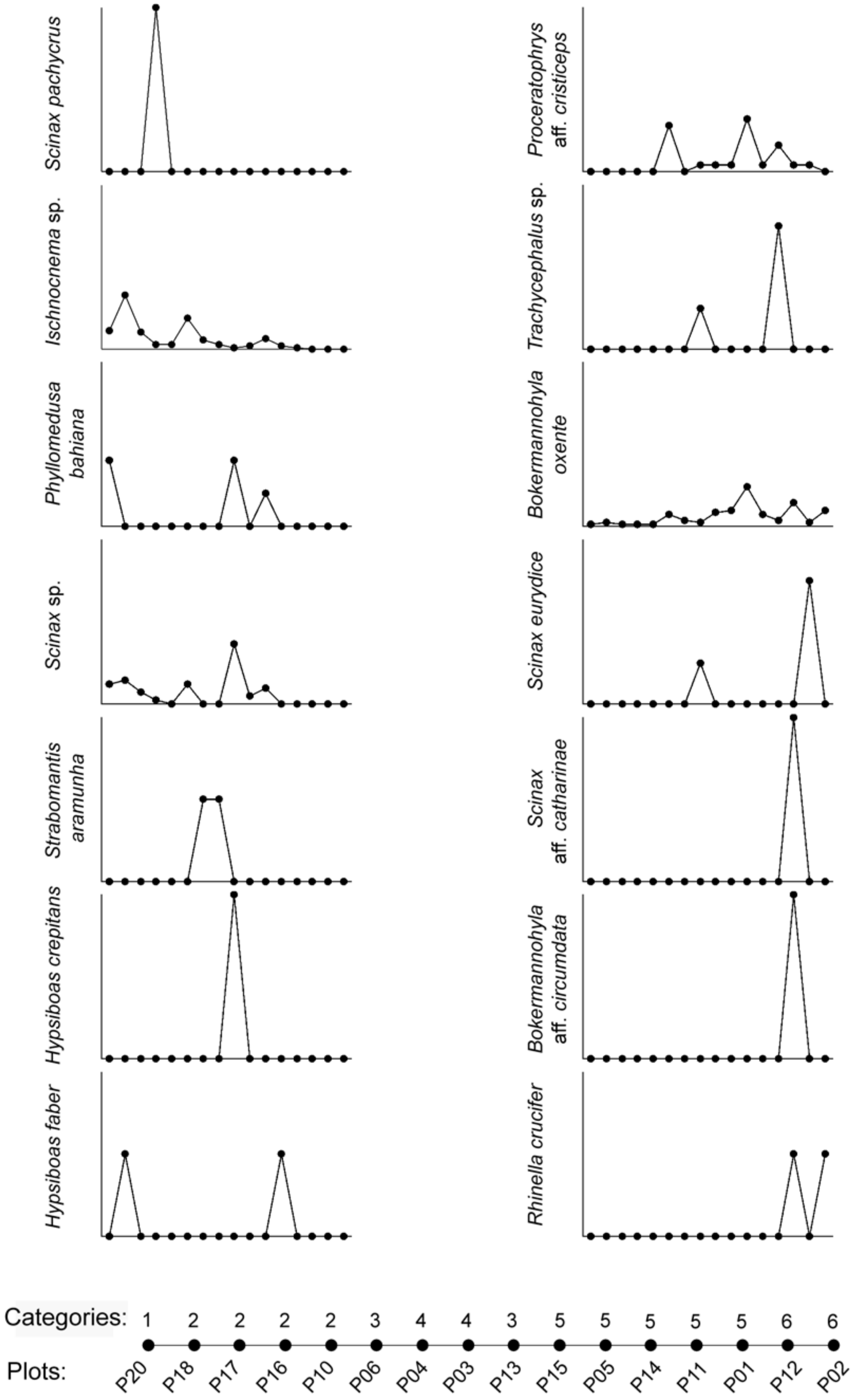
Scinax pachycrus
Ischnocnema sp.
Phyllomedusa bahiana
Scinax sp.
Strabomantis aramunha
Hypsiboas crepitans
Hypsiboas faber
Proceratophrys aff. cristiceps
Trachycephalus sp.
Bokermannohyla oxente
Scinax eurydice
Scinax aff. catharinae
Bokermannohyla aff. circumdata
Rhinella crucifer
Categories:
1
2
2
2
2
3
4
4
3
5
5
5
5
5
6
6
Plots:
P20
P18
P17
P16
P10
P06
P04
P03
P13
P15
P05
P14
P11
P01
P12
P02

FIG. 3

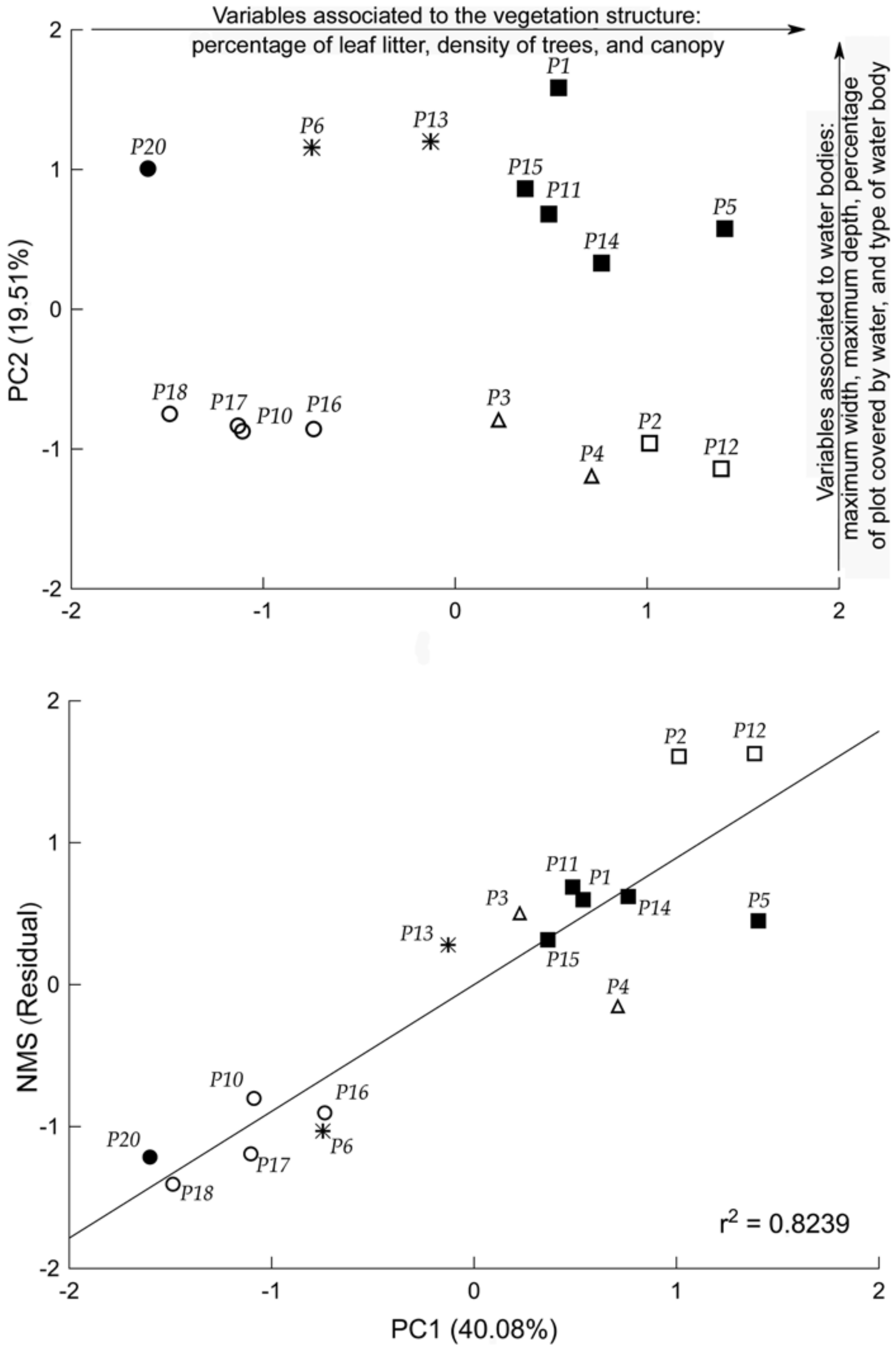
Variables associated to the vegetation structure: percentage of leaf litter, density of trees, and canopy
Variables associated to water bodies: maximum width, maximum depth, percentage of plot covered by water, and type of water body
PC2 (19.51%)
P1
P6
P13
P20
P15
P11
P5
P14
P18
P17
P10
P16
P3
P2
P12
P4
2
1
0
-1
-2
-2
-1
0
1
2
NMS (Residual)
PC1 (40.08%)
r² = 0.8239

FIG. 4

FIG. 5

III CONCLUSÃO GERAL

- Os anuros presentes no PESP refletem biogeografia complexa, apresentando espécies associadas a diferentes fitofisionomias, como caatinga, campo rupestre e floresta semi-decidual.
- A ocorrência de *Bokermannohyla* aff. *circumdata* na Serra de Jacobina agrega importante valor biogeográfico e conservacional, já que a presença deste táxon representa um relicto da distribuição original da espécie no domínio da Floresta Atlântica e o primeiro registro da espécie para o semi-árido.
- A comunidade de anfíbios anuros da área estudada revelou uma ordenação forte, apresentando uma associação de 82% com as variáveis relacionadas à estrutura da vegetação, sendo estas, em ordem crescente de contribuição: porcentagem da réplica coberta por serapilheira, altura do dossel e densidade de lenhosas. Evidenciou-se um gradiente relacionado primariamente à estrutura da vegetação: ambientes abertos – de transição – florestados. Em nosso estudo, áreas florestadas com vegetação densa (fechada), além de possuírem maior riqueza, abrigaram espécies cujas áreas de ocorrência estão relacionadas a formações do domínio Tropical Atlântico, enquanto que ambientes arbustivos como os de campo rupestre, estão geralmente relacionados a espécies generalistas e de ampla distribuição. Neste contexto, é necessário considerar durante a elaboração e execução das ações de manejo e uso do PESP, a relevância das áreas florestadas para a manutenção da sua anurofauna.

- O padrão de distribuição das espécies observado não reflete associação entre a posição geográfica das réplicas e a ordenação indireta da comunidade de anuros do PESP (eixo NMDS).
- A singularidade das espécies encontradas no PESP (matas estacionais) é percebida quando comparadas com aquelas registradas na área de entorno com formação vegetal de caatinga, havendo clara distinção entre as respectivas riqueza e composição de espécies de anuros. De interesse particular à conservação das espécies de anfíbios da Serra de Jacobina, destacamos que a manutenção das zonas protegidas pela poligonal do PESP protege apenas parte das espécies de anuros da região. As espécies que habitam áreas menos elevadas e circunjacentes ao PESP não estão sob o mesmo grau de proteção. Neste escopo, a área de entorno deve ter tratamento condizente com sua importância faunística, implicando em restrições severas a procedimentos que sejam poluidores ou que descaracterizem sua cobertura vegetal original.
- Existe uma tendência no Brasil em concentrar Unidades de Conservação em áreas montanhosas, o que é coincidente para UCs federais, estaduais e municipais de proteção integral no Estado da Bahia (MMA 2006). As regiões de baixadas, onde ocorrem extensas áreas de brejos e uma fauna com diferenças marcantes em relação às áreas de altitude, devem ser também priorizados em planejamentos para a estruturação de novas Unidades de Conservação (UCs).

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V ANEXO

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Abbreviations and their explanations should be collected in a list.

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Please use the recommended SI units.

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First-, second-, third-, and fourth-order headings should be clearly distinguishable but not numbered.

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Notes

Please use endnotes rather than footnotes. Notes should be indicated by consecutive superscript numbers in the text and listed at the end of the article before the References. A source reference note should be indicated by means of an asterisk after the title. This note should be placed at the bottom of the first page.

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In the text, a reference identified by means of an author‘s name should be followed by the date of the reference in parentheses and page number(s) where appropriate. When there are more than two authors, only the first author‘s name should be mentioned, followed by ‘et al.‘. In the event that an author cited has had two or more works published during the same year, the reference, both in the text and in the reference list, should be identified by a lower case letter like ‘a‘ and ‘b‘ after the date to distinguish the works.

Examples:

Winograd (1986, p. 204)

(Winograd 1986a, b)

(Winograd 1986; Flores et al. 1988)

(Bullen and Bennett 1990)

Acknowledgements

Acknowledgements of people, grants, funds, etc. should be placed in a separate section before the References.

References

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