ZOOLOGY AND ECOLOGY, 2017
https://doi.org/10.1080/21658005.2017.1381423

Influence of vegetation heterogeneity and landscape characteristics on anuran species composition in aquatic habitats along an urban-rural gradient in southeastern Brazil

Fabrício Hiroiuki Oda[a,b], Sidnei Gonçalves[c], Thiago Massao Oda[d], Lara Carolina Raphael Tschope[e], André Luiz Fraga Briso[f], Marcelo Rodrigues Freitas Oliveira[g], Ricardo Massato Takemoto[b] and Tiago Silveira Vasconcelos[h]

[a]Centro Universitário Cesumar, Programa de Pós-Graduação em Promoção da Saúde, Maringá, Brazil; [b]Departamento de Biologia, Universidade Estadual de Maringá, Núcleo de Pesquisas em Limnologia, Ictiologia e Aqüicultura, Laboratório de Ictioparasitologia, Maringá, Brazil; [c]S. Gonçalves Cursos, Treinamentos e Serviços ME, Araçatuba, Brazil; [d]SENAC MS – Unidade Três Lagoas, Três Lagoas, Brazil; [e]LBN Análises Laboratoriais, São Paulo, Brazil; [f]Universidade Estadual Paulista – Campus Araçatuba, Araçatuba, Brazil; [g]Departamento de Biologia, Universidade Estadual de Maringá, Programa de Pós-Graduação em Biologia Comparada, Maringá, Brazil; [h]Departamento de Ciências Biológicas, Universidade Estadual Paulista, Faculdade de Ciências de Bauru – Campus Bauru, Bauru, Brazil

ABSTRACT

Amphibians are exposed to a number of negative factors in urban areas and the influence of a specific variable can vary among different ecological systems. This study provides information on the anurofauna along an urban-rural gradient in Araçatuba, São Paulo State, Brazil. Anurans were sampled in 11 breeding habitats distributed throughout seven surveyed sites in urban, peri-urban and rural areas, during six field visits between May 2011 and January 2013. We recorded 23 species of anurans belonging to 12 genera and four families. For both urban and peri-urban regions, we recorded 11 species per area, the number of species in the rural area reaching 20. The greatest similarity in species composition found at urban and peri-urban sites showed the urbanization-induced impoverishment and homogenization of their anuran communities. In contrast, the anurofauna of the rural area was rich and diversified. Vegetation heterogeneity in breeding habitats and forest formations surrounding these water bodies was found to have a positive effect on species richness and composition and, therefore, to be an important factor affecting amphibian populations in water bodies in urban, peri-urban and rural areas.

ARTICLE HISTORY
Received 18 April 2017
Accepted 14 September 2017

KEYWORDS
Amphibians; conservation; vegetation heterogeneity; inventory; anthropic disturbance

Introduction

Brazil boasts the most diversified amphibian richness in the world (1080 species, including 1039 anurans), which is often related to the presence of extensive morphoclimatic domains formed of unique ecosystems that favour anuran diversification in different habitats, ranging from dry shrubby to moist forest habitats with high vegetation heterogeneity (Segalla et al. 2016; IUCN 2017).

Among different threats facing amphibians (Eterovick et al. 2005) and their preservation (e.g. da Silva, Gibbs, and Rossa-Feres 2011; Vasconcelos and Doro 2016) in Brazil, habitat loss and fragmentation rank as serious ones. The critical region in Brazil that has suffered most from the massive loss of native vegetation is the contact zone of two Brazilian hotspots (Mittermeier et al. 2004), i.e. the mesophytic semideciduous Atlantic Forest and Cerrado (sensu Ab'Saber 2003), located in inner areas of southeastern Brazil (see RAN/ICMBio 2014). This is the case in northwestern São Paulo State, where only 4% of the original vegetation has remained (SMA/IF 2005) in small fragments throughout pastureland, extensive sugarcane plantations, and urban areas (Rodrigues et al. 2008).

Herpetologists have widely explored mostly the northwestern region of the São Paulo State (Rossa-Feres et al. 2011), harbouring 37 of the 236 amphibian species known for the State (Rossa-Feres et al. 2011; Haddad et al. 2013). Most of these anuran species are generalist, typical of open areas and adapted to degraded environments (Vizotto 1967; Bernarde and Kokubum 1999; Vasconcelos and Rossa-Feres 2005; Santos, Rossa-Feres, and Casatti 2007; Prado et al. 2008; da Silva et al. 2009; Santos et al. 2009; da Silva, Prado, and Rossa-Feres 2010). However, new distribution records of *Pithecopus azureus* (Prado et al. 2008), *Chiasmocleis albopunctata* (da Silva et al. 2009), and *Dendropsophus melanargyreus* (da Silva, Prado, and Rossa-Feres 2010) reported over the past few years indicate the importance of continuous field work aimed to increase the knowledge of species distribution.

CONTACT Fabrício Hiroiuki Oda fabricio_oda@hotmail.com

Most ecological studies of anurans in this area were performed in agricultural areas or natural remnants of original vegetation (e.g. Vasconcelos and Rossa-Feres 2005; da Silva, Gibbs, and Rossa-Feres 2011; da Silva and Rossa-Feres 2011). However, anuran studies focusing on urban areas in a number of Brazilian regions (e.g. Ferreira, Silva-Soares, and Rödder 2010; Tonini et al. 2011), including northwestern São Paulo State are still rare. As persistence of anuran populations in urban landscapes depends on environmental conditions (Duellman and Trueb 1994), it may be affected by several environmental factors operating in a variety of spatial scales ranging from breeding habitats to entire landscapes (Pillsbury and Miller 2008). In urban areas, amphibians are exposed to a number of negative factors, such as loss, fragmentation and isolation of habitats, changes in the hydroperiod of water bodies (Hamer and McDonnell 2008). However, the influence of a specific variable can vary among ecological systems (Rubbo and Kiesecker 2005; Vasconcelos et al. 2009).

Vegetation structure is an important factor affecting anuran species composition both on regional (Parris 2004; Bastazini et al. 2007) and local scales (Vasconcelos et al. 2009; Oda et al. 2016). In addition, the urbanization process may affect the anuran species composition in the adjacent breeding habitats because of alterations/losses of forest formations (Hamer and McDonnell 2008). Thus, the objective of this study was to investigate changes in the anuran composition in response to urbanization-induced changes in vegetation structure and landscape characteristics of the study area. Since aquatic habitats in urban, peri-urban and rural areas differ in vegetation heterogeneity (e.g. number of plant types at the edge) and in the structural composition (e.g. presence or absence of forest remnants, high/low-density of urban areas) of their surrounding landscapes, we hypothesized that the anuran species composition varies depending on the vegetation heterogeneity in the breeding habitat and landscape characteristics. Specifically, we aimed at determining: (1) anuran species richness in the areas studied, (2) the relative impact of vegetation heterogeneity in breeding habitats as well as that of landscape characteristics on the anuran species composition at the surveyed sites, and (3) beta diversity along with the similarity of species composition among the sites surveyed.

Materials and methods

Study sites

The municipality of Araçatuba (−21.208889 S, −50.432778 W, 398 m. a.s.l.) is situated in northwestern São Paulo State between the Aguapeí and Tietê Rivers, both of which are tributaries of the Paraná River (Figure 1). Original vegetation in the area consists of mesophytic semideciduous Atlantic Forest and different patches of Cerrado physiognomies, including open formations (*cerrado sensu stricto*) and forest environments (*cerradão*) (SMA/IF 2005). The local climate is hot and humid with well-defined wet and dry seasons, classified as Aw according to the Köppen system (Peel, Finlayson, and McMahon 2007). The mean annual temperature is 24 °C (with the minimum average of 13 °C in June, and the maximum average of 32 °C in February), and the mean annual rainfall is 1300 mm^3 (CEPAGRI 2014).

In order to better understand the distribution of species from water bodies, we divided the study site into three areas: urban (UB), peri-urban (PB) and rural (RR). UB is characterized by high and PB by low density of houses and roads, while RR has extensive pastures, sugarcane plantations, and small remnants of mesophytic semideciduous Atlantic Forest scattered within the agricultural landscape. The seven sites surveyed in these areas are referred to as 'survey sites' (Figure 1). The delineation of each site was merely geographic, because the number, proximity and connectivity of water bodies differ among the survey sites (Figure 1, Table 1).

Anuran survey methods

We conducted six field sessions, i.e. four sessions during the breeding season (November 2011, February and October 2012, and January 2013) and two sessions during the non-breeding season (May 2011 and April 2012) (Vasconcelos and Rossa-Feres 2005; Vasconcelos et al. 2011; Santos, Vasconcelos, and Haddad 2012). The number of water bodies surveyed per area is as follows: six in UB; three in PB, and two in RR – giving a total of 11 water bodies surveyed (Table 1). We used the visual and auditory search methods to detect anuran species (Scott and Woodward 1994). Each water body was surveyed for 1 h by two researchers at night (from 7.00 to 12.00 pm) during each field session. The collected voucher specimens were subjected to the following procedures: 5% lidocaine anaesthesia, 10% formalin fixation, 70% ethanol preservation, storage at the Amphibian Collection of the Department of Zoology and Botany of the State University Paulista (UNESP), municipality of São José do Rio Preto, São Paulo State, Brazil.

Breeding habitat and landscape composition

Characteristics of breeding habitats (i.e. hydroperiod and plant types on the edge) and landscape (i.e. presence of forest remnants and urban area density [houses and roads]) were determined during the field sessions conducted in the rainy period (November 2011, February and October 2012, and January 2013), which is the breeding season of most anuran species in the region (Provete et al. 2011). Characteristics of breeding habitats and landscape were assessed visually using the following categorical variables (Table 1): The hydroperiod of breeding habitats (HP): 1 = permanent, 2 = semipermanent (decrease in water volume over 90% of the breeding pond), 3 = long temporary (lasting between 6 and 11 months), and 4 = short

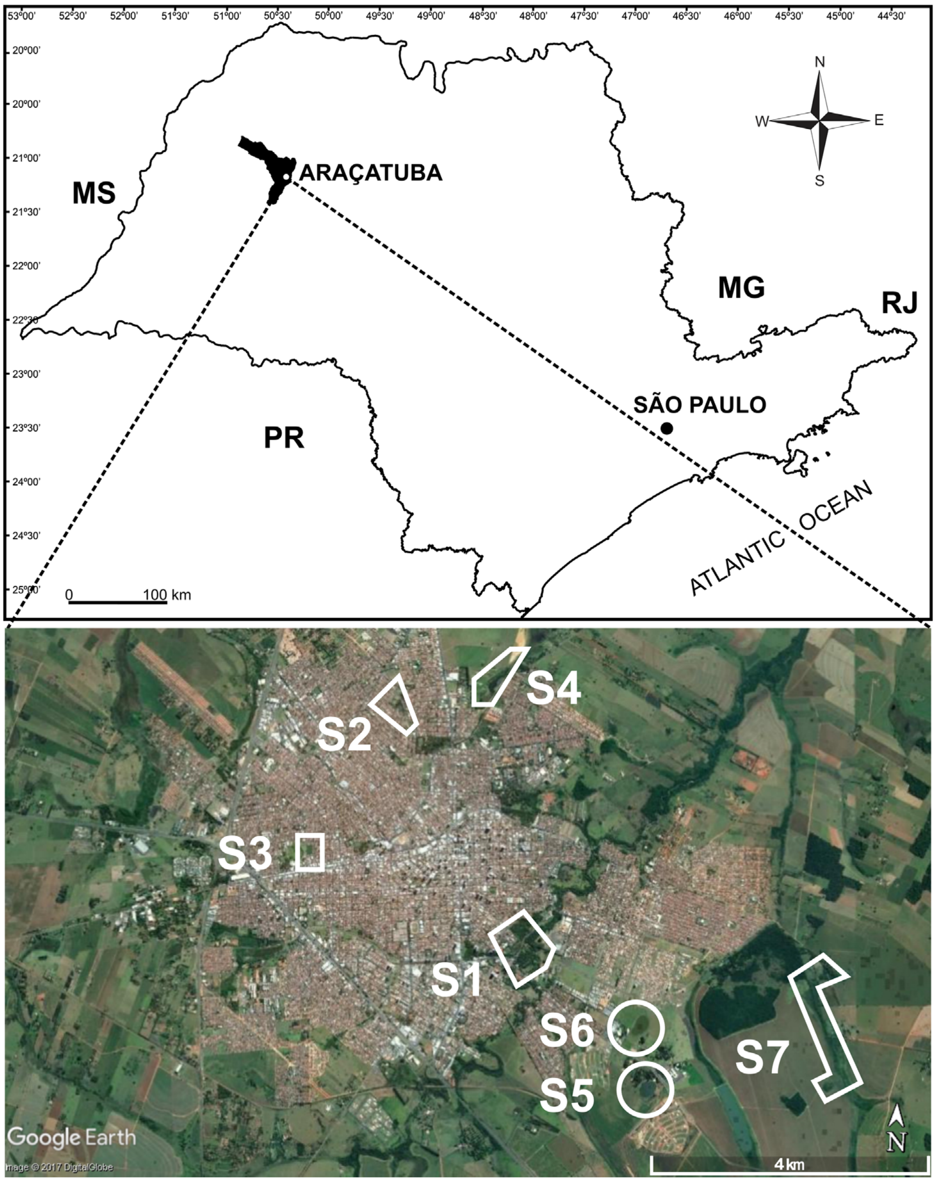

Figure 1. Distribution of the surveyed sites along the urban-rural gradient in the municipality of Araçatuba, São Paulo State, southeastern Brazil. See description of the surveyed sites in Table 1. Map modified from IGC (2014). Satellite image extracted from Google Earth (© 2016 Google/Landsat/Copernicus). See permission information at: https://www.google.com/permissions/geoguidelines/attr-guide.html

temporary (less than 6 months). Plant types (PT) at the edge: 1 = predominance of creeping herbaceous vegetation; 2 = predominance of creeping and erect herbaceous vegetation; 3 = predominance of creeping and erect herbaceous vegetation and shrubby vegetation, and 4 = presence of creeping and erect herbaceous vegetation, shrubby, and arboreal vegetation. Landscape characteristics (LC): 1 = presence of forest remnants in urban/peri-urban area; 2 = high-density of urban area; 3 = low-density of urban area, and 4 = presence of forest remnants in rural area. Both structural (i.e. hydroperiod) and biological characteristics (i.e. plant types at the edge) of the breeding habitats were classified as per Vasconcelos et al. (2009).

Data analysis

In order to assess the sampling effort, we built accumulation curves based on the presence or absence of anuran species in the breeding habitats for each surveyed site. We used the nonparametric Jackknife 1 estimator to extrapolate species richness at the study site. The species accumulation curve and the estimation of richness were generated using EstimateS v.9.1.0 (Colwell 2013).

We determined the relative impact of breeding habitat and landscape characteristics on anuran species composition at the survey sites by using a permutational multivariate analysis of variance (Permanova; Anderson 2001). Since all the aquatic habitats surveyed have a permanent hydroperiod, this descriptor was not considered in the analysis. Thus, the plant types at the edge as well as the landscape composition were included as predictor variables; response variables, in turn, were obtained from the species composition matrix. We calculated the Permanova significance using the main test with 1000 permutations of residuals under the full model. The

Table 1. Description of the surveyed sites along the urban-rural gradient in the municipality of Araçatuba, São Paulo State, south-eastern Brazil.

Surveyed site	Area	Coordinates	Breeding habitat	HP	PT	LC	Description
S1	UB	−21.219444 S −50.429444 W −21.220000 S −50.428333 W −21.220556 S −50.427778 W −21.221389 S −50.427778 W	Pedreira pond Capivaras pond Machadinho stream Baguaçú River	1	4	1	The Parque Ecológico do Baguaçú covers an area of approximately 1 km^2. It is composed of a riparian forest remnant located at the confluence of the Machadinho stream and the Baguaçú River. The ground inside the forest is partially covered with leaf litter
S2	UB	−21.187500 S −50.448056 W	Miguelão pond	1	3	2	The area surrounding the public recreational area is characterized by high-density built-up area, mainly composed of houses
S3	UB	−21.207778 S −50.460000 W	Flores pond	1	3	2	The area surrounding the rainwater pond is mainly characterized by high-density built-up area, mainly composed of houses
S4	PB	−21.183611 S −50.434722 W	UNESP pond	1	3	3	The area surrounding the pond is characterized by pasture areas, and low-density built-up area
S5	PB	−21.237222 S −50.410556 W	Chácara Ariane pond	1	3	3	The surrounding area is characterized by orchards, extensive pastures, and low-density built-up area
S6	PB	−21.229167 S −50.411667 W	Rancho Calamari pond	1	2	3	It is surrounded by extensive pastures and low-density built-up area
S7	RR	−21.228611 S −50.384444 W −21.235556 S −50.384444 W	Pond pond	1	4	4	These water bodies are located at the edge of the riparian forest in the agricultural landscape characterized by pastures and sugarcane plantations

Notes: S1 – Parque Ecológico do Baguaçú; S2 – public recreational area 'Lagoa do Miguelão'; S3 – rainwater retention pond 'Lagoa das Flores'; S4 – pond supplying water to domestic animals 'Lagoa da UNESP'; S5 – private recreational area 'Chácara Ariane'; S6 – private recreational area 'Rancho Calamari'; S7 – rural properties at the border between the municipalities of Araçatuba and Birigui; UB – urban area; PB – peri-urban area; RR – rural area; HP – hydroperiod; PT – plant types at the edge of breeding habitat; LC – landscape characteristic.

Permanova results revealed high values of *Pseudo-F*, indicating distinct, well-defined and separated clusters; low values indicate less defined clusters (Caliński and Harabasz 1974).

We determined beta diversity between the pairs from the surveyed sites through the Sørensen similarity index (C_s) (Sørensen 1948), which is one of the most effective presence/absence similarity measures (Southwood and Henderson 2000) and is accurate when used for small samples, minimizing the effect of sub-sampling (Soininen, McDonald, and Hillebrand 2007). The beta diversity between the pairs from the surveyed sites was considered high if $C_s < 0.50$. We proceeded with both the identification and comparison of similarity between potential clusters from the surveyed sites by using the unweighted pair group method with the arithmetic mean (UPGMA) with a similarity matrix. By using the Cophenetic Correlation Coefficient (r), we also verified to what extent the resulting graph of cluster analysis represents the original similarity matrix. The value of $r < 0.7$ represents a very poor fit, 0.7–0.8 a poor fit, 0.81–0.9 a good fit, and $r > 0.9$ a very good fit (Rohlf 2000). The multivariate analysis was performed using Primer 6.0 (Clarke and Gorley 2006) and Permanova + for Primer (Anderson, Gorley, and Clarke 2008). Both the similarity analysis and the Cophenetic Correlation Coefficient were performed using the Past version 2.17 software (Hammer, Harper, and Rian 2001).

Results

We recorded 23 anuran species belonging to 12 genera and four families. Leptodactylidae was the family with the highest number of species (n = 10 species) followed by Hylidae (n = 9), Microhylidae (n = 3), and Bufonidae (n = 1). *Pseudis platensis*, *Chiasmocleis albopunctata* and *Dermatonotus muelleri* were recorded in breeding habitats outside the surveyed sites (Table 2; Figure 2). The accumulation curve tended to stabilize and the estimated species richness for the study area was 20 species (±0), similar to the richness observed (Figure 3).

Eleven species of anurans were found both in UB and PB, while the number of species recorded in RR was 20. All surveyed sites both in UB and in PB had lower species richness than those in RR (Table 2). *Rhinella schneideri*, *Dendropsophus nanus*, *Leptodactylus fuscus*, *Leptodactylus* aff. *latrans*, *Leptodactylus podicipinus*, and *Physalaemus cuvieri* were found at most of the surveyed sites (Figure 4).

Plant types at the edge of breeding habitats (*Pseudo-F* = 42.02; p = 0.001) and landscape composition (*Pseudo-F* = 29.87; p = 0.001) were strongly correlated with the species composition among the surveyed sites, with approximately 34 and 24% of the total variation explained by these variables, respectively. Beta diversity was low in most of the pairs from the surveyed sites (n = 15), and only six pairs showed high beta diversity (Table 3). The cluster analysis revealed that by PT and LC, species composition at the surveyed sites formed two clusters (Figure 5). In the first cluster, a greater similarity was found between S05 and S04, similarity between S03 and S02 being even stronger. In the second cluster, S01 and S07 showed lower similarity. The comparison of S01 and S07 with the remaining surveyed sites (Figure 5) also revealed lower similarity.

Table 2. Anuran species recorded in breeding habitats along the urban-rural gradient in the municipality of Araçatuba, São Paulo State, southeastern Brazil.

	Urban			Peri-urban			Rural
Species	S01	S02	S03	S04	S05	S06	S07
Bufonidae							
Rhinella schneideri (Werner, 1894)	•	•	•	•	•	•	•
Hylidae							
Dendropsophus minutus (Peters, 1872)				•	•		•
Dendropsophus nanus (Boulenger, 1889)	•	•	•	•	•		•
Boana albopunctata (Spix, 1824)				•			•
Boana raniceps Cope, 1862	•			•	•		•
Pseudis platensis Gallardo, 1961*							
Scinax fuscomarginatus (A. Lutz, 1925)							•
Scinax fuscovarius (A. Lutz, 1925)	•				•		•
Scinax sp.							•
Trachycephalus typhonius (Linnaeus, 1758)	•						•
Leptodactylidae							
Leptodactylus chaquensis					•		•
Leptodactylus fuscus (Schneider, 1799)	•	•	•	•	•	•	•
Leptodactylus labyrinthicus (Spix, 1824)	•						•
Leptodactylus aff. *latrans*	•	•	•	•	•		•
Leptodactylus mystacinus (Burmeister, 1861)							•
Leptodactylus podicipinus (Cope, 1862)	•	•	•	•	•		•
Physalaemus cuvieri Fitzinger, 1826	•	•		•	•		•
Physalaemus marmoratus (Reinhardt & Lütken, 1862 '1861')							•
Physalaemus nattereri Steindachner, 1863							•
Pseudopaludicola cf. *mystacalis*	•						•
Microhylidae							
Chiasmocleis albopunctata (Boettger, 1885)*							
Dermatonotus muelleri (Boettger, 1885)*							
Elachistocleis cesarii (Miranda Ribeiro, 1920)							•
Species richness by surveyed site	11	6	5	9	10	2	20
Species richness by area		11			11		20

Note: (*) Asterisks indicate the species collected outside sampling sites.
See descriptions of the surveyed sites in Table 1.

Discussion

The anuran species richness recorded in this study accounts for 62% of the known species in the region (Provete et al. 2011). Sometimes, local richness was found to be higher than respective values in neighbouring areas (e.g. Santa Fé do Sul, 20 species; Icém, 18 species) (Santos, Rossa-Feres, and Casatti 2007; Silva, Martins, and Rossa-Feres 2011). In comparison with the values found in this study, other locations in the region (e.g. Guararapes and Nova Itapirema) show higher richness (26 and 27 species, respectively) (Bernarde and Kokubum 1999; Vasconcelos and Rossa-Feres 2005). Even though the accumulation curve provided a robust estimate of species richness in the study area, other species may be found in the region, since we did not observe the presence of *Scinax perereca*, *Scinax* aff. *similis*, *Elachistocleis bicolor*, *Pseudopaludicola* sp. (aff *falcipes* I or II; see taxonomic comments in Provete et al. 2011; Langone et al. 2015), reported by Bernarde and Kokubum (1999) in Guararapes (~23 km in a straight line from our study area), which suggests the possibility of new records in further field works using additional sampling methods and/or efforts.

Generally, low anuran species richness is more characteristic of urban areas than of rural ones, as has been reported from other Brazilian regions (Nascimento 1991; Nascimento, Miranda, and Balstaedt 1994; Ávila and Ferreira 2004). In this study, we also found more records of low species richness in urban and peri-urban areas than in rural ones, which is associated with severe impacts of habitat loss and fragmentation on these urbanized areas (Gardner, Barlow, and Peres 2007). For example, the increase in road density and distance between breeding habitats affects dynamics of the amphibian metapopulation by introducing barriers to dispersal routes (i.e. fragmentation of dispersal routes, increased distance between breeding habitats), eliminating or reducing the flow of individuals between populations (Rubbo and Kiesecker 2005). In this case, according to a previous study (Pillsbury and Miller 2008), anuran species suffer considerable impacts of the urban fragmentation of dispersal routes. In the study area, we found only six species occurring at most of the surveyed sites, which seems to indicate that these species may be more resilient to urbanization than most of the anuran community.

Vegetation structure on both local and regional scales is an important factor affecting species composition (Scheffer et al. 2006; Werner et al. 2007; Vasconcelos et al. 2009). The plant type at the edge of breeding habitats was the main predictor correlated to the species composition at the surveyed sites along the urban-rural gradient. Vegetation at the edge of water bodies plays an important role in the reproduction of anurans as it provides shelter for larvae and adults from predators, as well as for calling and oviposition sites (Vasconcelos and Rossa-Feres 2008; Vasconcelos et al. 2009; Oda et al. 2016). The landscape composition surrounding the surveyed sites was also related to species composition. At the surveyed sites surrounded by forest formations, the vegetation

Figure 2. Anuran species recorded at the surveyed sites along the urban-rural gradient in the municipality of Araçatuba, São Paulo State, southeastern Brazil. (A) *Rhinella schneideri*, (B) *Dendropsophus minutus*, (C) *Dendropsophus nanus*, (D) *Boana albopunctata*, (E) *Boana raniceps*, (F) *Pseudis platensis*, (G) *Scinax fuscomarginatus*, (H) *Scinax fuscovarius*, (I) *Trachycephalus typhonius*, (J) *Leptodactylus chaquensis*, (K) *Leptodactylus fuscus*, (L) *Leptodactylus labyrinthicus*, (M) *Leptodactylus* aff. *latrans*, (N) *Leptodactylus mystacinus*, (O) *Leptodactylus podicipinus*, (P) *Physalaemus cuvieri*, (Q) *Physalaemus marmoratus*, (R) *Physalaemus nattereri*, (S) *Pseudopaludicola* cf. *mystacalis*, (T) *Chiasmocleis albopunctata*, (U) *Dermatonotus muelleri*.

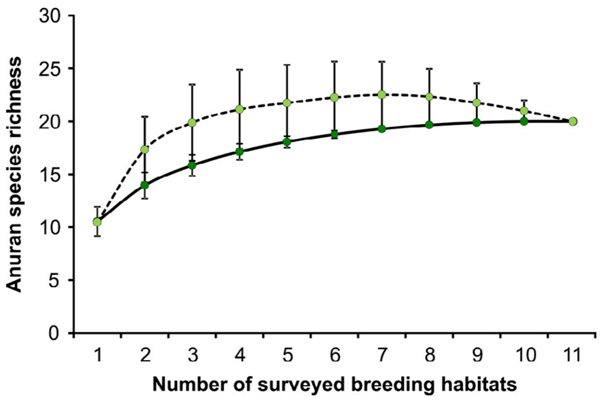

Figure 3. Comparison between the observed and estimated richness. Accumulation curves were generated from 1000 randomizations of the presence/absence records of anuran species in breeding habitats. The solid line with a dark green circle indicates observed richness; the dashed line with a light green circle indicates estimated richness.

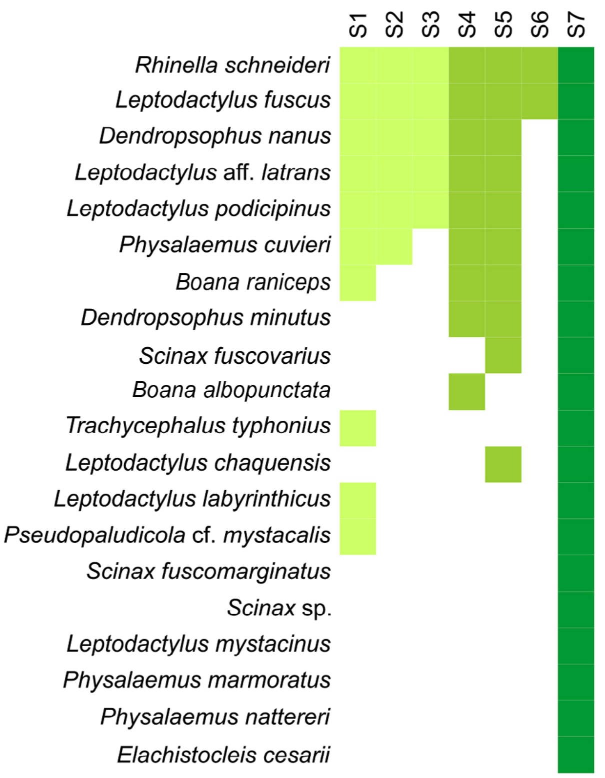

Figure 4. Distribution of anuran species at the surveyed sites along the urban-rural gradient in the municipality of Araçatuba, São Paulo State, southeastern Brazil. The light green square indicates urban surveyed sites; the medium green square peri-urban surveyed sites; the dark green square indicates rural surveyed sites.

structure creates microhabitats and provides favourable microclimatic conditions for a greater number of species exploiting the breeding habitats (Knutson et al. 1999). In this study, we found that the surveyed sites with low vegetation heterogeneity showed a lower proportion of arboreal species than sites with high vegetation heterogeneity. Such a situation was observed in S2, S3 and S6, where we found a higher proportion of terrestrial

Table 3. Similarity among the seven surveyed sites along the urban-rural gradient in the municipality of Araçatuba, São Paulo State, southeastern Brazil in the anuran species composition (Sørensen coefficient).

	S01	S02	S03	S04	S05	S06	S07
S01	*	**70.59**	**62.50**	**70**	**76.19**	30.77	**70.97**
S02	*	*	**90.91**	**80**	**75**	**50**	46.15
S03	*	*	*	**71.43**	**66.67**	**57.14**	40
S04	*	*	*	*	**84.21**	36.36	**62.07**
S05	*	*	*	*	*	33.33	**66.67**
S06	*	*	*	*	*	*	18.18
S07	*	*	*	*	*	*	*

Notes: Higher similarity and low beta diversity between pairs are highlighted in bold ($C_s \leq 50\%$). See descriptions of the surveyed sites in Table 1.

species (e.g. *Rhinella schneideri*, *Leptodactylus fuscus*, *Leptodactylus* aff. *latrans*, *L. podicipinus*, and *Physalaemus cuvieri*). At these sites, the loss of vegetation cover has a direct effect on arboreal species as it eliminates microhabitats used by these species as calling sites. Therefore, the loss of vegetation in S2, S3 and S6 probably caused the loss of arboreal species, resulting in decreased species richness and making the surveyed sites more similar to one another.

In fact, the low species richness recorded at both the urban and peri-urban sites surveyed contributed to low beta diversity in this study, as is indicated by the cluster analysis results. The cluster analysis revealed a greater similarity for pairs S3–S2 and S5–S4. In both S2 and S3, in addition to limiting factors in dispersal of amphibians, the sporadic removal of vegetation at the edge of water bodies (F. H. Oda personal communication) was found to lead to the microhabitat loss and unfavourable microclimatic conditions, which account for lower species diversity. In both S5 and S4, the factors limiting dispersal decrease and vegetation heterogeneity moderately increases (F. H. Oda personal communication), resulting in higher species diversity in comparison with that in S2 and S3. On the other hand, although S1 is located in the urban area and S7 in the rural area, the breeding habitats of these two surveyed sites are located at the edge of forest remnants, where species related to open environments and species associated with forest vegetation structure can be found (Oda et al. 2016). Thus, lower similarity between S1 and S7 results from the occurrence of *Trachycephalus typhonius* and *Pseudopaludicola* cf. *mystacalis*. Considering the fact that *Trachycephalus typhonius* is found in arboreal and in shrubby vegetation (Savage 2002; Rodrigues, Uetanabaro, and Lopes 2005) and *Pseudopaludicola* cf. *mystacalis* is found in marshy areas of ponds or in marshes with herbaceous vegetation (Pelinson, Garey, and Rossa-Feres 2016), we believe that the occurrence of these species is negatively affected by the habitat loss in both urban and peri-urban areas. This result indicates that the high beta diversity in rural surveyed sites is rather a consequence of the low species richness recorded in urban and peri-urban surveyed sites than a consequence of differences in anuran species composition, indicating that the nestedness component of beta diversity is the

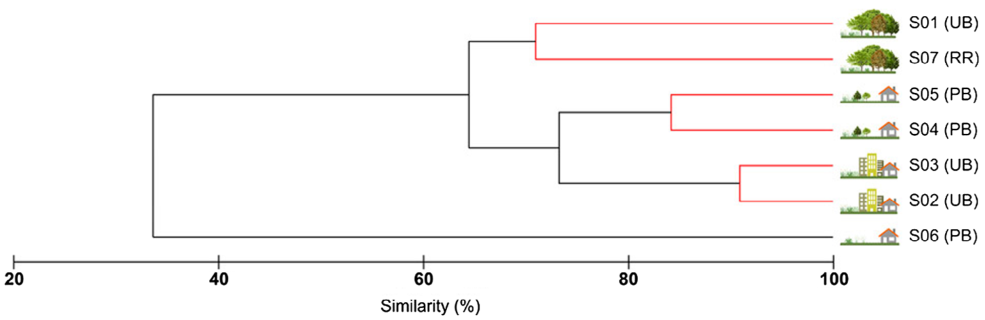

Figure 5. Similarity of anuran species composition at the surveyed sites along the urban-rural gradient in the municipality of Araçatuba, São Paulo State, southeastern Brazil. Red branches of the dendrogram represent three surveyed sites clustered based on a plant type at the edge of breeding habitats and on landscape characteristics. Cophenetic correlation coefficient = 0.87.

main factor determining the anuran diversity along the urban-rural gradient (Baselga 2010).

Conclusion

In summary, the anuran richness recorded in Araçatuba is relatively high considering the fact that the study area is one of the most degraded and fragmented in São Paulo State (Rodrigues et al. 2008). Our observations showed that at the surveyed sites, lower richness and losses of species are found in urban and peri-urban areas, while surveyed sites with high vegetation heterogeneity contained more anuran species. This fact emphasizes the importance of management and conservation strategies implementation for the protection of surveyed sites with high vegetation heterogeneity. We therefore suggest that the preservation of the surveyed sites with dense vegetation cover will contribute to the maintenance of anuran populations in aquatic habitats along the urban-rural gradient.

Acknowledgements

The authors would like to thank Camila Aoki for her valuable suggestions on previous versions of the manuscript, Célio H. Oda and Diego H. Oda for providing field assistance, the Secretaria de Meio Ambiente e Sustentabilidade de Araçatuba, the Faculdade de Medicina Veterinária of the Universidade Estadual Paulista (FMVA/UNESP), and rural property owners, who granted us access to their properties. The Instituto Chico Mendes de Conservação da Biodiversidade/Sistema de Autorização e Informação em Biodiversidade – ICMBio/SISBIO (process nº 31859-1) kindly provided a collecting permit. TSV's research is supported by Fundação de Amparo à Pesquisa do Estado de São Paulo – FAPESP (grant number 2011/18510-0). FHO received postdoctoral fellowship from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES. RMT and ALFB are a Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq grantee of a research productivity partnership. The satellite image of Araçatuba was extracted from Google Earth (© 2016 Google/Landsat/Copernicus), building images were designed by Ram_clotario/Freepix. Garden grass images were designed by Freepix, and tree images were designed by Pixeden.com.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Programa de Excelência Acadêmica – PROEX/Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES under Grant number 1586/2014.

ORCID

Fabrício Hiroiuki Oda http://orcid.org/0000-0003-0675-4762

References

Ab'Saber, A. N. 2003. *Os domínios de natureza no Brasil: potencialidades paisagísticas*. São Paulo: Ateliê Editorial.
Anderson, M. J. 2001. "A New Method for Non-Parametric Multivariate Analysis of Variance." *Austral Ecology* 26 (1): 32–46.
Anderson, M. J., R. N. Gorley, and K. R. Clarke. 2008. *PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods*. Plymouth: PRIMER-E.
Ávila, R. W., and V. L. Ferreira. 2004. "Richness of Species and Density of Vocalization of Anurans in an Urban Area of Corumbá, Mato Grosso do Sul, Brazil." *Revista Brasileira de Zoologia* 21 (4): 887–892.
Baselga, A. 2010. "Partitioning the Turnover and Nestedness Components of Beta Diversity." *Global Ecology and Biogeography* 19 (1): 134–143.
Bastazini, C. V., J. F. V. Munduruca, P. L. B. Rocha, and M. F. Napoli. 2007. "Which Environmental Variables Better Explain Changes in Anuran Community Composition? A Case Study in the Restinga of Mata de São João, Bahia, Brazil." *Herpetologica* 63 (4): 459–471.
Bernarde, P. S., and M. N. C. Kokubum. 1999. "Anurofauna do Município de Guararapes, Estado de São Paulo, Brasil (Amphibia, Anura)." *Acta Biologica Leopoldensia* 21 (1): 89–97.
Caliński, T., and J. Harabasz. 1974. "A Dendrite Method for Cluster Analysis." *Communications in Statistics* 3 (1): 1–27.
CEPAGRI – Centro de Pesquisas Meteorológicas e Climáticas Aplicadas à Agricultura. 2014. *Clima dos municípios paulistas: Araçatuba*. Accessed June 11, 2014. http://www.cpa.unicamp.br/outras-informacoes/clima_muni_032.html

Clarke, K. R., and R. N. Gorley. 2006. *PRIMER V6: User Manual/Tutorial*. Plymouth: PRIMER-E.

Colwell, R. K. 2013. *Estimate S: Statistical Estimation of Species Richness and Shared Species from Samples*. Accessed February 16, 2015. https://viceroy.eeb.uconn.edu/estimates

da Silva, F. R., J. P. Gibbs, and D. C. Rossa-Feres. 2011. "Breeding Habitat and Landscape Correlates of Frog Diversity and Abundance in a Tropical Agricultural Landscape." *Wetlands* 31 (6): 1079–1087.

da Silva, F. R., V. H. M. Prado, and D. C. Rossa-Feres. 2010. "Amphibia, Anura, Hylidae, *Dendropsophus melanargyreus*: Distribution Extension, New State Record and Geographic Distribution Map." *Check List* 6 (3): 402–404.

da Silva, F. R., V. H. M. Prado, T. S. Vasconcelos, T. G. Santos, and D. C. Rossa-Feres. 2009. "Amphibia, Anura, Microhylidae, *Chiasmocleis albopunctata*: Filling Gap and Geographic Distribution Map." *Check List* 5 (2): 314–316.

da Silva, F. R., and D. C. Rossa-Feres. 2011. "Influence of Terrestrial Habitat Isolation on the Diversity and Temporal Distribution of Anurans in an Agricultural Landscape." *Journal of Tropical Ecology* 27 (3): 327–331.

Duellman, W. E., and L. Trueb. 1994. *Biology of Amphibians*. Baltimore, MD: McGraw-Hill.

Eterovick, P. C., A. C. O. Q. Carnaval, D. M. Borges-Nojosa, D. L. Silvano, M. V. Segalla, and I. Sazima. 2005. "Amphibian Declines in Brazil: An Overview." *Biotropica* 37 (2): 166–179.

Ferreira, R. B., T. Silva-Soares, and D. Rödder. 2010. "Guide to the Amphibians of the Atlantic Forest: Diversity and Biology." *Salamandra* 46 (4): 187–196.

Gardner, T. A., J. Barlow, and C. A. Peres. 2007. "Paradox, Presumption and Pitfalls in Conservation Biology: The Importance of Habitat Change for Amphibians and Reptiles." *Biological Conservation* 138 (1–2): 166–179.

Haddad, C. F. B., L. F. Toledo, C. P. A. Prado, D. Loebmann, J. L. Gasparini, and I. Sazima. 2013. *Guide to the Amphibians of the Atlantic Forest: Diversity and Biology*. São Paulo: Anolis Books.

Hamer, A. J., and M. J. McDonnell. 2008. "Amphibian Ecology and Conservation in the Urbanizing World: A Review." *Biological Conservation* 141 (10): 2432–2449.

Hammer, O., D. A. T. Harper, and P. D. Rian. 2001. *Past: Palaeontological Statistics Software Package for Education and Data Analysis*. Version. 1.37. Accessed October 20, 2016. http://palaeo-electronica.org/2001_1/past/issue1_01.htm

IGC – Instituto Geográfico e Cartográfico. 2014. *Mapa da divisão municipal do estado de São Paulo*. Accessed March 14, 2015. http://www.igc.sp.gov.br/produtos/divisao_municipal.html

IUCN. 2017. *The IUCN Red List of Threatened Species*. Version 2016.3. Accessed March 22, 2017. http://www.iucnredlist.org.

Knutson, M. G., J. R. Sauer, D. A. Olsen, M. J. Mossman, L. M. Hemesath, and M. J. Lannoo. 1999. "Effects of Landscape Composition and Wetland Fragmentation on Frog and Toad Abundance and Species Richness in Iowa and Wisconsin, U.S.A." *Conservation Biology* 13 (6): 1437–1446.

Langone, J. A., E. O. Lavilla, R. O. de Sá, and D. Cardozo. 2015. "Comments on the Type Locality, Type Series, and Geographic Distribution of *Pseudopaludicola falcipes* (Hensel, 1867) (Amphibia, Anura)." *Zootaxa* 4058 (1): 145–150.

Mittermeier, R. A., P. R. Gil, M. Hoffmann, J. Pilgrim, T. Brooks, C. G. Mittermeier, J. Lamoreux, and G. A. B. Fonseca. 2004. *Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*. Mexico City: CEMEX.

Nascimento, L. B. 1991. "Bioecologia dos Anfíbios Anuros do Parque das Mangabeiras (Belo Horizonte, MG)." Master thesis, Museu Nacional do Rio de Janeiro/Universidade Federal do Rio de Janeiro.

Nascimento, L. B., A. C. L. Miranda, and T. A. M. Balstaedt. 1994. "Distribuição estacional e ocupação ambiental dos anfíbios anuros da área de proteção da captação da Mutuca (Nova Lima, MG)." *Bios* 2: 5–12.

Oda, F. H., V. G. Batista, P. G. Gambale, F. T. Mise, F. de Souza, S. Bellay, J. C. G. Ortega, and R. M. Takemoto. 2016. "Anuran Species Richness, Composition, and Breeding Habitat Preferences: A Comparison between Forest Remnants and Agricultural Landscapes in Southern Brazil." *Zoological Studies* 55: 1–14.

Parris, K. M. 2004. "Environmental and Spatial Variables Influence the Composition of Frog Assemblages in Sub-Tropical Eastern Australia." *Ecography* 27: 392–400.

Peel, M. C., B. L. Finlayson, and T. A. McMahon. 2007. "Updated World Map of the Köppen-Geiger Climate Classification." *Hydrology and Earth System Sciences* 11: 1633–1644.

Pelinson, R. M., M. V. Garey, and D. C. Rossa-Feres. 2016. "Effects of Grazing Management and Cattle on Aquatic Habitat Use by the Anuran *Pseudopaludicola mystacalis* in Agro-Savannah Landscapes." *PLoS ONE* 11 (9): e0163094.

Pillsbury, F. C., and J. R. Miller. 2008. "Habitat and Landscape Characteristics Underlying Anuran Community Structure Along an Urban-rural Gradient." *Ecological Applications* 18 (5): 1107–1118.

Prado, V. H. M., R. Borges, F. R. da Silva, T. T. Tognolo, and D. C. Rossa-Feres. 2008. "Amphibia, Anura, Hylidae, *Phyllomedusa Azurea*: Distribution Extension." *Check List* 4 (1): 55–56.

Provete, D. B., M. V. Garey, F. R. da Silva, and D. C. Rossa-Feres. 2011. "Anuran Fauna from Northwestern Region of the State of São Paulo: Species List and Taxonomic Key for Adults." *Biota Neotropica* 11 (2): 377–391.

RAN/ICMBio – Centro Nacional de Pesquisa e Conservação de Répteis e Anfíbios/Instituto Chico Mendes de Conservação da Biodiversidade. 2014. *Perda De Vegetação Até 2008 No Brasil*. Accessed March 12, 2015. http://www.icmbio.gov.br/ran/images/stories/Downloads/grid_perda_vegetacao.zip

Rodrigues, R. R., C. A. Joly, M. C. W. Brito, A. Paese, J. P. Metzger, L. Cassati, M. A. Nalon et al. 2008. *Diretrizes para conservação e restauração da biodiversidade no Estado de São Paulo*. São Paulo: Governo do Estado de São Paulo.

Rodrigues, D. J., M. Uetanabaro, and F. S. Lopes. 2005. "Reproductive Patterns of *Trachycephalus venulosus* (Laurenti, 1768) and *Scinax fuscovarius* (Lutz, 1925) from the Cerrado, Central Brazil." *Journal of Natural History* 39 (35): 3217–3226.

Rohlf, F. J. 2000. *NTSYSpc 2.10s: Numerical Taxonomic and Multivariate Analysis System*. New York: Exeter Software.

Rossa-Feres, D. C., R. J. Sawaya, J. Faivovich, J. G. Giovanelli, C. A. Brasileiro, L. Schiesari, J. M. B. Alexandrino, and C. F. B. Haddad. 2011. "Amphibians of São Paulo State, Brazil: State-of-art and Perspectives." *Biota Neotropica* 11 (suppl. 1): 47–66.

Rubbo, M. J., and J. M. Kiesecker. 2005. "Amphibian Breeding Distribution in an Urbanized Landscape." *Conservation Biology* 19 (2): 504–511.

Santos, T. G., D. C. Rossa-Feres, and L. Casatti. 2007. "Temporal and Spatial Distribution and Diversity of Anurans in a Region with Pronounced Dry Season in Southeastern Brazil." *Iheringia, Série Zoologia* 97 (1): 37–49.

Santos, T. G., T. S. Vasconcelos, and C. F. B. Haddad. 2012. "The Role of Environmental Heterogeneity in Maintenance of Anuran Amphibian Diversity of the Brazilian Mesophytic Semideciduous Forest." In *Tropical Forests*, edited by P. Sudarshana, M. Nageswara-Rao, and J. R. Soneji, 119–138. Rijeka: InTech.

Santos, T. G., T. S. Vasconcelos, D. C. Rossa-Feres, and C. F. B. Haddad. 2009. "Anurans of a Seasonally Dry Tropical

Forest: Morro Do Diabo State Park, São Paulo State, Brazil." *Journal of Natural History* 43 (15–16): 973–993.

Savage, J. M. 2002. *The Amphibians and Reptiles of Costa Rica*. Chicago, IL: University of Chicago Press.

Scheffer, M., G. J. van Geest, K. Zimmer, E. Jeppesen, M. Søndergaard, M. G. Butler, M. A. Hanson, S. Declerck, and L. De Meester. 2006. "Small Habitat Size and Isolation Can Promote Species Richness: Second-order Effects on Biodiversity in Shallow Lakes and Ponds." *Oikos* 112: 227–231.

Scott Jr., N. J., and B. D. Woodward. 1994. "Standard Techniques for Inventory and Monitoring: Surveys at Breeding Sites." In *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*, edited by W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L.-A. C. Hayek, and M. S. Foster, 118–125. Washington, DC: Smithsonian Institution Press.

Segalla, M. V., U. Caramaschi, C. A. G. Cruz, T. Grant, C. F. B. Haddad, P. C. A. Garcia, B. V. M. Berneck, and J. A. Langone. 2016. "Brazilian Amphibians: List of Species." *Herpetologia Brasileira* 5 (2): 34–46.

Silva, R. A., I. A. Martins, and D. C. Rossa-Feres. 2011. "Environmental Heterogeneity: Anuran Diversity in Homogeneous Environments." *Zoologia* 28 (5): 610–618.

SMA, IF – Secretaria do Meio Ambiente, Instituto Florestal. 2005. *Inventário florestal da vegetação natural do Estado de São Paulo*. São Paulo: Imprensa Oficial do Estado de São Paulo.

Soininen, J., R. McDonald, and H. Hillebrand. 2007. "The Distance Decay of Similarity in Ecological Communities." *Ecography* 30 (1): 3–12.

Sørensen, T. 1948. "A Method for Establishing Groups of Equal Amplitude in Plant Sociology Based on Similarity of Species Content and Its Application to Analyses of the Vegetation on Danish Commons." *Biologiske Skrifter Kongelige Danske Videnskabernes Selskab* 5: 1–34.

Southwood, R., and P. A. Henderson. 2000. *Ecological Methods*. Oxford: Blackwell Science.

Tonini, J. F. R., I. S. Mendonça, A. B. Coutinho, and J. L. Gasparini. 2011. "Anurans from Costa Bela, State of Espírito Santo, Southeastern Brazil: Inventory at an Urban Area and the Re-Discovery of *Allobates* in the State." *Herpetology Notes* 4: 435–444.

Vasconcelos, T. S., and J. L. P. Doro. 2016. "Assessing How Habitat Loss Restricts the Geographic Range of Neotropical Anurans." *Ecological Research* 31 (6): 913–921.

Vasconcelos, T. S., and D. C. Rossa-Feres. 2005. "Diversidade, distribuição espacial e temporal de anfíbios anuros (Amphibia, Anura) na região noroeste do estado de São Paulo, Brasil." *Biota Neotropica* 5 (2): 137–150.

Vasconcelos, T. S., and D. C. Rossa-Feres. 2008. "Habitat Heterogeneity and Use of Physical and Acoustic Space in Anuran Communities in Southeastern Brazil." *Phyllomedusa* 7: 12–142.

Vasconcelos, T. S., T. G. Santos, D. C. Rossa-Feres, and C. F. B. Haddad. 2009. "Influence of the Environmental Heterogeneity of Breeding Ponds on Anuran Assemblages from Southeastern Brazil." *Canadian Journal of Zoology* 87 (8): 699–707.

Vasconcelos, T. S., T. G. Santos, D. C. Rossa-Feres, and C. F. B. Hadadd. 2011. "Spatio-temporal Distribution of Calling Male Frogs in Morro Do Diabo State Park (Southeastern Brazil): Implications for Conservation and Management in a Seasonally Dry Tropical Forest." *South American Journal of Herpetology* 6 (2): 107–118.

Vizotto, L. D. 1967. "Desenvolvimento de anuros da região norte-ocidental do Estado de São Paulo." PhD diss., Universidade de São Paulo.

Werner, E. E., D. K. Skelly, R. A. Relyea, and K. L. Yurewicz. 2007. "Amphibian Species Richness across Environmental Gradients." *Oikos* 116 (10): 1697–1712.