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Article

Taxonomic Distinctness of the subterranean fauna from Peruaçu Caves National Park, state of Minas Gerais, eastern Brazil

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Abstract: Limiting factors of subterranean environments, high relative air humidity and, especially, permanent darkness, represent ecological filters for organisms and biodiversity patterns of surface and subterranean communities display wide disparities. Subterranean diversity and singularity are, thus, better expressed when the common presence of rare and endemic species are considered. Our study aimed to describe the diversity of the cave fauna from 14 caves from Peruaçu Caves National Park (PCNP), eastern Brazil. We analyzed the regional diversity using the index that includes the average taxonomic distinction (TD - Δ +, AvTD). We recorded 1,674 individuals belonging to 10 Classes and 237 morphotypes, 11 troglobitic and two troglomorphic and possible troglobites. Greatest species abundance (N=330) and richness (s=76) were recorded at Lapa do Cipó cave, followed by Gruta Olhos d'Água (N=330, s=71), which shows the highest TD value (Δ + = 90.18) in relation to the others, including the richest Lapa do Cipó (Δ + = 85.24), consequence of the several taxonomic units with large number of species. The below-expected values of TD (Δ + = 87.70) may indicate anthropic impacts on these communities. Our results demonstrate that Gruta Olhos d' Água and Lapa do Cipó caves are the most important sites for the occurrence of endemic and troglobitic species and may be part of a complex system that should be considered for a more efficient conservation planning.
Keywords: *Diversity, Gruta Olhos d' Água cave, troglobites, subterranean environment.*

Distinção Taxonômica da fauna subterrânea do Parque Nacional Cavernas do Peruaçu, estado de Minas Gerais, leste do Brasil

***Resumo*:** Fatores limitantes dos ambientes subterrâneos como alta umidade relativa do ar e, principalmente, a falta de luz, representam filtros ecológicos para organismos e padrões de biodiversidade de comunidades superficiais e subterrâneas, nas quais mostram grandes disparidades. Diversidade e singularidade subterrâneas são, portanto, mais bem expressas quando os presença de espécies raras e endêmicas. Nosso estudo teve como objetivo descrever a diversidade da fauna da caverna de 14 cavernas do Parque Nacional das Cavernas de Peruaçu (PCNP), leste do Brasil. Analisamos a diversidade regional usando o índice que inclui a distinção taxonômica média (TD - Δ +, AvTD). Registramos 1,674 indivíduos pertencentes a 10 classes e 237 morfotipos, 11 troglóbios e dois troglomórficos e possíveis troglóbios. A maior abundância de espécies (N = 330) e riqueza (s = 76) foram registradas na caverna da Lapa do Cipó, seguida por Gruta Olhos d´Água (N = 330, s = 71), que mostra o maior valor de DT (Δ + = 90,18) em relação aos outros, incluindo a Lapa do Cipó mais rica (Δ + = 85,24), consequência das várias unidades taxonômicas com grande número de espécies. Os valores abaixo do esperado de TD (Δ + = 87,70) podem indicar impactos antrópicos nessas comunidades. Nossos resultados demonstram que as cavernas Gruta Olhos d 'Água e Lapa do Cipó são os locais mais importantes para a ocorrência de espécies endêmicas e troglóbias e pode fazer parte de um sistema complexo que deve ser considerado por mais planejamento eficiente de conservação.
Palavras-chave: *Diversidade, Gruta Olhos d' Água, troglóbios, ambiente subterrâneo.*

Introduction

Subterranean or hypogean environments have striking features which represent environmental filters, because selective regimen contrasts sharply with those of surface environments. Permanent darkness at deeper zones is the main difference (Hoenen 2005, Hervant et al. 2000, Poulson & White 1969), leading to the dependence of allochthonous energy inputs because photoautotrophic organisms do not thrive there (Poulson & Lavoie 2000). Environmental stability is other noteworthy aspect of subterranean ecosystems. Unlike surface communities, little variation occurs in parameters such temperature and air humidity, due to the isolation caused by the surrounding rock (Juberthie 2000, Culver & Pipan 2009). Such contrasts between subterranean and superficial environments are related to processes of colonisation and reproductive isolation of subterranean species (Trajano 2012).

Subterranean communities are formed by populations which present distinct ecological-evolutionary relationships with the environment and, consequently, may be classified at three categories (Racovitza 1907, Trajano 2012), according to its degree of specialisation to the subterranean realm: trogloxenes are those who need to leave the cave periodically in order to complete its life cycle because subterranean resources are insufficient (Racovitza 1907). Troglophiles are those capable of completing its life cycle inside as well as outside subterranean environments. They represent the majority of the taxa found at subterranean communities (Racovitza 1907). Some species only live at subterranean environments (Racovitza 1907), not being able to colonise surface environments anymore, because they evolved isolated at subterranean environments and, during this period, accumulated specialisations that hampers survival or reproduction in surface environments. They are called troglobites (Racovitza, 1907). This condition is recognised by the presence of autapomorphies acquired throughout evolutionary process, known as troglomorphisms (Holsinger & Culver 1988, Holsinger 1988, Trajano & Bichuette 2010). Even though the term troglomorphism (*sensu* Christiansen 1962) had been originally proposed for morphological characteristics, it has been applying to behavioural and physiological characteristics as well (Barr 1968). This classification has been extended and discussed by Trajano and Cobolli (2012) to include source-population concept and, thus, population characteristics has been included for recognizing the troglobitic status of a given species.

Diversity patterns of subterranean and superficial communities show significant disparities. Even though richness of subterranean communities is much lower when compared to superficial communities, it can be considered high on a global scale (Gibert & Deharveng 2002). In addition, when lineages that colonised both habitats at the same geographical area are compared, subterranean communities have much higher proportion of endemic species than superficial communities (Gibert & Deharveng 2002). Recognition of such patterns is essential to support conservation proposals (Trajano 2010).

Knowledge about Brazilian subterranean fauna has been broadened at the last two decades. The first faunistic lists were produced for the karst area of Ribeira Valley (Trajano & Gnaspini 1991), states of São Paulo and Paraná (Trajano & Bichuette 2010). Later, other regions had their diversity assessed, including karst areas at the states of Minas Gerais, Bahia, Mato Grosso do Sul, Goiás and Rio Grande do Norte (Gnaspini & Trajano 1994, Pinto-da-Rocha 1993, Trajano & Bichuette 2010, Ferreira et al. 2010, Gallão & Bichuette 2018).

Some are important because they have high species richness, presence of phylogenetic indicators or high genetic diversity. (Trajano et al. 2016). High genetic diversity is based on the degree of specialisation of individual species, with accumulation of autapomorphies, that may evolve into a troglobitic species, while phylogenetic indicators are related to the presence of biogeographical relicts (Trajano et al. 2016). Exclusively subterranean populations are generally fragile and represent one of the main arguments in favour of the conservation of caves and its systems (Trajano 2010, Trajano et al. 2016, Gallão & Bichuette 2018). For this reason, to understand the evolutionary processes and patterns that occur in underground environments, faunal studies are needed to identify high diversity spots and to propose actions and political for conservation. (Trajano et al. 2016).

We investigated the biodiversity of caves located at Peruaçu Caves National Park (PCNP), northern state of Minas Gerais, taking into account not only the number of species, but its identity as well. The region has 140 caves registered so far, of which, Gruta Olhos d' Água cave is the largest one, with approximately 9,100 m of conduits and passageways, and harbors the highest number of troglobites (Trajano et al. 2016, Gallão & Bichuette 2018). For this, two main questions were considered: 1) Do the PCNP caves have high phylogenetic diversity? 2) Does Gruta Olhos d 'Água cave present higher diversity compared to the other caves of the PCNP?

Materials and Methods

1. Study Area

We conducted the study herein presented in 14 caves located at Peruaçu Caves National Park (PCNP), municipalities of Itacarambi and Januária, northern of Minas Gerais state (Figure 1). The region has outcrops composed by carbonate rocks from Bambuí Group, more precisely laminated limestone and dolomites from Januária-Itacarambi Formation (Piló & Kohler 1991). Inside the limits of PCNP, Peruaçu river traverses about 17 Km of its valley surrounded by enormous rocky walls, channels and dolines, forming the Peruaçu river, left tributary of the upper-middle São Francisco River.

Peruaçu Valley, where PCNP is located, occurs in a transition zone between Cerrado and Caatinga morphoclimatic Domains (Ab'Saber 1977). Climate covering Peruaçu, according to Köppen-Geiger, is tropical humid with dry winters ("Aw") (Peel et al. 2007), characterised by dry winters, between March and October, and rainy summers, between April and November, with annual average temperature of 24°C and average annual rainfall of 800 mm (INMET 2010).

2. Samplings

We conducted field campaigns between the years along the years of 2013 and 2015 at the following caves: Lapa da Onça, Lapa d' Água, Lapa do Branco I, Lapa do Branco IV, Toca do Pedrinho, Toca Mina d'Água, Gruta Olhos d' Água, Lapa do Cipó, Lapa do Mogno, Gruta Troncos, Caverna dos Cascudos, Caverna Janelão, Caverna Boquete and Caverna Bonita (Figure 2). During this period, we visited Gruta Olhos d' Água seven times, Lapa do Cipó four times and only once the other caves.

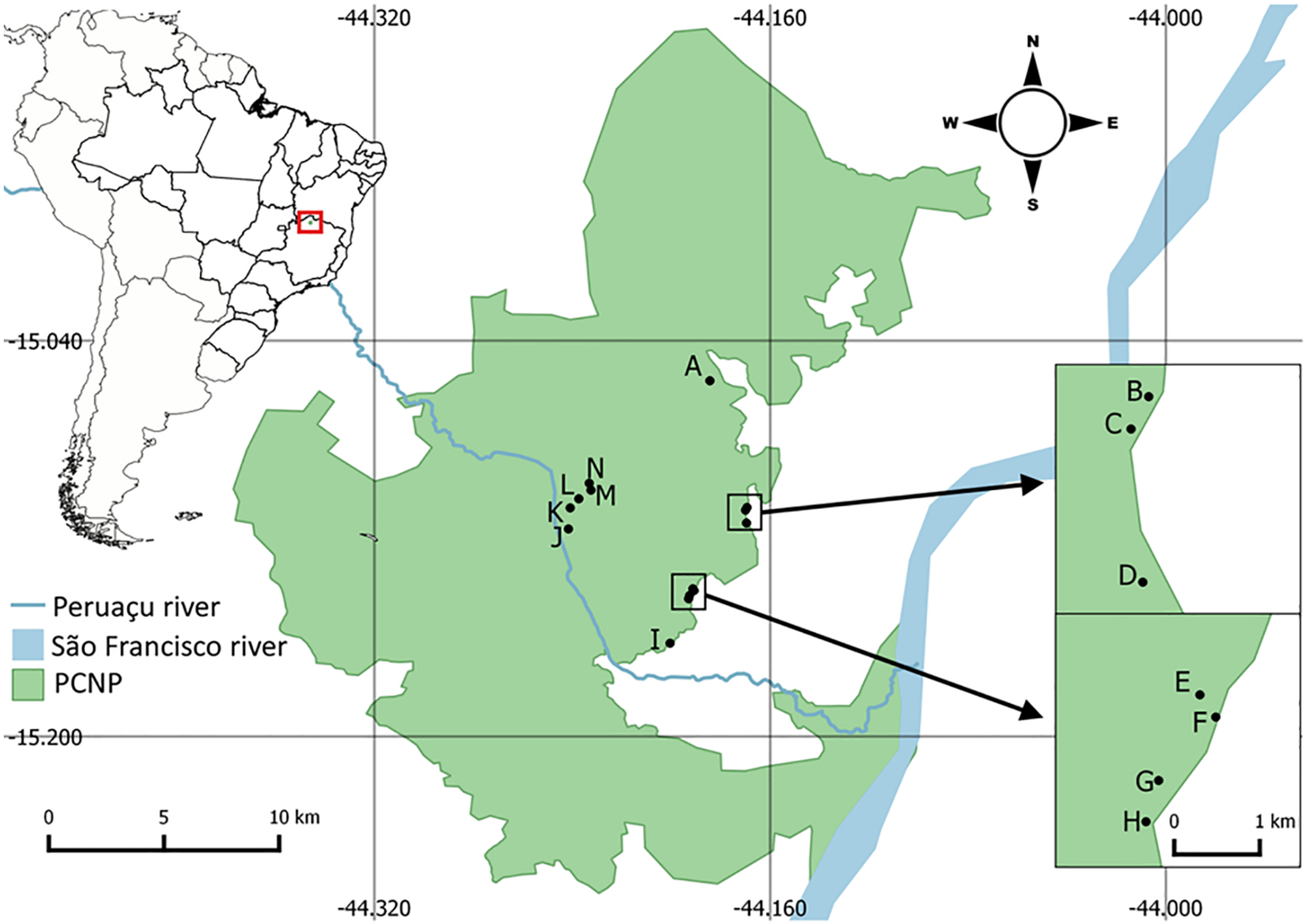

Figure 1. Study area. Peruaçu Cave National Park (PCNP), Itacarambi municipality, state of Minas Gerais, Brazil. A = Lapa do Cipó; B = Gruta Mina d' Água; C = Toca do Pedrinho; D = Gruta Olhos d' Água; E = Lapa da Onça; F = Lapa do Branco I; G = Lapa do Branco IV; H = Lapa dos Sonhos; I = Lapa do Mogno; J = Gruta Janelão; K = Gruta Bonita; L = Caverna Boquete; M = Gruta dos Troncos and N = Caverna dos Cascudos.

We sampled potential microhabitats by active search and then the collected specimens were euthanized and preserved in 50% and 70% alcohol. We then identified morphotypes at the least inclusive taxonomic level we could reach using specialised literature (Borror et al., 1989; Adis, 2002; Costa et al., 2006). In addition, we consulted specialists in order to refine identification: Bolfarini, M.P. (Orthoptera - LES/UFSCar), Brescovit, A. (Ctenidae – Instituto Butantan), Carvalho, L.S. (Pholcidae - UFMG), Chagas-Jr, A. (Chilopoda - UFMT), Fernandes, C.S. (Isopoda – LES/UFSCar), Gallão, J.E. (Scorpiones - LES/UFSCar), Gallo, J.S. (Diplopoda - LES/UFSCar), Prado, L.P. (Formicidae – Museu de Zoologia/USP), Cizauskas, I. (Araneae - Museu de Zoologia/USP), von Schimonsky, D.M. (Pseudoscorpiones - LES/UFSCar) and Salvador, R.D. (Gastropoda - State Museum of Natural History Stuttgart, Germany).

3. *Data analysis*

We used Taxonomic Distinctness index (TD) (Δ+, AvTD) for diversity analysis, defined as the mean distance between two randomly chosen species, traced by means of a Linnean or phylogenetic classification of all the species in the data-set (Warwick & Clarke 1998, Clarke & Warwick 2001).

Differently of a traditional diversity index, the Taxonomic Distinctness TD (Δ+, AvTD) take into account the abundance of rare and common species by giving them different weights (Warwick & Clarke 1998, Cianciaruso et al. 2009). Besides considering the relative contribution of each species at a given community by using the number of species and the distribution of individuals, TD also includes the taxonomic value of each species.

Taxonomic distinctness is, thus, estimated by the expected number of nodes between any two individuals of different species randomly drawn from the full species set. The biggest number of nodes or links among them, the higher will be the distinctness of a given species (Warwick & Clarke 1998, Cianciaruso et al. 2009). Also, Taxonomic Distinctness index is a robust measure, when compared to traditional indexes of diversity, because it is independent of sampling effort (Warwick & Clarke 1998). We used PRIMER 7 statistical package to calculate TD (Δ+, AvTD) (Clarke & Gorley 2015) using the data-set.

Results

We recorded a total abundance of 1,674 individuals inside all caves we visited, from 237 morphotypes inside ten Classes: Actinopterygii (Osteichthyes), Amphibia, Arachnida, Chilopoda, Clitellata, Diplopoda,

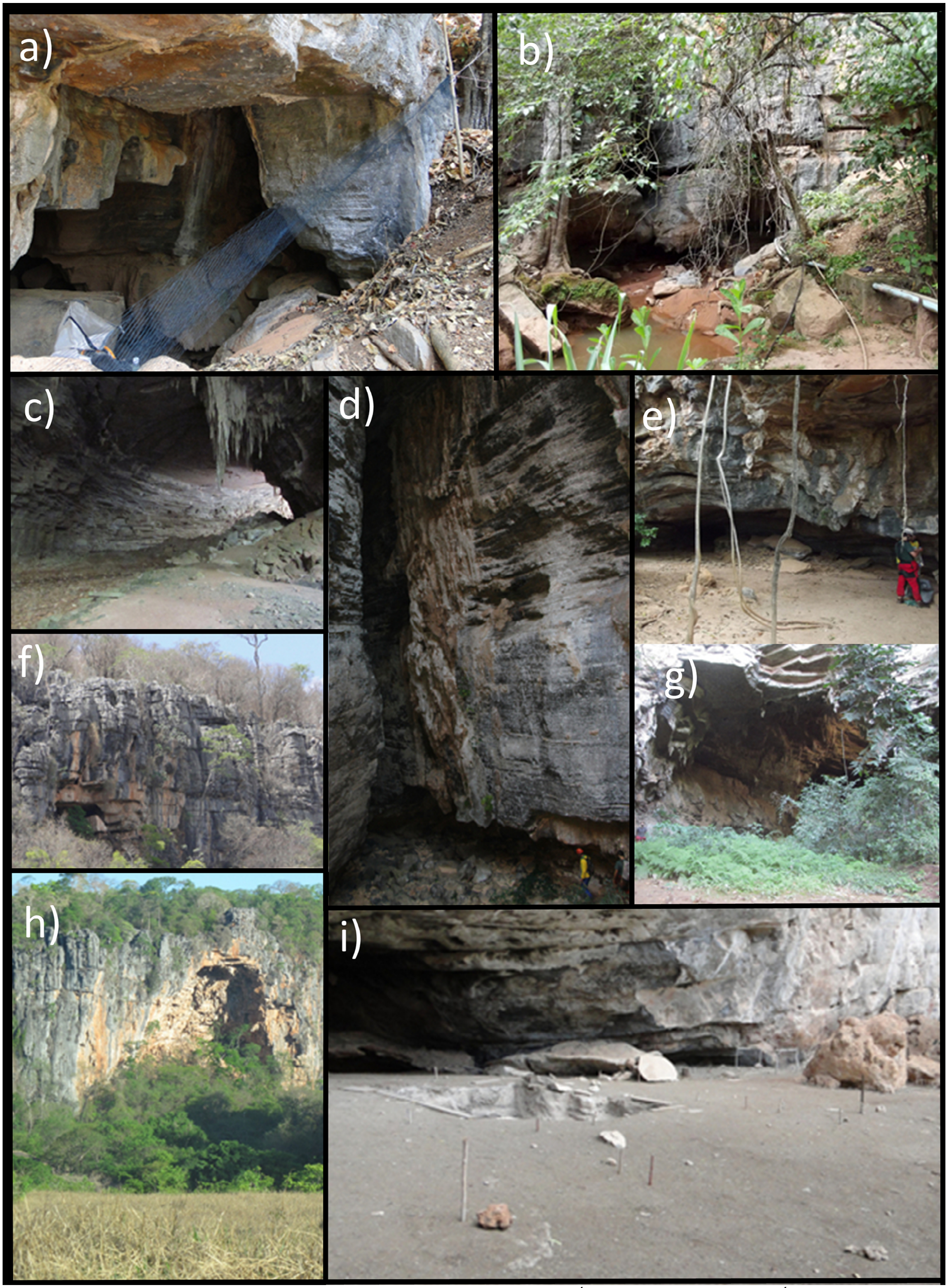

Figure 2. Caves studied at Peruaçu Caves National Park (PCNP). a) mist net armed at Gruta Olhos d' Água resurgence, b) Gruta Olhos d' Água resurgence, c) Caverna do Cascudo, d) Entrance Lapa do Cipó, e) Entrance Toca do Pedrinho, f) Entrance Gruta Bonita, g) Entrance Caverna dos Troncos, h) Entrance Gruta Janelão, i) archaeological excavations at Caverna Boquete. Photo: a, f – Arnone, I.; b, h, i – Bichuette, M. E.; c, g – Gallão, J.E.; d – Bolfarini, M.P.; e – Fonsceca-Ferreira, R.

Entognatha, Gastropoda, Insecta and Malacostraca. Both Arachnida and Insecta were richer (42.2% and 38.5%, respectively) and more abundant (46.6% and 35.9%, respectively) than the other recorded Classes.

The sole representative of Actinopterygii was the troglobitic catfish *T. itacarambiensis,* endemic from Gruta Olhos d' Água cave. Entognatha and Mammalia presented equal relative abundance of 1.06% and richness at 0.81% and 1.63%, respectively. Mammals were represented by the bats *Carollia perspicillata*, *Desmodus rotundus, Diphylla ecaudata* and an unidentified Glossophaginae, all recorded at Gruta Olhos d' *Água*. Amphibia, Clitellata and Actinopterygii, were the less abundant, with 0.22%, 0.28% and 0.67%, respectively and the less rich, with 0.81%, 0.81% and 0.4%, respectively. Diplopoda had an abundance of 1.63% and a richness of 2.04%, while Chilopoda had abundance of 1.23% and richness of 2.86%. Diplopods *Katantodesmus* showed a small abundance in several stretches of Gruta Olhos d' Água, particularly at sediment banks.

Relative abundance of Malacostraca and Gastropoda represented 8.65% and 2.58% out of the total, respectively. When considering relative richness, Gastropoda had 6.55% and Malacostraca, 3.27%. Spiders, herein including both infraorders Araneomorphae and Mygalomorphae, represented 60.7% of all arachnids recorded, with predominance of Araneomorphae. Less representative but not least important, were the arachnids of the following Orders: Opiliones (14.3%), Amblypygi (1.3%), Pseudoscorpiones (12.1%), Scorpiones (1.2%), Acari (5.4%) and Opilioacarida (0.9%) (Figure 3). Insects were represented by 13 Orders with the predominance of Coleoptera (19.3%), followed by Lepidoptera (16.6%) and Diptera (19.3%).

The PCNP has 11 troglobitic species described (Table 1), such as the amphibious isopod *Xangoniscus odara* Campos-Filho, Araujo & Taiti, 2014 (Figure 4a), found at small puddles (Campos-Filho et al. 2014) and under submerged rocks inside Lapa do Cipó cave;

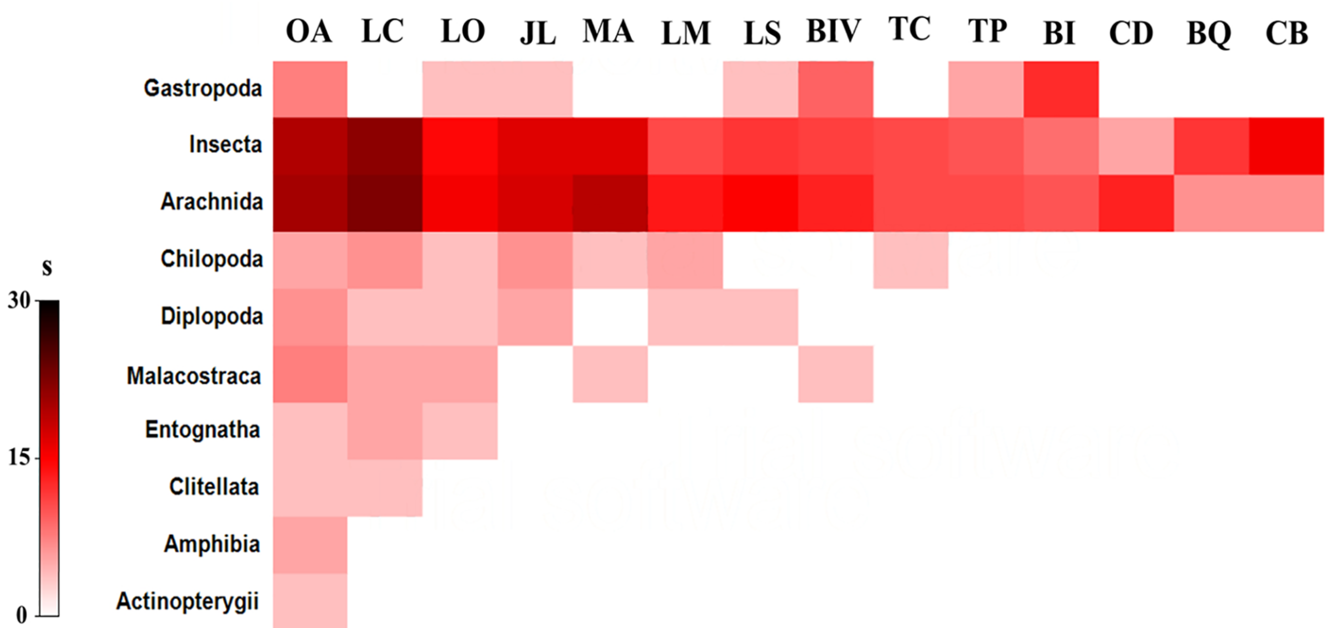

Figure 3. Species richness among Classes at 14 caves studied at Peruaçu Caves National Park (PCNP), Itacarambi municipality, state of Minas Gerais, Brazil. OA = Gruta Olhos d' Água; LC = Lapa do Cipó; MA = Gruta Mina d' Água; JL = Gruta do Janelão; LO = Lapa da Onça; CB = Caverna Bonita; BI = Lapa do Branco I; BIV = Lapa do Branco IV; LS = Lapa dos Sonhos; LM = Lapa do Mogno; BQ = Caverna Boquete; TC = Caverna Troncos; CD = Caverna Cascudo and TP = Toca do Pedrinho.

Table 1. Described troglobitic species of the PCNP.

Specie	Cave
Trichomycterus itacarambiensis Trajano & de Pinna, 1996	Gruta Olhos d' Água
Iandumoema uai Pinto-da-Rocha, 1996	Gruta Olhos d' Água and Lapa do Cipó
Pseudochthonius biseriatus Mahnert, 2001	Gruta Olhos d' Água
Charinus eleonorae Baptista & Giupponi, 2003	Gruta Olhos d' Água and Lapa do Cipó
Endecous peruassuensis Bolfarini, 2015	Gruta Olhos d' Água and Lapa do Cipó
Xangoniscus odara Campos-Filho & Taiti, 2016	Lapa do Cipó
Xangoniscus itacarambiensis Bastos- Pereira, Souza & Ferreira, 2017	Gruta Olhos d' Água
Relictopiolus galadriel Pérez-González, Monte & Bichuette, 2017	Gruta Olhos d' Água
Spelaeogammarus uai Bastos-Pereira & Ferreira, 2017	Lapa d' Água do Zezé
Spelaeometra gruta Polhemus e Ferreira, 2018	Lapa d' Água do Zezé, Lapa do Nestor, Lapa do Saco Velho and Lapa do Caboclo
Schendylops janelao Nunes, Chagas-Jr & Bichuette, 2019	Gruta do Janelão

the cricket *Endecous peruassuensis* Bolfarini & Bichuette, 2015 (Figure 4b) from Gruta Olhos d' Água and Lapa do Cipó caves (Bolfarini & Bichuette 2015), the relict Kimulidae harvestmen, *Relictopiolus galadriel* Pérez-González, Monte & Bichuette, 2017 (Pérez-González et al. 2017) (Figures 4c), the pseudoscorpion *Pseudochthonius biseriatus* Mahnert, 2001 (Figure 4d) and the recently described centipede from Gruta do Janelão cave, *Schendylops janelao* Nunes, Chagas-Jr & Bichuette, 2019 (Nunes et al. 2019) (Table 1). In addition to those described, we recorded species with conspicuous troglomorphisms such as the Diplopoda of family Oniscodesmidae (Figure 4f) and one species of Collembola (Entognatha). For troglophile category, a new spider of genus *Plato* was recorded (I. Cizauskas, pers. comm).

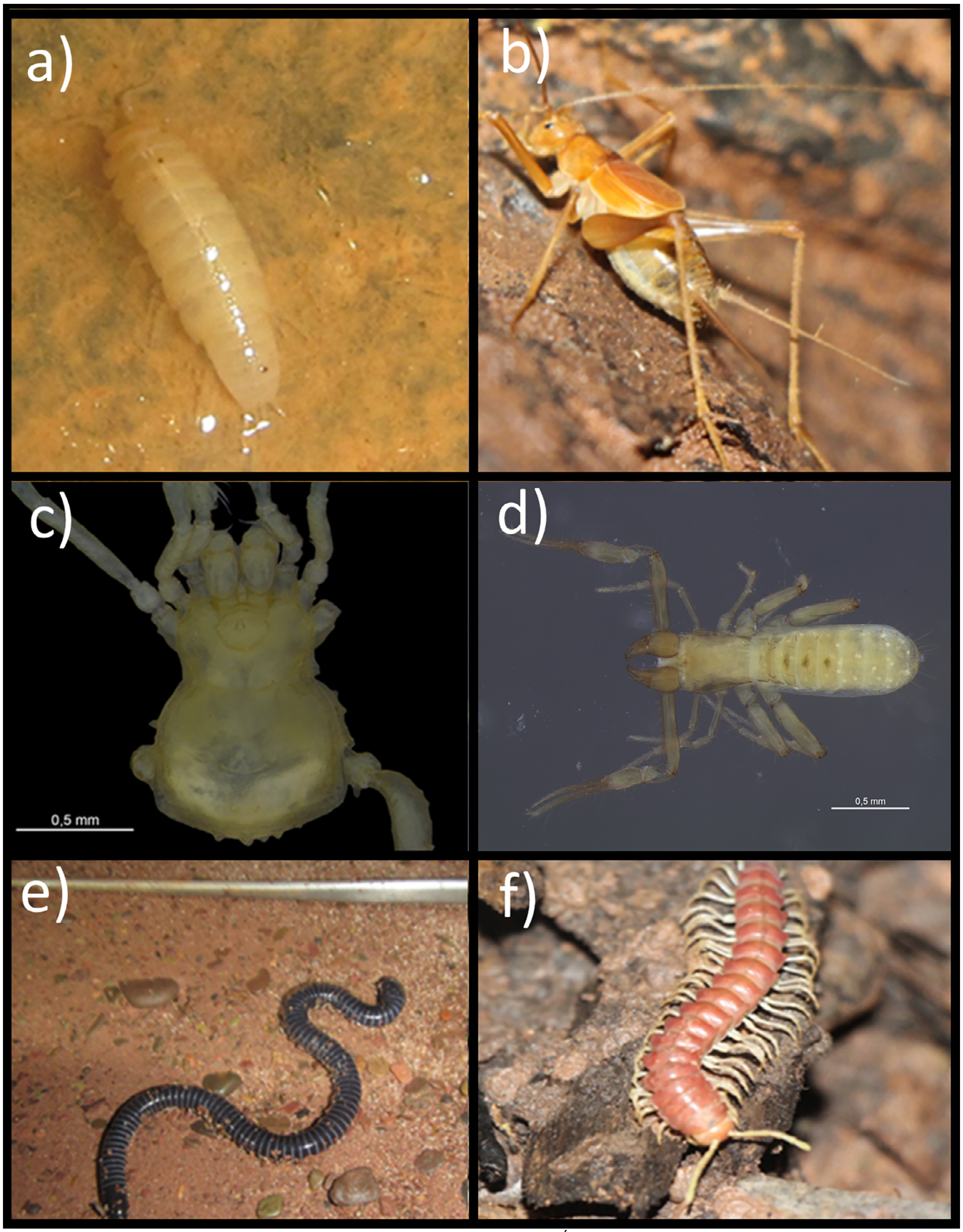

Figure 4. Records of new species and new records of species at Gruta Olhos d' Água and Lapa do Cipó. a) *Xangoniscus odara* (Isopoda) (Lapa do Cipó, troglobitic), b) *Endecous peruassuensis* (Orthoptera) (Gruta Olhos d' Água and Lapa do Cipó, troglobitic), c) *Relictopiolus galadriel* (Opiliones, Kimulidae) (Gruta Olhos d' Água, troglobitic, relict) dorsal habitus, d) *Pseudochthonius biseriatus* Mahnert, 2001 (Pseudoscorpiones) (Gruta Olhos d' Água, troglobitic), e) *Siphonops paulensis* (Gymnophiona) (Gruta Olhos d' Água, accidental), f) *Katantodesmus* n. sp. (Gruta Olhos d' Água, troglobitic). Photo: a, e - von Shimonsky, D.M.; b,d,f – Bolfarini, M.P.; c, d– Fernandes L.B.R.

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Development and extension of aphotic zones were the most contrasting physical parameters when comparing the caves (Table 2). Gruta Olhos d' Água is the longest cave with an extensive aphotic zone in the region, Gruta do Janelão presents large galleries and an extensive twilight zone with several openings to the epigean environment. The other caves show small extensions, some without aphotic zones or perennial drainages, such as Lapa do Sonho, Toca do Pedrinho and Gruta Mina d' Água. A general characterization of each cave is presented at Table 2.

Expected Taxonomic Distinctness (TD, Δ+) was 87.7. The highest value of TD (Δ+) was of Gruta Olhos d' Água (Δ+ = 90.18) (Figure 5).

Table 2. Description of the caves studied at PCNP, Itacarambi, Minas Gerais, Brazil.

Cave	Geographical coordinates	Horizontal Development (m)	Entrance	Entrance Altitude (m)	Water Stream	Zonation	Degree of preservation
Gruta Olhos d' Água	S15.1137;W44.1696	9,100	Resurgence	NI	Present	EZ/TZ/AZ	High
Lapa do Branco IV	S15.1443;W44.1930	200	Sinkhole	NI	Absent	EZ/TZ	Medium
Toca do Pedrinho	S15.1085;W44.1700	200	Sinkhole	510	Absent	EZ/TZ	Medium
Lapa da Onça	S15.1403;W44.1913	1,680	Sinkhole	501	Present	EZ/TZ/AZ	Medium
Lapa do Cipó	S15.0562;W44.1844	1,800	Sinkhole	616	Present	EZ/TZ/AZ	High
Gruta Janelão	S15.1161;W44.2416	4,740	Sinkhole	520	Present	EZ/TZ/AZ	Medium
Lapa do Mogno	S15.16231;W44.2004	230	Sinkhole	506	Present	EZ/TZ/AZ	Medium
Gruta Mina d' Água	S15.1074;W44.1694	160	Resurgence	507	Absent	EZ/TZ	Medium
Gruta Bonita	S15.1076;W44.2409	420	Sinkhole	NI	Absent	EZ/TZ/AZ	Low
Lapa do Branco I	S15.1430;W44.1926	180	Sinkhole	544	Absent	EZ/TZ	Medium
Caverna dos Troncos	S15.1004;W44.2325	220	Sinkhole	572	Present	EZ/TZ	Medium
Lapa dos Sonho	S15.0804;W44.1004	190	Sinkhole	NI	Absent	EZ/TZ	Medium
Gruta Boquete	S15.1039;W44.2374	400	Sinkhole	NI	Absent	EZ/TZ/AZ	Low
Caverna dos Cascudos	S15.0976;W44.2332	180	Sinkhole	546	Present	EZ/TZ	Medium

EZ = entrance zone; **TZ** = twilight zone; **AZ** = aphotic zone; **NI** = no information.

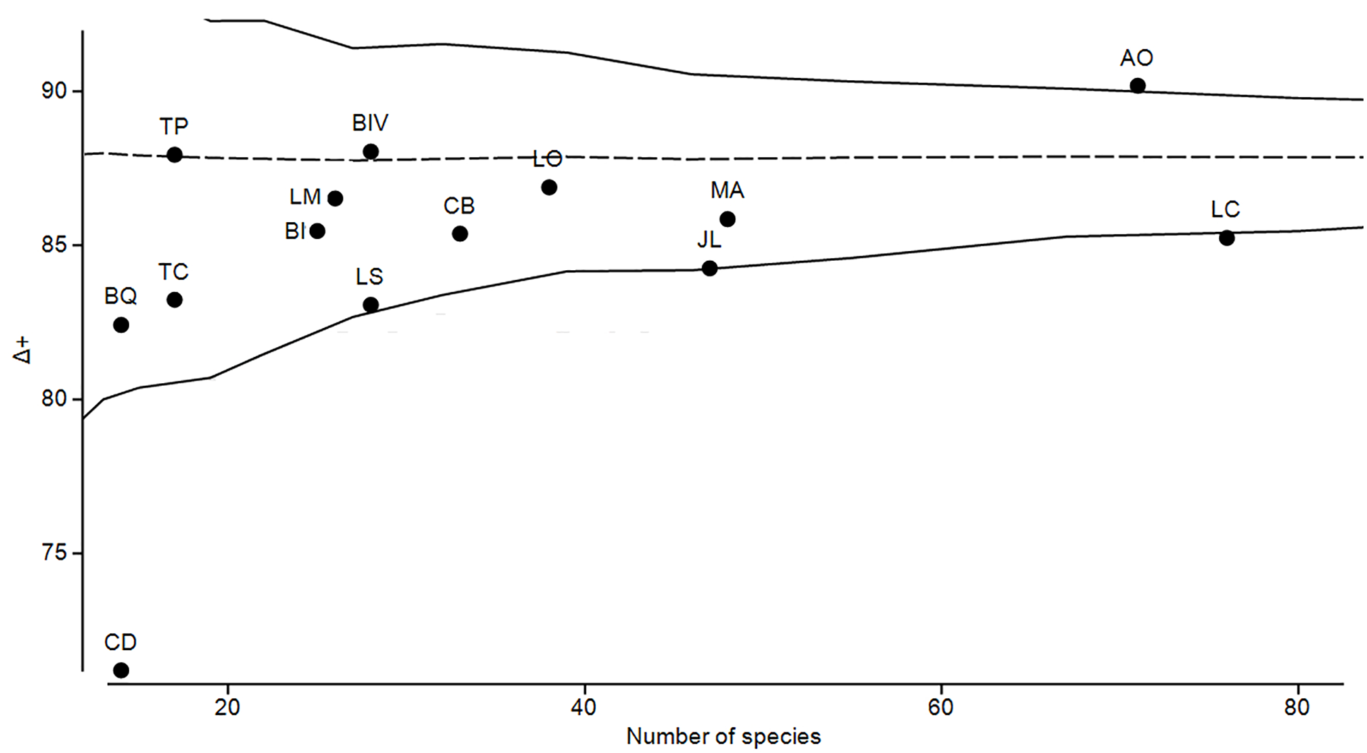

Figura 5. Values of taxonomic distinctness for the 14 caves from Cavernas do Peruaçu National Park (PNCP), Itacarambi, state of Minas Gerais, Brazil. Average Taxonomic Distinctness (Δ+, AvTD). OA = Gruta Olhos d' Água; LC = Lapa do Cipó; MA = Gruta Mina d' Água; JL = Gruta do Janelão; LO = Lapa da Onça; CB = Caverna Bonita; BI = Lapa do Branco I; BIV = Lapa do Branco IV; LS = Lapa dos Sonhos; LM = Lapa do Mogno, BQ = Caverna Boquete; TC = Caverna Troncos; CD = Caverna Cascudo and TP = Toca do Pedrinho.

Four caves presented values of TD lower than expected and outside the confidence interval: Caverna Cascudo (Δ+ = 71.21), Caverna Boquete (Δ+ = 81.54) and Lapa dos Sonhos (Δ+ = 83.07) (Figure 5, Table 3).

Discussion

Subterranean fauna of PCNP is remarkable. Our results corroborate the hypothesis that Gruta Olhos d'Água cave is a spot of subterranean biodiversity (Trajano et al. 2016) probably due the long period of environmental stability, as evidenced by its high troglobitic species richness, at least 13 so far (Perez-González et al. 2017, Gallão & Bichuette 2018). In addition, we identified another important locality of endemic and troglobitic species, the Lapa do Cipó cave (Table 4).

Besides the great number of taxa, we also recorded a significant number of troglobites at Peruaçu region. For Brazil, the highest number of troglobites is recorded at Areias System, located at the Alto Ribeira karst area, state of São Paulo, accounting for 20 species described so far, followed by Alambari de Cima cave, at the same region, with 10 troglobites (Trajano & Bichuette 2010, Trajano et al. 2016). Other spot of high subterranean diversity (Gallão & Bichuette 2015, Trajano et al. 2016) has been identified at Chapada Diamantina region, at the state of Bahia, with 23 troglobites recorded at 11 caves, 13 of them from a single cave.

The analysis of taxonomic distinction (Δ+, AvTD) takes into account that the more phylogenetically distinguishes species in a given community, the greater the diversity (Cianciaruso et al. 2009). However, when taxonomic relationships are taken into account, high TD values (Δ+, AvTD) indicate high diversity preserved spots (Clarke & Warwick 2001), as we observed for Gruta Olhos d 'Água (s = 71, Δ+ = 90.18) (Figure 5). On the other hand, despite presenting higher richness, Lapa do Cipó presented a lower than expected TD (s = 76, Δ+ = 85.24), indicating possible degradation and / or the existence of some genera with many species (Figure 5).

Among the 14 caves we studied, Gruta Olhos d' Água is remarkable by its high faunistic singularity, as shown by the high value of Taxonomic Distinctness. This value also indicates the presence of singular taxa as, for instance, troglobitic species (Cianciaruso et al. 2009, Gallão & Bichuette 2015).

A relict species (*Relictopiolus galadriel*) recorded at Gruta Olhos d'Água corroborates environmental stability, enabling survival and evolution of species whilst its populations and sister groups outside caves were extinct by several factors as, for instance, climatic changes, competitive exclusion and stochastic factors.

The Lapa do Cipó cave presented the highest species richness, among which the troglobitic populations of *I. uai*, *C. eleonorae* (Monte et al. 2015), *E. peruassuenssis* (Bolfarini & Bichuette 2015) and *X. odara* (Campos-Filho et al. 2014). Besides the importance of its fauna, species richness is also high. Even more, these three troglobitic populations occur at Lapa do Cipó and Gruta Olhos d' Água caves, suggesting that both caves are part of a complex system. However, Lapa do Cipó showed a low TD value, probably because of its faunistic similarity with other caves.

In a study conducted at Chapada Diamantina, state of Bahia, a highest value of TD was recorded for the lowest richness cave, followed by the cave with the highest number of troglobitic species (Gallão & Bichuette 2015). In the region of Presidente Olegário, state of Minas Gerais, the highest TD value among seven caves studied is related to the presence of frugivorous guano patches and the presence of some animals that have a preference for this type of substrate such as Chilopoda of the genus *Lamyctes* (Zepon 2015).

Lower values of TD may indicate severe environmental degradation and pollution (Warwick & Clarke 1998). TD values at Caverna Cascudo, Caverna Boquete, Lapa dos Sonhos and Gruta Mina d' Água caves were significantly lower than expected at least for one of these,

Table 3. Taxonomic Distinctness values of the caves studied at PCNP, Itacarambi, Minas Gerais, Brazil.

Cave	Δ+	N	s	Tgb
Gruta Olhos d' Água	90.18	330	71	10
Lapa do Branco IV	88.04	84	28	0
Toca do Pedrinho	87.94	26	17	0
Lapa da Onça	86.88	108	38	0
Lapa do Mogno	86.52	69	26	0
Gruta Mina d' Água	85.85	125	48	0
Caverna Bonita	85.56	145	32	0
Lapa do Branco I	85.47	66	25	0
Lapa do Cipó	85.24*	330	76	4
Caverna Janelão	84.62	197	47	0
Caverna dos Troncos	83.24	34	17	0
Lapa dos sonhos	83.07*	78	28	0
Caverna Boquete	81.54*	50	14	0
Caverna do Cascudo	71.21**	27	14	0

Δ+ = average Taxonomic Distinctness; **N =** number of individuals; **s =** species richness and **Tgb =** number of troglobitic species. '*' p<0,05 and '**'p< 0,001.

Table 4. Faunistic listing with the abundance of taxa for the 14 caves from Peruaçu Caves National Park (PNCP), Itacarambi, state of Minas Gerais, Brazil. **OA** = Gruta Olhos d' Água, **LC** = Lapa do Cipó, **MA** = Gruta Mina d' Água, **JL** = Gruta do Janelão, **LO** = Lapa da Onça, **CB** = Caverna Bonita, **BI** = Lapa do Branco I, **BIV** = Lapa do Branco IV, **LS** = Lapa dos Sonhos, **LM** = Lapa do Mogno, **BQ** = Caverna Boquete, **TC** = Caverna Troncos, **CD** = Caverna Cascudo, **TP** = Toca do Pedrinho, SubF = Subfilo, SubC = Subclass, O = Ordem, F = Family, SubF = Subfamily, C = Class, InfO = Infraordem and * = troglobites not yet described.

TÁXON	CB	BQ	CD	JL	OA	TC	MA	LO	BI	BIV	LC	LM	LS	TP
SubC. Lissamphibia														
O. Anura														
sp. 1					3									
O. Gymnophiona														
F. Siphonopidae														
Siphonops paulensis Boettger, 1892					1									
C. Clitellata														
sp. 1											2			
sp. 2					3									
C. Arachnida														
sp. 1					1									
sp. 2	1													
SubC. Acari														
O. Trombidiformes														
F. Erythraeidae														
sp. 1	1				4		1			6		1		
sp. 2	3				2		1					1		
sp. 3					1		1							
sp. 4					10					1	1	1		
O. Ixodida														
F. Ixodidae														
sp. 1							1		1					
sp. 2							1	1						
sp. 3							1							
O. Opilioacarida														
sp. 1				7						1				
F. Argasidae														
sp. 1					3									
O. Amblypygi														
F. Charinidae														
Charinus eleonorae Baptista & Giupponi, 2003					11						4			
F. Phrynichidae														
Trichodamon princeps Mello-Leitão, 1935							1		2	1				
O. Araneae														
InfraO. Araneomorphae														
sp. 1					1									
sp. 2								1						
sp. 3				1										

continuation Table 4

F. Araneidae														
sp. 1						1	1				8			
sp. 2												1		
Alpaida sp. 1					1			1						
F. Caponiidae														
sp. 1				1										
Nops sp. 1				2										
F. Corinnidae														
sp. 1			1	1										
sp. 2							1							
F. Ctenidae														
sp. 1				1		1	3				3		1	
sp. 2											1			
F. Deinopidae														
sp. 1													1	
F. Filistatidae														
sp. 1							1							
Misionella sp. 1		27								2		1	4	
F. Linyphiidae														
Agyneta sp. 1				1										
Sphecozone sp. 1					2									
F. Lycosidae														
sp. 1								2					2	
sp. 2					1									
F. Mysmenidae														
sp. 1	1													
F. Nesticidae														
Eidmannella pallida Emerton, 1875											7			
F. Ochyroceratidae														
Ochyrocera sp. 1				1										
F. Oonopidae														
sp. 1					1								1	
Neotrops sp. 1				1										
F. Pholcidae														
sp. 1	1			7				20		1	1	2		1
sp. 2													3	
Ibotyporanga sp. 1							1							
Mesabolivar sp. 1			1		1		5	2	2	3	5	3	2	1
F. Prodidomidae														
sp. 1								1			1			
F. Salticidae														
sp. 1			1			4	5				1	5	2	

continuation Table 4

F. Scytodidae														
sp. 1				2										
Scytodes sp. 1				6										
Scytodes sp. 2				4				1						
F. Segestriidae														
sp. 1				1										
Ariadna sp. 1				4										
F. Selenopidae														
Selenops sp. 1					2									
F. Sicariidae														
sp. 1		1					5	2			3			
sp. 2											1			
Loxosceles sp. 1			4			2	8	4	5	6	19	7	3	1
Loxosceles karstica Bertani, von Schimonsky & Gallão, 2018				6										
Loxosceles ericsoni Bertani, von Schimonsky & Gallão, 2018	4	1												
F. Tetrablemmidae														
Matta sp. 1				14										
F. Tetragnathidae														
sp. 1	8		3			2	6	20		1	1	8	1	2
sp. 2													2	
sp. 3													3	
Leucauge sp. 1								3	9	10				2
F. Theridiidae														
sp. 1				1	2						4		6	
sp. 2											1			
sp. 3					2						1			
sp. 4											1			
sp. 5											1			
Nesticodes rufipes Lucas, 1846					14						8			
Steatoda sp. 1					1									
F. Theridiosomatidae														
sp. 1												4		
sp. 2	1													
sp. 3	1										2			
Plato sp. 1	11		1								12			
Plato sp. 2*											5			
F. Thomosidae														
sp. 1					1									
F. Trechaleidae														
sp. 1	2						3	5	4		3	3		
sp. 2						1					1			

continuation Table 4

F. Uloboridae														
sp. 1				34										
sp. 2			1											
InfraO. Mygalomorphae														
sp. 1							1	4						
O. Opiliones														
F. Cosmetidae														
sp. 1	1		9	1	1	1					24			
sp. 2			1		2									
F. Sclerosomatidae														
SubF Gagrellinae														
sp. 1											5			
F. Gonyleptidae														
sp. 1											1		2	
sp. 2											1			
Eusarcus aduncus Mello Leitão, 1942			1		13						6			
Eusarcus cavernicola Hara & Pinto-da-Rocha, 2010			1		12						11			
Iandumoema uai Pinto-da-Rocha, 1996					20						15			
F. Kimulidae														
Relictopiolus galadriel Pérez-González, Monte & Bichuette, 2017					12									
F. Sclerosomatidae														
sp. 1			1	1							1		10	1
O. Pseudoscorpiones														
sp. 1							2			3		4	1	1
sp. 2							2					2		
F. Cheiridiidae														
sp. 1					1									
sp. 2	1													
F. Chernetidae														
sp. 1													1	
Spelaeochernes bahiensis Brum, 1975	6													
F. Chthoniidae														
Pseudochthonius sp. 1							1				3			
Pseudochthonius biseriatus Mahnert, 2001					2		1				1			
F. Olpiidae														
sp. 1					14		3	7		2				
Progarypus sp. 1					7		2	1	4					1
Progarypus setifer Mahnert, 2001	1	3		27										
O. Scorpiones														

continuation Table 4

Tityus serrulatus Lutz & Mello, 1922			1	2	1						
O. Palpigradi											
F. Eukoeneniidae											
Eukoenenia sp. 1		1									
C. Chilopoda											
O. Geophilomorpha											
F. Geophilidae											
Hyphydrophilus sp. 1	3										
F. Schendylidae											
Schendylops sp. n. *									1		
Schendylops janelao Nunes, Chagas-Jr & Bichuette, 2019	1										
O. Scolopendromorpha											
F. Scolopendridae											
Otostigmus sp. 1								1			
Newportia Tidops balzanii Silvestri, 1895				2					2		
Otostigmus muticus Karsch, 1888					2				2		
F. Pselliodidae											
Sphendononema guildingii Newport, 1845	3		1			1		3			
C. Diplopoda											
sp. 1	2	12						1		1	
O. Polyxenida											
sp. 1					1						
O. Polydesmida											
sp. 1		7							1		
O. Spirostreptida											
sp. 1	2										
F. Oniscodesmidae											
sp. 1							1				
sp. 2		1					1				
sp. 3							1				
F. Bulimulidae											
Drymaeus sp. 1						3					
Kora corallina Simone, 2012	2					3	1			1	1
F. Epiphragmophoridae											
Epiphragmophora bernardius Pilsbry & Ihering, 1900							2				
F. Helicinidae											
Helicina brasiliensis Gray, 1824						6					
F. Odontostomidae											
Cyclodontina inflata Wagner, 1827						1					
F. Pomatiopsidae											
Idiopyrgus souleyetianus Pilsbry, 1911						5					
F. Scolodontidae											

continuation Table 4

Happia vitrina Wagner, 1827					1									
Systrophia sp. 1									1					
F. Streptaxidae														
Martinella aff. *prisca* Thiele, 1927									1					
Streptartemon cookeanus Baker, 1914									3					
Streptaxis tumescens Suter, 1900					1				3					1
F. Subulinidae														
Obeliscus sp. 1									1					
SubF. Hexapoda														
C. Entognatha														
O. Collembola														
sp. 1*					6			1			8			
sp. 2											4			
C. Insecta														
O. Archaeognatha														
sp. 1								1						
O. Blattaria														
sp. 1				3	1						2			
sp. 2											1			
F. Blatidae														
sp. 1											2		1	
F. Blattellidae														
sp. 1				3	1						2			
O. Coleoptera														
sp. 1				9							2			
sp. 2	1				27		1			1	12			
sp. 3			1		1									
sp. 4							4							
sp. 5					1					9	1			
sp. 6						5						4		
sp. 7						1	7				2			
sp. 8						1								
sp. 9						1								
sp. 10														4
sp. 11														1
sp. 12										1				
sp. 13										1				
sp. 14							1							
sp. 15											4			
sp. 16											1			

continuation Table 4

F. Carabidae														
Nemotarsus sp. 1	6													
sp. 1				2										
F. Curculionidae														
sp. 1	1													
F. Elateridae														
sp. 1	1													
F. Endomychidae														
sp. 1	7													
F. Ptilodactylidae														
sp. 1					12									
F. Staphylinidae														
sp. 1	1				5	1		2			2			
sp. 2	1				7		1	1			8			
sp. 3										1				
O. Diptera														
sp. 1							1				4	2	5	2
sp. 2											1	1		
F. Cecidomyiidae														
sp. 1				1	1					12				
F. Ceratopogonidae														
sp. 1										2				
sp. 2	1													
F. Chironomidae														
sp. 1				20										
sp. 2				2										
F. Culicidae														
sp. 1											4	1	1	
sp. 2													1	
F. Dolichopodidae														
sp. 1	2	1												
F. Drosophilidae														
Drosophila sp. 1					23									
F. Keroplatidae														
sp.1					1									
Neoditomyia sp. 1							2							
F. Lauxaniidae														
sp. 1											1			
sp. 2		1												
F. Limoniidae														
sp. 1				1	3		3				1			

continuation Table 4

F. Milichiidae														
sp. 1				1	3									
F. Phoridae														
Conicera sp. 1					2									
F. Psychodidae														
sp. 1		1		1	4									
sp. 2											1			
F. Sciaridae														
sp. 1											1			
F. Sphaeroceridae														
sp. 1					1									
Ephidroidea sp. 1	1			1										
Ephidroidea sp. 2				1										
O. Hemiptera														
sp. 1					1	1	4	1			6		7	1
sp. 2													1	
F. Cixiidae														
sp. 1							1							
F. Lygaeidae														
sp. 1				1										
F. Miridae														
sp. 1	1													
F. Reduviidae														
Zelurus sp. 1	3	5		2	1		3	5			2			
Zelurus ochripennis Stal, 1854									1					
F. Gerridae														
Brachymetra albinervis Amyot & Serville, 1843						3								
O. Hymenoptera														
F. Formicidae														
sp. 1		1	1	1			1		3	3	4		2	4
sp. 2							1	1						
sp. 3								1						
sp. 4								1						
sp. 5								1						
Brachymyrmex sp. 1					5									
Brachymyrmex sp. 2					2									
Cephalotes atratus Linnaeus, 1758					1									
Hypoponera sp.1											1			
Pheidole sp. 1					1									
Sericomyrmex sp. 1				1										
Solenopsis sp. 1								2						

continuation Table 4

O. Lepidoptera													
sp. 1						2	1			2			1
sp. 2						1							
F. Noctuidae													
sp. 1	9		5					1		4			
F. Tineidae													
sp. 1	10	4	4			7		1		19	7	9	
sp. 2		1				4							
sp. 3		1											
O. Neuroptera													
sp. 1				2									
sp. 2							1						
F. Myrmeleontidae													
sp. 1	1	2											
F. Mantispidae													
sp. 1											1		
O. Orthoptera													
sp. 1			1			3	1			11	2	1	
sp. 2							1			1			
sp. 3				1									
F. Gryllidae													
sp. 1				1									
F. Mogoplistidae													
sp. 1										1			
F. Phalangopsidae													
sp. 1								3		3			
sp. 2	3		1		7	2							1
F. Phalangopsidae													
Endecous peruassuenssis Bolfarini & Bichuette, 2015				15						15			
O. Psocoptera													
sp. 1	43	1		13		11	4		4	5	2	4	
O. Thysanura													
sp. 1										1			
O. Zygentoma													
sp. 1				3									
C. Malacostraca													
O. Isopoda													
F. Armadillidae													
Cubares sp. 1						3							

continuation Table 4

F. Dubinoniscidae					
sp. 1	14				
sp. 2		2	2		
sp. 3		4			
F. Scleropactidae					
sp. 1				1	
F. Stylonicidae					
Xangoniscus itacarambiensis Bastos-Pereira, Souza & Ferreira, 2017		9			
Xangoniscus odara Campos-Filho, Araujo & Taiti, 2014					20
sp. 1		1			
C. Osteichthyes					
O. Siluriformes					
F. Trichomycteridae					
Trichomycterus itacarambiensis Trajano & Pinna, 1996		12			
C. Mammalia					
O. Chiroptera					
F. Phyllostomidae					
Carollia perspicillata Linnaeus, 1758		9			
Desmodus rotundus Geoffroy, 1810		6			
Diphylla ecaudata Spix, 1823		1			
Sub. F. Golossophaginae					
sp. 1		3			

Caverna Boquete, we can state that this value may be related to anthropic impacts because of visitation. Non-significant values of TD were also found at caves from other localities. Zepon (2015), for instance, argued that the low value found at Gruta Juruva cave, Presidente Olegário, state of Minas Gerais, was due to low variety and quality of resources. In caves from Bahia, Gallão & Bichuette (2015) associated the low values of TD to extensive diamond mining in the past, which continues nowadays as a residual and clandestine activity.

Our results show that contextualized studies of diversity are indispensable to conservation policies because, more than only characterize the fauna and spots of troglobitic occurrence, they also help the identification of complex subterranean systems and expand the potential for subsequent studies. Those discoveries are fundamental to conservation of the entire subterranean systems and its area of influence, a much more efficient approach to subterranean conservation than those focusing only in a given cave.

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Author contributions

Bruno Gabriel Oliveira do Monte - Substantial contribution in the concept and design of the study, contribution to data collection, contribution to data analysis and interpretation, contribution to manuscript preparation, contribution to critical revision, adding intellectual content.

Maria Elina Bichuette - Substantial contribution in the concept and design of the study, contribution to data collection, contribution to data analysis and interpretation, contribution to manuscript preparation, contribution to critical revision, adding intellectual content.

Conflicts of interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

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