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Linking spatial scale dependence of land-use descriptors and invertebrate cave community composition

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Abstract

Patterns of biodiversity respond to habitat disturbances and different land-uses. Those patterns possibly vary according to the spatial scale under analysis. Although other studies have shown such responses for different systems, no study has ever demonstrated spatial-scale influences in subterranean terrestrial communities. Therefore, the objective of this paper was to analyze how land use and cave physical structure could influence the terrestrial cave invertebrate species composition. We also determined the influence of different spatial scale on the structure of invertebrate cave composition. We collected environmental data at local scale (e.g. cave size, substrate and environmental stability). For spatial scale we determined land uses at three different landscape scales; we gathered these data into circular areas of different sizes (50, 100 and 250 meters) with centroids in the cave entrances. We finally performed three Distance Based Linear Modeling analyses to test for differences among the predictability of environmental variables when comparing different spatial scales. The best explanatory variable for cave invertebrate similarities was the percentage of covering of the external environment by limestone outcrops. We confirm the scale-dependence hypothesis through the different patterns showed among distinct buffer areas. Models become more precise when larger scales were analyzed to explain cave invertebrate composition. This suggests that larger scales capture important environmental features that explain the cave fauna similarities more precisely. Additionally, we found a strong influence of limestone outcrops at all landscape scale structuring cave communities.

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Keywords
Subterranean, habitat heterogeneity, land-use, limestone outcrop, native vegetation, cattle pasture

Introduction

Environmental heterogeneity in natural landscapes has been historically replaced by anthropogenic mosaics around the world. As a consequence, several hypothesis describing how landscape characteristics affect biodiversity patterns have been proposed (Tscharntke et al. 2012). Ecological functions and processes are dependent on larger spatial scales than a single habitat patch (Gustafson 1998, Steffan-Dewenter et al. 2002). Biodiversity is often positively correlated with the amount of available habitat (Fahrig 2003), but the effect of land-use changes on biodiversity depends on the landscape context (MacDonald et al. 2000) and on the spatial scale that has been analyzed (McGlinn and Hurlbert 2012, Dumbrell et al. 2008, Zimmermann et al. 2010, Morueta-Holme et al. 2013). Furthermore, ecological communities are structured under processes that act on the landscape, in which both regional and local scales are important factors (Harrison and Cornell 2008).

In the context of landscape influences on biodiversity distribution patterns, caves are good models since they represent simplified and fragile ecosystems (Culver 1982, Culver and Pipan 2009). Since the cave communities are dependent on the allochthonous input of nutrients, alterations in the availability, properties and abundance of these nutrients in the landscape surrounding the caves may affect cave biodiversity. Despite their fragility, caves are under several anthropogenic pressures, and only few studies evaluated how such human activities can affect the invertebrate cave communities, such as inadequate tourism (e.g. Poulson et al. 1995, Moldovan et al. 2003, Pellegrini and Ferreira 2012). Such studies are even scarcer when considering human impact at landscape scale, such as agriculture, urban development, deforestation and mineral resources extraction (Eme et al. 2014, Zagmajster et al. 2014). All these activities lead to aquifer pollution, cave destruction, and biodiversity loss (Beynen et al. 2012). Considering this, the current Brazilian legislation (Brazil. Decree nº 6.640/2008) imposes that caves should bear a protection area of 250 meters in radius surrounding the cave linear projection on the surface (Portaria IBAMA nº 887/1990). Although other studies have shown responses for different spatial scales under analysis (e.g. Steffan-Dewenter et al. 2002), few studies have demonstrated such influences in subterranean communities patterns (Eme et al. 2014, Zagmajster et al. 2014).

The main goal of this paper is to explain cave invertebrate composition through environmental variables from within the cave and also from the landscape surrounding the caves at different spatial scales. To that end, we tested the hypothesis that the spatial scale affects the predictability of environmental variables. We also checked for grouping patterns among cave fauna according to the most explanatory variables.

Methods

Study area

The present study was carried out at the conservation unit "*Parque Estadual do Sumidouro*" – PESU (Sinkhole State Park), in the suburban mesoregion of Belo Horizonte, Minas Gerais state, Brazil (Fig. 1). The PESU is in a karstic area, presenting a Savanna wet tropical weather. The caves are located in an anthropic landscape, in which there are areas with native vegetation but most areas are covered with cattle pasture (Iniesta et al. 2012). We chose 10 caves in this park based on the main surrounding landscape matrix, vegetation cover and land-use types, thus encompassing a heterogeneous landscape around the caves. The caves present sizes ranging from 16.85 to 137.68 meters. We performed one sampling event at each cave.

Terrestrial invertebrate collection

We only used terrestrial invertebrates for our analysis because they account for most of cave richness and abundance in Brazilian caves (Pinto-da-Rocha 1995), especially considering the caves in study, poor in water bodies. In each cave, we collected invertebrates manually, using tweezers and brushes, with special attention to microhabitats such as under wood trunks and rocks, as well as other organic matter accumulations. In the laboratory, the collected specimens were identified to the lowest taxonomic level possible and separated into morphotypes in order to obtain species presence/absence for each cave (Oliver and Beattie 1996). Such morphospecies separation is sufficient for ecological biodiversity studies and conservation purposes. Oliver and Beattie (1996) demonstrated that morphospecies identified by non-specialists could led to estimates of richness comparable with those elaborated using species identified by specialists. Furthermore, Oliver and Beattie (1996a) have shown that the use of morphospecies provides results usually concordant with conventional species inventories. Biological material is deposited in the Zoology Collection (Coleção de Invertebrados Subterrâneos de Lavras), Seção de Invertebrados Subterrâneos (from ISLA 3478 to ISLA 3618).

Local environmental data collection

We considered environmental variables at different spatial scales, thus encompassing traits inside the cave (local scale), and those belonging to the landscape scale. At the local scale, we measured the linear extension of the cave and number and size of the entrances. We used those variables to estimate the cave Environmental Stability Index (*ESI*), proposed by Ferreira (2004) and also used by Bento et al. (in press). This

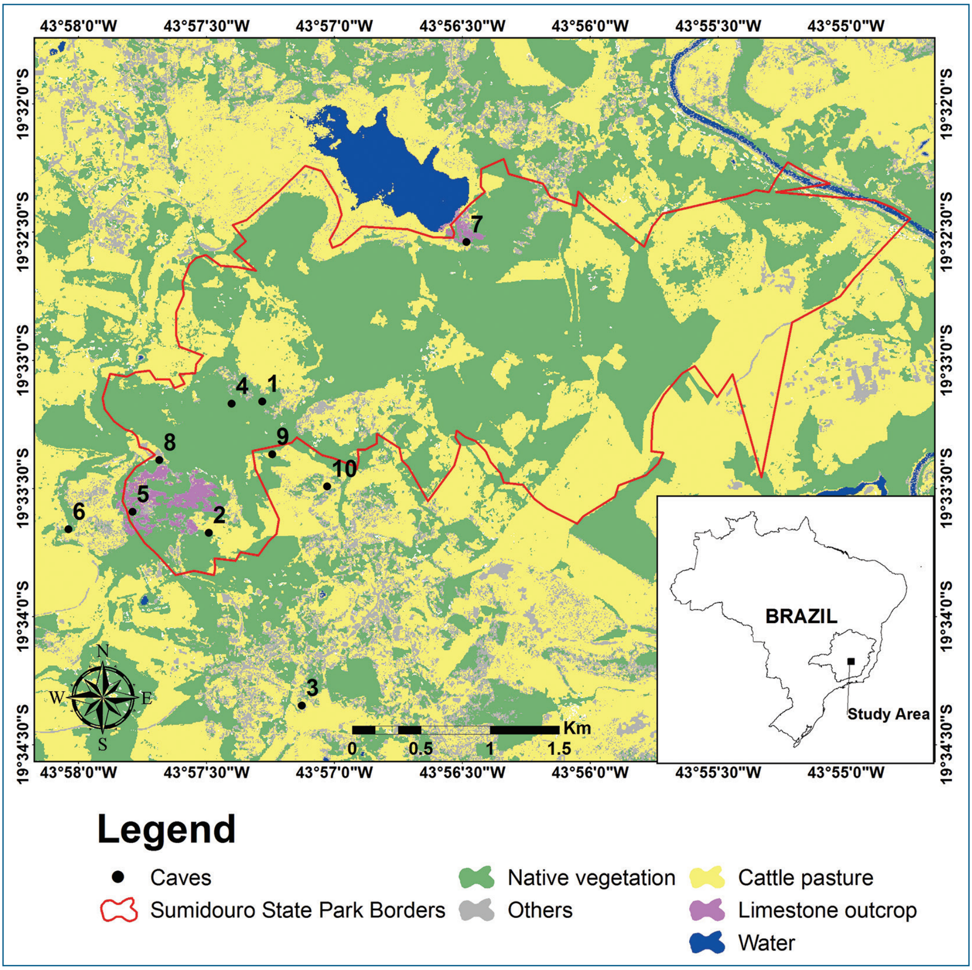

Figure 1. Spatial characterization of landscape at "Parque Estadual do Sumidouro". Different colors represent distinct vegetation cover or land-use types. The numbers indicate the sampled caves, indicated by name. Legend: **1** Gruta Ninho de Pérolas **2** Gruta Macaco das Cavernas **3** Lapa da Várzea **4** Gruta do Grilão **5** Gruta Helictites **6** Lapa das Pacas **7** Gruta do Sumidouro **8** Gruta Lagoa Seca **9** Gruta do Feneme **10** Gruta do Lixo.

index accounts for outside interference on the cave environment, as a ratio between the number and size of entrances (as their spatial distribution) and the cave size (Eq. 1). In Eq.1, *LE* is the linear extension (total length) of the cave, ∑EE is the sum of all entrances extension, *NE* is the number of entrances, and *DEE* is the average distance from all entrances to a reference cave entrance (remaining that all distance between entrances must be considered). Big caves with small entrances would be more stable than small caves with big entrances, which would possess an internal environment more disturbed by the external environment.

$$ESI = \frac{\frac{LE}{\sum EE}}{\frac{(NE)(DEE)}{LE}} \qquad [1]$$

In order to determine the habitat heterogeneity inside each cave, we classified and quantified the different types of habitat. We divided each cave main conduit into at least 11 transects, equally distanced. Bigger caves were divided with more transects with a maximum distance between them corresponding to 15 meters. Each transect was then subdivided at five points, and at these points we visually examined substrate type (guano, water, trash, organic matter and the size of inorganic grains), along the five equidistant points, encompassing a minimal number of 55 measurements for each cave. The size of inorganic grains was classified into eight classes (bedrock, large boulders, boulders, cobbles, coarse gravel, fine gravel, sand, silt and hardpan). This methodology was modified from Peck et al. (2006) and from Hughes and Peck (2008). We used these values to assess habitat heterogeneity parameter as explained hereafter. Considering the local scale, the cavities under study showed different patterns in their physical variables. Based on the 55 habitat measurements, we calculated the proportion of each habitat class within each cave and estimated the habitat heterogeneity using Shannon`s diversity index, using such values of habitat classes encountered in each cave. We calculate Shannon`s index using PAST 3.11 software (Hammer et al. 2001).

Landscape environmental data collection

In order to obtain environmental variables at a landscape scale we quantified the main land-use types at different buffers through image classification and matrix characterization. These buffers were circular areas centered at each cave entrance, with a radius of 50 m, 100 m, and 250 m. For those caves with multiple entrances, the biggest entrance was used as reference in this analysis. Therefore, we delimited three circular areas, named respectively Buffer 50 m, Buffer 100 m, and Buffer 250 m (Figure 1). The percentages of each land-use type at each buffer were then included as environmental variables on further tests.

Spatial characterization of PESU required a RapidEye remote sensing image from 2010; images were obtained in LEMAF (*Laboratório de Estudos e Projetos em Manejo Florestal*), in the Federal University of Lavras, Lavras city, Brazil. We created an image subset delimiting only the park area. Then we segmented and classified that subset into five classes: native vegetation, water, cattle pasture, limestone outcrop, and others (which included roads, cities, constructions, bare land and general urbanized areas) (Figure 2), using algorithm K *Nearest Neighbor* with the software ENVI EX v.4.8 (ITT 2010).

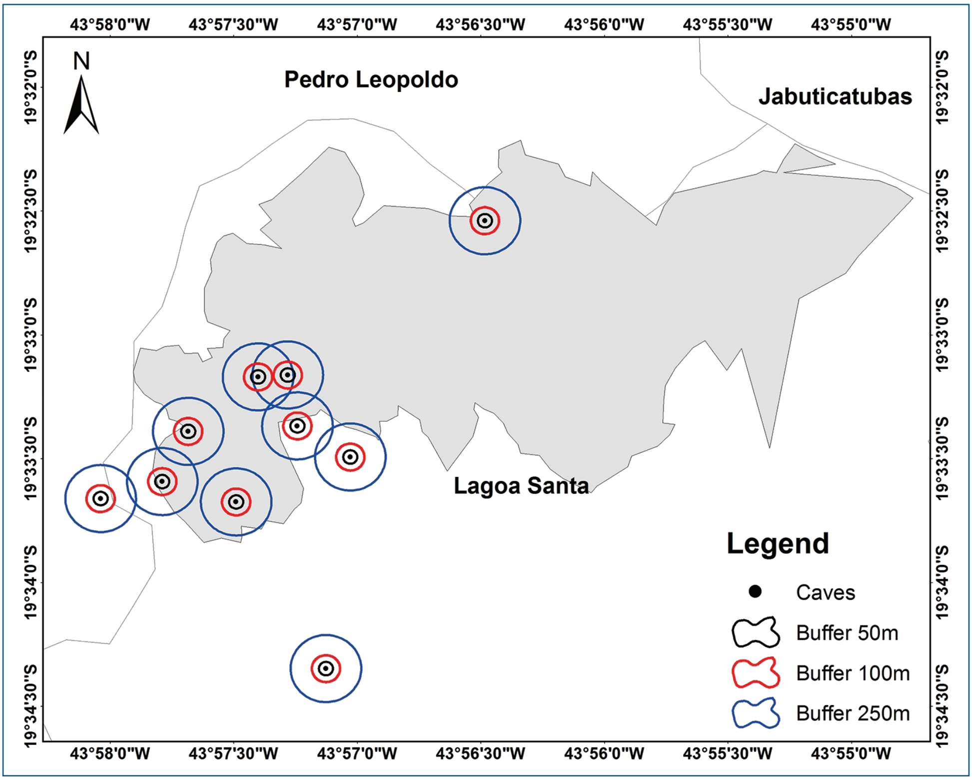

Figure 2. Study area location, sampling design used in sampled caves at "Parque Estadual do Sumidouro", and the Buffers of 50m, 100m, and 250m for analyzing the effect of spatial scale on the explanatory power of environmental variables in the cave invertebrate communities.

Data analysis

In order to detect if the geographic distance is responsible for the highest similarities between the studied caves, we performed a Mantel test with PAST 3.11 software (Hammer et al. 2001). Environmental variables at different scales were used to analyze cave invertebrate communities. The influence of spatial scale (Buffer 50 m, Buffer 100 m, and Buffer 250 m) on invertebrate fauna composition was assessed with three independent Distance Based Linear Modeling (DistLM) analyses (software PRIMER 6.0). We performed the analyses based on species composition data, by a resemble matrix using *Jaccard* index (qualitative data) for calculating the species similarities between the caves. As predictor variables, we used environmental data: percentage of land-use types at each buffer scale (thus representing the landscape spatial scale), added to local scale information (linear extension, environmental stability index and Shannon`s diversity index for substrate). We chose *adjusted* R^2 as a selection criterion using the *Best* procedure, which examines the value of the selection criterion for all possible combinations of predictor variables (Anderson et al. 2008).

Results

We found 186 invertebrate species, distributed along at least 78 families and 23 orders (Table 1). Among them, the order Diptera was the most representative, presenting 40 species, which belong to at least 17 families. The order Araneae, with 14 families and 33 species was the second richest. We found three troglomorphic species, two belonging to the order Collembola (Entomobryomorpha and Hypogastruroidea) and one Isopoda (Platyarthridae, *Trichorhina* sp.). Entomobryomorpha was found in two caves, while Hypogastruroidea was restricted to a single cave. *Trichorhina* sp. was more broadly distributed, being found in four caves.

We found no correlation between geographical distance and caves invertebrate similarity (Correlation $R_{\text{MANTEL TEST}} = -0.3366$; $p = 0.9111$).

Lapa das Pacas Cave had the highest Environmental Stability Index (*ESI*=3.53). Ninho de Pérolas Cave presented the smallest value, *ESI* = -0.56 (Table 2). The habitat varied highly among caves. Only two caves showed bat guano, Gruta do Sumidouro and Lapa da Várzea. Water bodies were also found in only two caves, Gruta do Sumidouro and Lapa das Pacas. Gruta do Sumidouro Cave presented 12 different types of habitats and the Shannon diversity index for this parameter was 2.25, the highest value among the caves analyzed. The lowest Shannon diversity value was found at the Lapa da Várzea Cave (1.30) with only 6 different types of habitats (Table 3).

At landscape scale we found four main types of land cover: limestone outcrop, cattle pasture, native vegetation and others. At all buffers the two principal land covers were pasture and native vegetation. The only buffer with water was the 250 m buffer of the Gruta do Sumidouro Cave (Table 4).

Limestone outcrop was the most important predictor variable of community composition (*Jaccard* index - considering species identity in the community) in all buffer scales, although other variables varied with landscape scale. The best model for the 50 m Buffer presented an *adjusted* R^2 value of 0.40, and used only two variables (limestone outcrop and others). The best model solution for Buffer 100 m presented an *adjusted* R^2 value of 0.45, and revealed three variables, limestone outcrop, cattle pasture and native vegetation. Finally, the best model for Buffer 250 m showed an *adjusted* R^2 value of 0.73 and used four variables (limestone outcrop, water, environmental stability index and substrate Shannon`s diversity index) (Table 5). Therefore, large-scale models have higher R^2 values.

Discussion

There are few studies on spatial patterns of cave communities although some studies evaluate differences of spatial scale sampling on species patterns (e.g. Zagmajster et al. 2008, Eme et al. 2014). Few studies evaluated spatial-scale dependence on community-land uses relationships for cave invertebrates (e.g. Bento 2011). These studies are important to reliably identify essential features and patterns for conservation and management

Table 1. Taxon and families collected at Parque Estadual do Sumidouro Caves. NI: Not Identified. In each column is represented the number of morphospecies found at that cave.

TAXON		FAMILIES	Gruta do Grilão	Gruta do Lixo	Gruta do Sumidouro	Gruta Feneme	Gruta Pacas	Helictites	Lagoa Seca	Lapa da Varzea	Macacos da Caverna	Ninho de pérolas
Annelida	Oligochaeta	NI	0	0	0	0	1	0	0	0	0	0
Crustacea	Isopoda	Platyarthridae	1	0	1	0	2	1	0	1	0	0
Gastropoda	Gastropoda	NI	0	0	0	0	2	1	0	2	1	1
Myriapoda	Diplopoda	Pseudonannolenidae	1	0	1	1	0	1	0	0	1	1
		Polyxenidae	0	0	0	0	0	0	0	1	0	0
	Scolopendromorha	NI	0	1	0	0	0	0	0	0	0	0
	Symphyla	Scutigerellidae	0	1	0	0	1	0	0	1	0	0
Arachnida	Acari	NI	0	0	0	0	0	0	0	3	0	0
		Anystidae	0	1	0	1	0	0	1	0	0	0
		Argasidae	1	1	0	0	0	1	0	1	1	1
		Ixodidae	0	0	0	0	1	0	1	1	0	0
		Macronyssidae	0	0	1	0	0	0	0	0	0	0
		Rhagidiidae	0	1	0	0	0	0	0	1	0	0
		Tydeidae	0	0	0	0	0	0	0	1	0	0
	Aranae	NI	0	0	0	0	0	0	0	1	0	0
		Araneidae	0	0	0	1	0	0	1	0	1	0
		Ctenidae	1	1	2	2	0	1	1	1	2	1
		Deinopidae	0	0	0	0	0	0	0	0	1	0
		Linyphiidae	0	0	0	1	0	0	0	0	2	0
		Nemesiidae	0	0	0	0	0	0	0	0	0	1
		Oonopidae	0	0	0	0	1	0	0	1	0	0
		Pholcidae	1	1	2	1	1	2	2	1	1	1
		Salticidae	0	1	0	0	0	3	2	0	2	1
		Sicariidae	1	1	1	0	0	1	1	1	1	1
		Symphytognathidae	1	1	0	0	0	0	0	0	0	1
		Theraphosidae	0	0	0	0	1	0	0	0	0	0

TAXON		FAMILIES	Gruta do Grilão	Gruta do Lixo	Gruta do Sumidouro	Gruta Feneme	Gruta Pacas	Helictites	Lagoa Seca	Lapa da Varzea	Macacos da Caverna	Ninho de pérolas
		Theridiidae	0	0	2	0	2	0	0	3	2	0
		Theridiosomatidae	0	1	0	1	0	0	0	1	1	0
		Uloboridae	0	0	0	0	1	1	0	0	0	0
	Pseudoscorpiones	NI	1	0	1	0	1	1	0	0	1	0
		Cheiridiidae	1	0	0	0	0	0	0	0	0	0
		Chthoniidae	0	0	0	1	0	1	1	0	0	0
	Opiliones	Gonyleptidae	0	1	0	0	0	0	0	0	0	0
	Palpigradi	Eukoeneniidae	0	0	1	0	0	0	0	1	0	0
Hexapoda	Blattodea	NI	0	1	1	0	1	0	0	0	1	0
	Coleoptera	NI	0	0	0	1	0	0	0	2	0	0
		Carabidae,	0	0	0	0	0	0	0	1	0	0
		Cholevidae	0	0	0	0	0	0	0	1	0	0
		Elateridae	0	0	1	0	0	0	0	0	0	0
		Histeridae	0	0	1	0	0	0	0	0	1	0
		Pselaphidae	0	0	0	0	1	1	0	0	0	1
		Ptiliidae	0	0	0	0	0	0	0	1	0	0
		Ptilodactylidae	1	2	1	0	0	0	1	2	0	1
		Rhizophagidae	0	1	0	0	0	0	0	0	0	0
		Scarabaeidae	0	0	0	0	0	0	0	0	1	0
		Staphylinidae	0	0	0	0	0	0	0	0	1	0
		Tenebrionidae	1	0	0	0	0	1	1	1	0	1
	Collembola	NI	3	0	2	1	2	1	0	4	3	1
	Diptera	NI	0	1	2	0	1	0	0	2	0	0
		Anthomyiidae	0	0	0	0	0	0	0	0	0	1
		Bibionidae	0	0	0	0	0	0	0	1	0	0
		Calliphoridae	0	1	0	0	0	0	0	0	0	0
		Ceratopogonidae	1	0	0	0	0	0	0	0	1	0
		Chloropidae	0	1	0	1	0	0	0	0	1	0
		Culicidae	0	1	0	0	1	1	1	0	1	0

TAXON		FAMILIES	Gruta do Grilão	Gruta do Lixo	Gruta do Sumidouro	Gruta Feneme	Gruta Pacas	Helictites	Lagoa Seca	Lapa da Varzea	Macacos da Caverna	Ninho de pérolas
		Dolichopodidae	1	1	0	0	0	0	1	0	1	0
		Drosophilidae	0	1	0	1	0	0	0	3	2	1
		Lauxanidae	0	0	0	0	0	1	1	0	0	0
		Milichiidae	0	0	0	0	0	1	0	0	0	0
		Mycetophilidae	0	0	0	0	0	0	0	1	1	0
		Phoridae	0	0	1	1	0	0	0	2	1	0
		Psychodidae	0	0	0	0	1	0	0	1	1	1
		Sciaridae	0	1	0	0	0	0	0	1	1	0
		Stratiomyiidae	0	0	0	0	0	0	0	1	0	0
		Tabanidae	0	0	0	0	0	0	0	0	1	0
		Trichoceridae	0	0	0	0	0	1	0	0	0	0
	Ensifera	Gryllidae	0	0	0	0	1	0	0	0	0	0
		Pahlangopsidae	1	0	1	2	1	1	0	1	2	1
	Hemiptera	NI	0	0	0	0	0	0	0	2	0	0
		Cixiidae	1	1	0	1	0	1	0	1	1	0
		Miridae	0	0	1	0	0	0	0	0	0	0
		Ploiaridae	0	0	1	0	0	0	0	0	1	0
		Reduviidae	1	1	2	0	1	1	1	0	2	1
	Hymenoptera	NI	0	0	0	0	0	0	0	0	0	1
		Formicidae	1	1	1	3	3	3	1	0	2	2
		Eulopidae	0	0	1	0	0	0	0	0	0	0
	Isoptera	Rhinotermitidae	0	0	0	0	1	0	0	0	0	0
		Termitidae	0	0	0	0	1	0	1	0	0	0
	Lepidoptera	NI	0	1	0	1	0	0	0	1	0	0
		Geometridae	0	1	0	0	0	0	0	0	0	0
		Hesperiidae	1	0	0	0	0	0	0	0	0	0
		Noctuidae	1	4	1	3	0	2	0	2	1	2
		Tineidae	1	2	2	2	1	2	0	2	2	1
	Neuroptera	Myrmeleontidae	0	0	1	0	0	1	0	0	0	0

TAXON		FAMILIES	Gruta do Grilão	Gruta do Lixo	Gruta do Sumidouro	Gruta Feneme	Gruta Pacas	Helictites	Lagoa Seca	Lapa da Varzea	Macacos da Caverna	Ninho de pérolas
	Pauropoda	NI	2	0	0	1	1	0	0	2	2	1
	Psocoptera	NI	2	0	0	1	1	0	0	1	2	1
		Epipsocidae	0	1	0	0	0	0	0	0	0	0
		Lepidopsocidae	0	0	1	1	1	0	0	0	1	0
		Liposcelidae	0	0	1	0	0	0	0	0	0	0
		Psocidae	0	0	0	0	0	1	1	0	0	0
		Psyllipsocidae	0	0	0	0	0	1	1	0	0	0
		Ptiloneuridae	0	1	2	0	1	0	0	0	1	0
	Thysanura	Nicoletiidae	0	1	0	0	0	0	0	0	0	0
TOTAL RICHNESS			**27**	**37**	**35**	**29**	**34**	**34**	**20**	**58**	**51**	**26**

Table 2. Values of physical variables found at each cave at PESU. ESI: Environmental Stability Index; LE: Linear Extension; ΣEE: Sum of Entrances Area; NE: Number of Entrances.

CAVE	*ESI*	LE	ΣEE	NE
Gruta do Grilão	0.5983	42.82	2.74	3
Gruta do Lixo	0.0829	16.85	8.28	1
Gruta do Sumidouro	3.3859	137.68	6.47	1
Gruta do Feneme	3.2335	26.13	0.8	1
Gruta Helictites	1.8935	69.48	3.45	1
Gruta Lagoa Seca	1.7884	28.39	7.59	3
Lapa da Várzea	2.806	134.35	2.53	1
Lapa das Pacas	3.5262	319.56	1.41	1
Gruta Macaco das Cavernas	1.5085	42.7	8.19	2
Gruta Ninho de Pérolas	-0.5618	27.22	11.42	1

actions. Our findings confirm the scale-dependence hypothesis on explaining similarities among cave communities. Models get more precise at larger scales, it is possible to incorporate new explanatory variables that may be absent at smaller scales. The combination of different scales variables explain better cave community composition.

Karst areas have different historical land uses and human impacts vary according to landscape characteristics (Frumkin 1999). While karst depressions are more easily cultivated, rocky karst slopes and carbonate outcrops are less suitable for such uses (Frumkin 1999). At PESU we could clearly observe this pattern, since impacted areas, with cattle pasture, are mainly those located in depressed areas. Additionally, the best-preserved areas were those located on limestone outcrops or in their surroundings and they were the best predictor of cave community structure for all landscape scales. Such areas also host denser vegetation ensuring better conditions for cave invertebrate communities, most identified species in this study were troglophiles, also present in the surface habitats.

The second factor that explained the cave similarity in the 50 m buffer was "*others*", represented by cities, human constructions, roads and bare land, as results of urbanization. According to McIntyre and Hobbs (1999), urbanization is one of the most destructive human activities generating habitat change and loss of ecological function. As urbanization may cause a strong reduction in invertebrate diversity (Buczkowski and Richmond 2012), this effect could influence cave communities in two ways: *i)* we suggest that caves could be a refuge for invertebrate species, especially for those caves near such areas or *ii)* urbanization could reduce both, epigean and hypogean invertebrate communities. Here, smaller scales indicated an intensified urbanization impact near cave entrances (Figure 3), thus suggesting that caves may offer shelter to invertebrate species, offering optimal conditions for many invertebrate species, especially for edaphic species that establish a continuum of life from the surface soil to the deep subterranean environment (Gers 1998, Ortuño et al. 2013).

The 100 m buffer indicated, in addition to limestone outcrops, cattle pasture and native vegetation as important variables. The landscape cover determines food availability

Table 3. Environmental variables at local scale. Kinds of substrates found at each cave at PESU study.

CAVE	Gruta do Grilão	Gruta do Lixo	Gruta do Sumidouro	Gruta Feneme	Gruta Helictites	Lagoa Seca	Lapa da Varzea	Lapa das Pacas	Macacos das Cavernas	Ninho de pérolas
Bat guano	0	0	2	0	0	0	3.5	0	0	0
Waterbody	0	0	1	0	0	0	0	28	0	0
Trash	0	3	0	0	0	0	0	0	0	0
Organic matter	3.5	3	10.5	11.5	0	5.5	12.5	0	2	1.5
Bedrock	17	5	3	6	17	37	0	13	7	0
Large boulders	1	5	2	0	2	2	0	0	8	3
Boulders	0	9	9	12	2	2	0	2	16	6
Cobbles	8	3	2	5.5	2	0	0	3	12	9
Coarse gravel	3	2	2	8	3	2	0	2	12	12
Fine gravel	15	12	7.5	5	18	4.5	2	1	15	1
Sand	17	4	5	2	4	6	3	0	8.5	0.5
Silt	0.5	0	5.5	0	6	0	44	68	3	58
Hardpan	0	9	10.5	15	1	11	25	8	11.5	4
Substrate Richness	8	10	12	8	9	8	6	8	10	9
Dominance	0.2105	0.1332	0.1219	0.1563	0.2271	0.3242	0.3386	0.3622	0.1218	0.4048
Shannon_H	1.709	2.148	2.295	1.963	1.754	1.527	1.307	1.338	2.189	1.347

Table 4. Environmental variables at landscape scale. Percentage of each land-use type at all Buffer sizes.

	Limestone Outcrop			Others			Cattle Pasture			Native Vegetation			Water
BUFFER AREA SIZE	**50**	**100**	**250**	**50**	**100**	**250**	**50**	**100**	**250**	**50**	**100**	**250**	**250**
Gruta do Grilão	0.0	0.0	0.0	0.0	2.2	5.8	9.1	7.1	7.0	90.9	90.6	87.2	0.0
Gruta do Lixo	0.0	0.0	0.0	17.8	22.0	11.9	76.0	56.2	57.7	6.2	21.8	30.4	0.0
Gruta do Sumidouro	37.6	29.1	2.6	10.1	8.8	1.5	16.9	16.2	3.5	35.4	45.9	15.8	76.7
Gruta do Feneme	0.0	0.0	0.0	3.5	3.2	2.4	47.7	28.6	30.8	48.8	68.2	66.8	0.0
Gruta Helictites	33.0	35.0	20.7	14.9	20.1	18.3	1.9	5.3	20.4	50.2	39.6	40.6	0.0
Gruta Lagoa Seca	2.8	12.9	9.4	35.9	19.2	9.9	19.2	20.2	18.3	42.2	47.7	62.4	0.0
Lapa da Várzea	0.0	0.0	0.0	22.1	16.5	13.4	59.5	69.7	63.4	18.4	13.7	23.2	0.0
Lapa das Pacas	0.0	0.0	0.0	4.9	14.7	12.1	43.8	47.1	70.7	51.3	38.2	17.2	0.0
Gruta Macaco das Cavernas	0.0	1.9	9.1	3.0	2.9	6.9	52.0	53.7	35.0	45.0	41.5	49.1	0.0
Gruta Ninho de Pérolas	0.0	0.0	0.0	0.1	9.0	8.5	1.3	6.1	26.8	98.6	84.9	64.8	0.0

Table 5. DistLM results for the tree different landscape scales, Buffer 50m, Buffer 100m and Buffer 250m. Legend: Limest. Out. = Limestone Outcrop; Others = Cities, constructions, roads and bare soil; Cat. Past. = Cattle Pasture; Nat. Vegetation = Native vegetation; *ESI* = Environmental Stability Index; LE = Linear Extension; Habitat Hete. = Habitat Heterogeneity.

Predictor Variables					
Buffer 50 m		**Buffer 100 m**		**Buffer 250 m**	
Adjusted R^2	Selections	*Adjusted R^2*	Selections	*Adjusted R^2*	Selections
0.40	Limest. Out., Others.	0.45	Limest. Out., Cat. Past., Nat. Vegetation.	0.73	Limest. Out., Water, *ESI*, Subt. Diversity.

Marginal Tests			**Marginal Tests**			**Marginal Tests**		
	p-value	Proportion		p-value	Proportion		p-value	Proportion
Limest. Out.	0.008	0.3381	**Limest. Out.**	0.039	0.42614	**Limest. Out.**	0.012	0.53295
Others	0.114	0.2406	**Others**	0.84	1.9433E-2	**Others**	0.935	8.3714E-3
Cat. Past.	0.996	-4.5387E-2	**Cat. Past.**	0.792	2.3529E-2	**Cat. Past.**	0.263	0.13365
Nat. Vegetation	0.51	7.9518E-2	**Nat. Vegetation**	0.261	0.14627	**Nat. Vegetation**	0.895	1.3282E-2
ESI	0.413	0.12744	***ESI***	0.226	0.18016	**Water**	0.203	0.35578
LE	0.843	-4.9594E-3	**LE**	0.962	7.2133E-3	***ESI***	0.186	0.20154
Habitat Hete.	0.595	6.742E-2	**Habitat Hete.**	0.134	0.23179	**LE**	0.936	6.5205E-3
						Habitat Hete.	0.099	0.29352

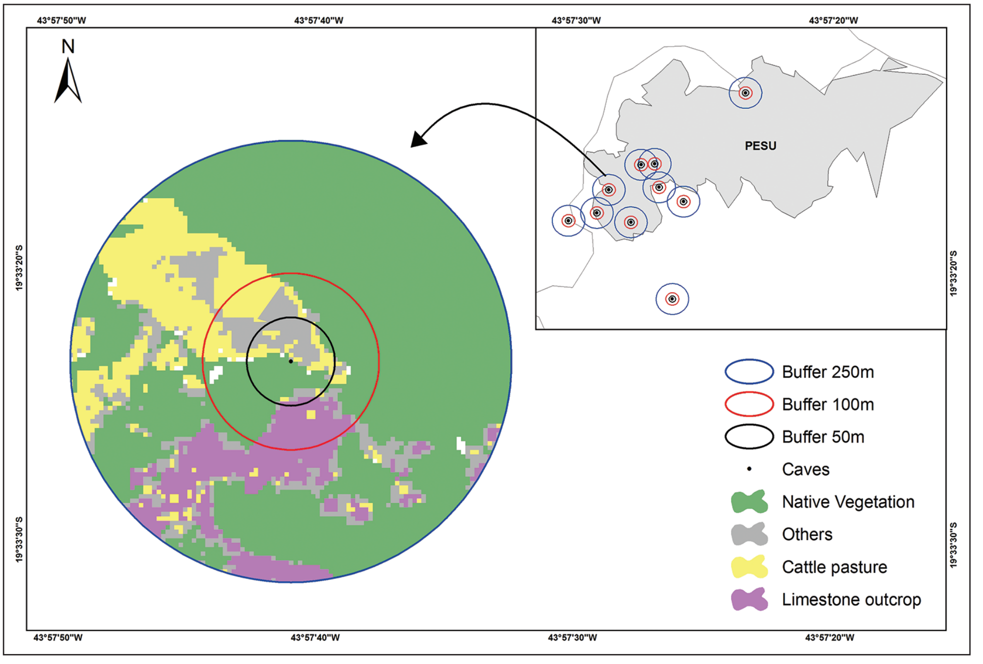

Figure 3. Detailed figure of Gruta Helictites showing different land uses within the 50, 100 and 250 m buffers.

inside caves, which possibly affects cave communities. Although one would expect to have richer communities in caves surrounded by forests (as a rich source of organic matter that can be brought inside caves), guano also constitutes an important resource for many cave invertebrates. Some species are highly dependent on guano, and cave communities associated to this resource can be relatively complex (Ferreira and Martins 1999, Ferreira et al. 2007). The conversion of forests to pastures may favor some species (Gillieson and Thurgate 1999), aside from also reducing foraging habitats for several bat species. Habitat loss and fragmentation seems to favor *Desmodus rotundus*, a hematophagous bat species that remains in areas transformed into rural landscapes (Aguiar et al. 2010). The change in the organic resource quality can result in a remarkable invertebrate substitution (Souza-Silva et al. 2011), which, in turn, could result in several changes in patterns and processes inherent to the cave fauna. Such changes could eventually enhance the cave community instability, which can become more vulnerable to environmental disturbances.

Considering the 250 m buffers, the model incorporated three different explanatory variables aside from the limestone outcrops: water bodies, environmental stability index and habitat heterogeneity. The importance of the allochthonous nutrient input through water transport is well known (e.g. Hawes 1939, Culver 1982, Romero 2009). Water acts as a molding agent and a vehicle in which nutrients, gases, minerals and even microorganisms are transported underground (Culver and Pipan 2009). The only cave that presented epigean water in the 250 m buffer was the Gruta do Sumidouro. That water is a lake connected to the cave by a sink and its invertebrate fauna is unique because flood pulses continually disturb and remove the accumulated food resource (Souza-Silva et al. 2011). In addition, floods may help maintain a regular food supply to caves, thus operating as distribution agents (Hawes 1939), contributing to the faunal singularity.

The higher community similarity among caves with similar values of *ESI* was expected. Stable associations by community in some cave sectors, which exhibit optimal climatic conditions, were reported for some invertebrate species (Di Russo et al. 1997). In this context, Bento et al. (in press) conducted a work in 24 cavities in the Brazilian Caatinga (semi-arid landscape) and found that more stable caves showed less variation in the invertebrate community composition when comparing their communities in both seasons (rainy and dry) than less stable caves. In this paper cave stability was calculated by the same index used in this study. Considering these, the more stable the cave environment the more similar the faunal elements at PESU, favoring some species over others (Tobin et al. 2013); especially species with high specialization for cave life, or edaphic spaces.

The habitat diversity hypothesis proposes that species diversity in a landscape will increase as the greater structural complexity increases, because of the higher resource abundance and the potential addition to the number of partitionable niche dimensions (MacArthur and MacArthur 1961). Environmental heterogeneity is correlated to patterns of groundwater crustacean richness (Eme et al. 2014), although it is not correlated to distribution patterns of this group (Zagmajster et al. 2014). Furthermore, cracks and stones, which increase environmental heterogeneity, may provide shelter for small invertebrates in caves (Carchini et al.1982). We found that habitat heterogeneity is an important factor explaining community composition.

Although the landscape scale explains better species composition, the local scale model suggests an influence of the habitat heterogeneity and stability on cave community. The variables *ESI* and habitat heterogeneity were important only in Buffer 250 m, the largest evaluated scale. In smaller buffers, such local variables were not important probably because other landscape variables had already explained the community variation. In that case, including *ESI* and habitat heterogeneity in smaller buffers would not increase the model explanation. It has long been known that cave ecosystems are highly vulnerable to external events, even those occurring at some distance from the cave (Gillieson and Thurgate 1999). This indicates the importance of studies on larger areas, which could avoid erroneous conclusions on the real influence of each epigean environmental variable on the cave communities. It is worthy to mention that in situations of geographically closer caves, as Ninho de Pérolas Cave and Gruta do Grilão Cave, the results found could be at least in part due to the 250 meters buffer superposition. However, the distance between caves was not related to caves invertebrate similarity.

Landscape use can even make terrestrial troglophile populations more isolated, severely reducing their dispersal possibilities, by conversion from forest to pasture (Eberhard et al. 1991). Hence, results of community influences by landscape structure (predominance of natural vegetation or disturbed spaces) clearly indicate the need to conserve the adjacent landscapes of caves in karstic zones. Furthermore, attention should be given not only for intact landscapes, but also to continuous forest corridors between caves, that promote fauna dispersal between habitat patches, that should be also protected. In this study, the caves surrounding landscapes show impacts of the human use, and the small remaining forest patches were important for cave invertebrate species maintenance.

Considering the current Brazilian legislation (Brazil. Decree nº 6.640/2008), there is an obligation to protect the area corresponding to the cave linear projection on the surface and also a radius of 250 meters around this projection (Portaria IBAMA nº 887/1990). Unfortunately, there are no studies showing an eventual efficiency of such radius to preserve cave communities. Our study could be the first step to improve Brazilian legislation, since it provides a new methodology to evaluate three aspects: cave invertebrate communities, cave physical traits and surface land use.

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