Biospeleology of the Lagoa Santa Karst

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Abstract

The region of Lagoa Santa stands out as the cradle of studies on epigean and subterranean ecology in Brazil. The subterranean habitats in the Lagoa Santa Karst area are structurally and biologically diverse, especially due to the wide variety of macro and microhabitats and food resources availability for the fauna. The observed biodiversity is a consequence of the distinct conditions of isolation, atmospheric stability, food availability, and the presence of dry and wet subterranean habitats. In terms of obligate cave fauna, the Lagoa Santa karst tends to present a moderate richness in absolute numbers (41 spp.) but low richness in relative terms (0.48 species per cave). However, such numbers were counted from inventories conducted in approximately 80 out of the 900 caves, so that many other species may still be discovered. The four described troglobites are *Brasilomma enigmatica, Tisentnops onix, Charinus taboa,* and *Spelunconiscus castroi*, but 37 other sampled troglomorphic species are still not described. Moreover, there are many human activities causing impacts to the Lagoa Santa Karst, which come from agriculture, cattle ranching, water exploitation, urbanization, deforestation, industries, mining, road construction, etc. The urgency for conservation actions is evident since studies on the population size and ecology of cave fauna are incipient and the low number of conservation units has led these species to an extreme degree of vulnerability and threats. In this perspective, the intensification of biological studies in caves of the Lagoa Santa karst is highly recommended to avoid species loss.

Keywords

Subterranean biology • Karst fauna • Cave ecology • Troglobites • Impacts

1 Subterranean Environments in the Lagoa Santa Karst

The high age of the limestone at the Lagoa Santa Karst (Neoproterozoic) and its long exposition to surface weathering contributed to the modeling of landscape in plateaus with different landforms (Berbert-Born 2000; Auler and Piló 2015). Such features influenced directly the hydrological dynamics, the availability of habitats and organic debris availability for the fauna associated with caves and other subterranean environments. Furthermore, rainfall and seasonality favor heterogeneous and peculiar vegetation (Brazilian Savannah) and primarily autogenic hydrology, which forms vertically dissected limestone outcrops with paragenetic caves and frequently short subterranean drainages (Auler and Piló 2015). The elevation ranging from 650 to 900 m asl represents a catchment divide between the basins of Mata Creek and Velhas River (Berbert-Born et al. 1998). Such dynamics and interaction of landscape elements have generated different habitats throughout the time, capable to shelter a specialized fauna occupying subsurface (epikarst) and deep subterranean habitats (dry caves, deep cracks, subterranean rivers, flooded travertines, water table, among others) from millimetric to decametric volumes.

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The epikarst can be characterized as the uppermost weathered zone of carbonate rocks with substantially enhanced and more homogeneously distributed permeability and porosity when compared to the bulk rock mass below it (Klimchouk 2004). Despite the fact that this environment is poorly studied for caves of this region, it is plausible to assume that they represent important habitats for several species (e.g., copepods), as happens in several other karstic areas around the world (Culver and Pipan 2009). The meteoric water infiltrating the soil is partially retained in the epikarst and slowly percolates reaching caves via active speleothems even in dry periods of the year. Such waters may transport organic matter dissolved in the soil, therefore representing an important organic resource for microorganisms and small invertebrates, both in epikarstic zones and caves. In this sense, the great variety of mineral deposits (speleothems) present in caves of the region, besides improving the availability of microhabitats for fauna, are good indicators of the intense current and previous hydric dynamics.

Lotic and lentic groundwater bodies certainly comprise essential habitats for several organisms. However, more than 900 caves recorded for the region comprise dry passages with entrances in the lower portion of depressions or in the basis of limestone outcrops. Caves of different extensions that may be associated with the water table represent a minor percentage in this region (Auler 1998), although the occurrence of periodic swallets supplying the phreatic zone is not rare (Berbert-Born et al. 1998).

In these different subterranean habitats, the dynamics of food resource availability for the fauna tend to be complex due to the large territorial extension of the karst submitted to variations on the density of fractures (and caves) at different elevations. Thus, there are several and distinct possibilities of resource input into the caves due to biological (bats, rodents, accidentals) or physical elements (percolation water, rivers, flash flood) (Ferreira and Pompeu 1997; Berbert-Born et al. 1998; Ferreira et al. 2000; Souza-Silva et al. 2005). The input of organic resources (mainly plant debris) may occur gravitationally (via ceiling openings), from the deciduous vegetation present in the top of outcrops, by means of the water movement of flash flood and allogenic drainages, or by organic matter dissolved in percolation water. The vegetation associated with the limestone outcrops of Lagoa Santa karst present many deciduous plant species, which provides a greater accumulation of leaves in the litter during dry periods of the year (see chapter "The Vegetation of Lagoa Santa Karst", this volume). Part of this material may be carried to the interior of caves mainly during rainy periods, as described for other Brazilian karst regions (Souza-Silva et al. 2011). On the other hand, in permanently dry caves bat guano seems to be predominant trophic resource, comprising an important food source for several groups of invertebrates (Berbert-Born et al. 1998; Ferreira et al. 2000a) and microorganisms (Ferreira et al. 2000b).

In summary, caves in the Lagoa Santa Karst area are structurally and biologically too variable and complex, especially due to the wide variety of macro and microhabitats and food resources for the fauna. Thus, the invertebrates and vertebrates' communities have variable composition and diversity and were structured based on distinct conditions of isolation, atmospheric stability, food availability, and terrestrial and aquatic habitats.

2 Species Composition

Caves of the karst region of Lagoa Santa shelter a great variety of organisms that have been described since the nineteenth century. Paleontological sites sampled by the naturalist Peter W. Lund in caves of the region revealed living species that possibly used such environments as shelter, besides the extraordinary Pleistocene fauna (see chapter "Cave Paleontology in the Lagoa Santa Karst", this volume). Among such discoveries, the canids *Cerdocyon thous* Hamilton Smith 1839 (Berta 1982) and *Speothos venaticus* Lund 1842 (DeMatteo and Loiselle 2008) stand out, besides some rodent species like *Phyllomys brasiliensis* Lund 1840 (Emmons et al. 2002), *Blarinomys breviceps* Winge 1888 (Silva et al. 2003, Machado et al. 2016) and *Pseudoryzomys simplex* Winge 1887 (Machado et al. 2016). In the same century, members of the expedition Thayer (1865–1866) collected mite specimens, although they were described only 100 years after (*Whartonia W. pachywhartoni* Vercammen—Grandjean 1966, recently reviewed by Silveira et al. 2015). Although they had sampled components of cave fauna, these first studies involved themes non-related to subterranean biology (e.g., paleontology, photographic inventory).

Later, descriptions of new species sampled in caves of the region were published (ex. Costa-Lima 1940; Wygodzinsky 1950; Schubart 1956) and from 1990 on many works took into account the occurrence of subterranean fauna in the area (ex. Berbert-Born and Horta 1994; Pinto-da-Rocha 1995; Fontanetti 1996; Hermann et al. 1998; Trajano et al. 2000). Currently there are several studies reporting species of Lagoa Santa caves regarding different areas of biology, like ecology (Ferreira and Martins 1999; Gomes et al. 2000; Iniesta et al. 2012; Pellegrini et al. 2016), parasitology (Oliveira et al. 2000; Filho et al. 2007; Coelho-Finamore et al. 2011; Sábio et al. 2015), taxonomy (Gil-Santana et al. 1999; Pena et al. 2005; Mews and Sperber 2008; Campos-Filho et al. 2016), biochemistry (Dantas et al. 2014, 2016), among others. As a result, despite the volume of information being still incipient, such karst region may be considered one of the better sampled areas of Brazil in terms of subterranean fauna, what does not mean it is sufficiently known regarding bioespeleology.

Subterranean arthropods recorded for this karst are beyond those species considered restricted to underground habitats (as indicated in the topic "Troglobites"). Several non-troglobitic species (belonging to different taxonomic groups) were described for those caves, like Amphipoda (Hyalellidae: *Hyalella warmingi* Stebbing 1899), Gastropoda (Bulimulidae: *Thaumastus T. lundi* Pena et al. 2005), Pseudoscorpiones (Olpiidae: *Progarypus gracilis* Mahnert 2001), Diplopoda (Pseudonannolenidae: *Pseudonannolene microzoporus* Mauries 1987 and *Pseudonannolene chaimowiczi* Fontanetti 1996; Chelodesmidae: *Obiricodesmus rupestris* and *Sandalodesmus stramineus* Schubart 1956), Orthoptera (Phalangopsidae: *Endecous cavernicolus* Costa-Lima 1940, reviewed by Mews and Sperber 2008), Heteroptera (Reduviidae: *Mayemesa lapinhaensis* Wygodzinsky 1950, reviewed by Gil-Santana et al. 1999) and Isopoda (*Trichorhina pataxosi* Campos-Filho et al. 2016). Other species of wide distribution were sampled in some caves, among which some dipterans with medical importance stand out (Psychodidae: *Lutzomyia longipalpis* Lutz and Neiva 1912, in Oliveira et al. 2000 and Coelho-Finamore et al. 2011; *Lutzomyia L. renei* Martins, Falcão and Silva 1957, in Sábio et al. 2015; *Nyssomyia intermedia* Lutz and Neiva 1912 and *Nyssomyia neivai* Pinto, 1926, in Filho et al. 2007). Besides Diptera, other groups were also recorded, as spiders (Araneidae: *Alpaida septemmammata* Octavius Pickard-Cambridge 1889, in Hermann et al. 1998; Ctenidae: *Enoploctenus maculipes* Strand 1909, in Pinto-da-Rocha 1995; Oecobidae: *Oecobius annulipes* Lucas 1846, in Hermann et al. 1998; Theridiidae: *Nesticodes rufipes* Lucas 1846, in Hermann et al. 1998; Sicariidae: *Loxosceles similis* Moenkhaus 1898, in several studies like Pinto-da-Rocha 1995; Hermann et al. 1998; Gomes et al. 2000; Dantas et al. 2014, 2016; Trechaleidae: *Trechaleoides keyserlingi* Octavius Pickard-Cambridge 1903, in Hermann et al. 1998), scorpions (Buthidae: *Tityus serrulatus* Lutz and Mello 1922, in Hermann et al. 1998), pseudoscorpions (Chthoniidae: *Pseudochthonius strinatii* Mahnert 2001, Chernetidae: *Spelaeochernes dubius, Spelaeochernes eleonorae* and *Spelaeochernes gracilipalpus* Mahnert 2001), mites (Anystidae: *Erythracarus nasutus* Otto 1999, in Iniesta et al. 2012; Argasidae: *Ornithodoros talaje* Guerin-Méneville 1849, in Hermann et al. 1998), gastropods (Subulinidae: *Subulina octona* Bruguière 1798, in Hermann et al. 1998), bettles (Leiodidae: *Dissochaetus murrayi* Reitter 1884, in Pinto-da-Rocha 1995), Psocoptera (Psyllipsocidae: *Psyllipsocus ramburii* Selys-Longchamps 1872, in Lienhard and Ferreira 2015) and Hemiptera (Reduviidae: *Zelurus variegatus* Costa-Lima 1940, in Hermann et al. 1998). Even components of microbiota were identified in sand flies sheltered in subterranean habitats of the region, like bacteria and protozoa (*Stenonotrophomonas maltophilia*, *Enterobacter cloacae*, *Pseudomonas putida*, *Acinetobacter lwoffii*, *Flavimonas orizihabitans*, *Klebsiella p. ozaenae*, *Bacillus thuringiensis* in Oliveira et al. 2000; and *Leishmania infantum* Coelho-Finamore et al. 2011).

These records represent only a small part of specimens observed and/or collected, since many of them were not identified to the species level, and consequently they were not formally described (as indicated in Pinto-da-Rocha 1995; Hermann et al. 1998; Ferreira and Martins 1999; Gomes et al. 2000; Trajano et al. 2000; Mahnert 2001; Iniesta et al. 2012; Pellegrini et al. 2016 and in several other abstracts of meetings and thesis conducted in this karst region). Some species from the caves in the Lagoa Santa Karst are shown in Fig. 1.

Besides recent (living) species of mammals revealed by excavations of Peter W. Lund, several other vertebrates were recorded in caves of the Lagoa Santa karst. Many representatives of birdlife from Cerrado eventually use the caves entrances to build nests, like João-de-Barro (*Furnarius rufus badius* Lichtenstein 1823, in Pinto-da-Rocha 1995), Juriti (*Leptotila verreauxi decipiens* Salvadori 1871, in Pinto-da-Rocha 1995), Saí-Andorinha (*Tersina viridis* Illiger 1811, in Herman et al. 1998), Graúna (*Gnorimopsar chopi* Vieillot 1819, in Herman et al. 1998), owls (*Tyto furcata* Temminck 1827, in Herman et al. 1998), parrots and parakeets (*Amazona aestiva* Linnaeus 1758, *Eupsittula aurea* Gmelin 1789; in Pinto-da-Rocha 1995). In relation to anurans, most of the records do not have a taxonomic refinement to the species level, except for the species *Rhinella schneideri* Werner 1894 (Herman et al. 1998). However, amphibians are frequently found in Brazilian caves and there are occurrences in many studies in the region of Lagoa Santa (ex. Berbert-Born and Horta 1994; Pinto-da-Rocha 1995; Hermann et al. 1998; Matavelli et al. 2015). In relation to fishes, the only identified species comprises the Characidae *Astyanax bimaculatus* Linnaeus 1758 (Herman et al. 1998), although, as for other groups, there are records of other species identified at higher taxonomic levels (Pinto-da-Rocha 1995; Herman et al. 1998). Among mammals, bats may be considered the most efficient in using caves as shelters (Kunz 1982). Besides performing several ecological functions, they are responsible for the resource input to the hypogean environment (see the topic *Ecology*). In Lagoa Santa area, studies have indicated the presence of at least 23 species of bats inhabiting caves or cracks in the exokarst (Table 1). Besides the bats, other mammals are also frequently found, like raccoon (*Procyon cancrivorous* Cuvier 1798) and skunks (*Didelphis albiventris* Lund 1840).

In this sense, the faunistic composition of Lagoa Santa Karst comprises a great diversity of taxonomic groups that are not exclusive of subterranean environments, although there are species found exclusively in caves. Their adequate

Fig. 1 Some troglophile and trogloxene species found in the caves of the Lagoa Santa Karst: **a** *Endecous cavernicolus* (Phalangopsidae); **b** *Zelurus zikani* (Reduviidae); **c** Diplatyidae earwig (Dermaptera); **d** *Hypena* sp. (Noctuidae); **e** *Psyllipsocus falcifer* (Psyllipsocidae); **f** *Pseudonannolene taboa* (Pseudonannolenidae); **g** *Symphytognatha carstica* (Symphytognathidae); **h** *Loxosceles similis* (Sicariidae); **i** *Mesabolivar* sp. (Pholcidae); **j** *Eusarcus* sp. (Gonyleptidae); **k** *Eukoenenia florenciae* (Eukoeneniidae); **l** *Progarypus* sp. (Olpiidae)

management depends on the knowledge on levels of adaptation and uses for different species that compose such communities. Moreover, the knowledge regarding all the present fauna allows distinguishing invasive species in these systems (Mazza et al. 2014). Then, it is increasingly necessary to study communities present in caves of this region

Table 1 Bat species recorded for the karst region of Lagoa Santa. The references indicate studies in which the individuals were sampled. Only occurrences in caves and shelters were considered

Family/Species	References
Emballonuridae	
Peropteryx macrotis Wagner 1843	Tavares et al. (2010), Talamoni et al. (2013), Guimarães and Ferreira (2014)
Phyllostomidae	
Anoura caudifer E. Geoffroy 1818	Guimarães and Ferreira (2014)
Anoura geoffroyi Gray 1838	Guimarães and Ferreira (2014)
Artibeus literatus Olfers 1818	Grelle et al. (1997), Guimarães and Ferreira (2014)
Artibeus obscurus Schinz, 1821	Talamoni et al. (2013)
Artibeus planirostris Apix 1823	Grelle et al. (1997), Talamoni et al. (2013)
Carollia perspicillata Linnaeus 1758	Grelle et al. (1997), Tavares et al. (2010), Talamoni et al. (2013), Guimarães and Ferreira (2014)
Chiroderma villosum Peters 1860	Talamoni et al. (2013)
Chrotopterus auritus Peters 1865	Hermann et al. (1998), Guimarães and Ferreira (2014)
Desmodus rotundus E. Geoffroy 1810	Grelle et al. (1997), Hermann et al. (1998), Tavares et al. (2010), Torquetti et al. (2013), Talamoni et al. (2013), Guimarães and Ferreira (2014)
Diaemus youngi Jentink 1893	Torquetti et al. (2013)
*Diphylla ecaudat*a Spix 1823	Tavares et al. (2010), Talamoni et al. (2013), Guimarães and Ferreira (2014)
Glossophaga soricina Pallas 1766	Grelle et al. (1997), Torquetti et al. (2013), Talamoni et al. (2013), Guimarães and Ferreira (2014)
Micronycteris megalotis Gray 1842	Talamoni et al. (2013), Guimarães and Ferreira (2014)
Mimon bennettii Gray 1838	Talamoni et al. (2013)
Phyllostomus hastatus Pallas 1767	Tavares et al. (2010), Torquetti et al. (2013)
Phyllostomus discolor Wagner 1843	Guimarães and Ferreira (2014)
Platyrrhinus lineatus E. Geoffroy 1810	Grelle et al. (1997), Talamoni et al. (2013)
Vampyressa pusilla Thomas 1900	Grelle et al. (1997), Tavares et al. (2010)
Vespertilionidae	
Histiotus velatus I. Geoffroy, 1824	Talamoni et al. (2013)
Myotis nigricans Schinz 1821	Grelle et al. (1997), Talamoni et al. (2013)
Molossidae	
Molossus molossus Pallas 1766	Grelle et al. (1997)
Nyctinomops laticaudatus E. Geoffroy 1805	Talamoni et al. (2013)

for conservation purposes. As the number of inventories increases new species certainly will be described and/or new occurrences will be published for the Lagoa Santa Karst.

3 Troglobites

Different karst areas in Cerrado (Brazilian Savannah) were inventoried and revealed distinct richness of troglobitic species. The Lagoa Santa Karst, when compared to other areas, tends to present a moderate richness of troglobites (in absolute terms), although this richness, in relative terms, may be considered low. Until the present, there are 41 species with troglomorphic traits (potentially troglobitic) recorded for the Lagoa Santa caves. This number was taken from inventories performed in approximately 80 caves, as the mean of troglobites per cave is considerably low (mean of 0.48 troglomorphic species per cave). However, it is important to mention that such inventories were made in a small number of the caves recorded in the area, and then many other species may still be found, as happens for most of the Brazilian karst areas.

For comparison between the troglobites richness of Lagoa Santa Karst and other regions, some studies will be mentioned. A study performed in 15 caves in the karst region of Cordisburgo (adjacent to Lagoa Santa Karst area) revealed 39 troglomorphic species (mean of 2.6 species per cave) (Souza 2012). In the limestone speleological province of Arcos-Pains-Doresópolis, 294 caves were inventoried and 79 troglomorphic species were recorded (mean of 0.27 species per cave) (Zampaulo 2010). Simões (2013) studied 55 caves located in the karst region of Northwest Minas Gerais and found 35 troglomorphic species (mean of 0.84 species per cave). Finally, one study performed in 51 limestone caves from Central-North Minas Gerais revealed 94 troglomorphic species (mean of 2.75 species per cave) (Rabelo 2016).

It is noticeable that the absolute number of troglomorphic species observed for the region of Lagoa Santa Karst (41) is comparable to those found in other regions (such as Cordisburgo—39 species—and Northwest Minas Gerais—35 species). However, the relative number of troglobitic species (0.48 species/cave) is low and only higher to be observed for the region of Arcos-Pains-Doresópolis (0.27 species/cave). It is important to cite that these two previously mentioned areas stand out due to the predominance of small and dry caves, factors that may have contributed to the low relative richness of troglobitic species. Simões et al. (2015) demonstrated that the presence of water bodies and the length of caves are determining factors for the occurrence and richness of troglomorphic species in caves of some karst areas of the Cerrado.

More than 40 troglomorphic (potentially troglobitic) species have been found in the Lagoa Santa Karst, but only 4 have been described: the spiders *Brasilomma enigmatica* (Prodidomidae—Fig. 2a) and *Tisentnops onix* (Caponiidae—Fig. 2b), the tailless whip scorpion *Charinus taboa* (Charinidae—Fig. 2d) and the isopod *Spelunconiscus castroi* (Styloniscidae). However, there is a larger number of troglomorphic species already identified from caves of this area (37 species). Great part of these species is deposited in the reference collection of the Study Center on Subterranean Biology at the Federal University of Lavras (CEBS/UFLA 2016), and some of them are under the process of description. Such species were collected in the municipality of Confins (palpigrades, isopods, and spiders—Prodidomidae and Oonopidae), Lagoa Santa (mites Labidostomatidae, spiders *Nesticus* sp and isopods *Trichorhina*), Matozinhos (pseudoscorpions Chthoniidae, springtails Entomobryiidae, isopods *Trichorhina* and Styloniscidae and bettles Rizophagidae), Prudente de Morais (spiders Oonopidae, springtails *Arrhopalites*, millipedes Cryptodesmidae and isopods *Trichorhina* and Styloniscidae) and in Sete Lagoas (springtails Entomobryomorpha, isopods *Trichorhina* and *Spelunconiscus*, harvestmen *Spelaeoleptes* and millipedes Pyrgodesmidae). Some troglobitic species from the caves in the Lagoa Santa Karst are shown in Fig. 2.

Until the present, no exclusively aquatic species has been found in the Lagoa Santa Karst. Considering the 41 known species, 78% are terrestrial and the others are amphibious Styloniscidae (which favor the water but can move along terrestrial environments). Furthermore, most of the troglobitic species present a restricted distribution (occurring in only one cave) and only 5% of them occur in two or more caves. The caves that stand out in the region for their number of troglobitic species are Taboa Cave (6 species), Rei do Mato Cave (4), Lapa Vermelha Cave (4), and Meandro Abismante Cave (3).

In relation to the described species, *Charinus taboa* (Charinidae) is found in only two relatively close caves (Taboa Cave, 800 m long and BR24 cave, 33.8 m long), both in the municipality of Sete Lagoas, Minas Gerais state. The adults of *C. taboa* are found in the deeper portions of caves, mainly among speleothems, wall, and ceiling, while juveniles shelter in spaces under the rocks. This species may be considered vulnerable since only 31 specimens were observed in the two caves over years of research. Moreover, the epigean environment around the cave has been altered by human activities. Other species described for Taboa Cave is *Tisentnops onix* (Caponiidae) through the unique female collected under a rock in aphotic zone (at 15–20 m from the entrance). The occurrence of *T. onix* in other cave close to Taboa (Cave 64, 58.2 m long) is a strong indicator of the subterranean connectivity of these caves.

Fig. 2 Some troglobitic species found in the caves of the Lagoa Santa Karst: **a** *Brasilomma enigmatica* (Prodidomidae); **b** *Tisentnops onix* (Caponiidae—photo: Ubirajara Oliveira); **c** *Lygromma* sp. (Prodidomidae); **d** *Charinus taboa* (Charinidae); **e** Labidostomatidae mite; **f** *Spaeleoleptes* sp. (Escadabiidae); **g** Pyrgodesmidae millipede; **h** *Trichorhina* sp. (Platyarthridae); **i** *Spelunconiscus castroi* (Styloniscidae)

The isopod *Spelunconiscus castroi* (Styloniscidae) was described for the cave MOC32 (Campos-Filho et al. 2014), although nearly no information about this species was presented by the authors (except mentioning that it is an amphibious species). On the other hand, the spider *Brasilomma enigmatica* occurred in only one cave from Lagoa Santa karst (MOC131) but was also found in other areas (Brescovit et al. 2012). This species presents a wide distribution beyond the Lagoa Santa Karst, also occurring in ferruginous and quartzite caves along with an extension of more than 300 km without apparent subsurface connection with caves of the Lagoa Santa Karst (in this scenario the species was named "*enigmatica*" alluding to its distribution). The only specimen collected in MOC31 was collected 30 m below the surface level (Brescovit et al. 2012).

Information on the population size and ecology of the described troglobites and the other undescribed troglomorphic species does not exist until the present. Such lack of information associated with the intense human activities in the region and the reduced number of conservation units has led these species to an extreme degree of vulnerability and threats. In this perspective, the intensification of biological studies in caves of the Lagoa Santa karst is highly recommended in order to avoid the species extinction (mainly the troglobites) even before they are formally described (see the topic "Threats").

4 Ecology

The Lagoa Santa Karst certainly presents an historical relevance regarding biospeleology in Brazil, not only due to the species described from caves (as previously cited) but also especially considering that the first studies on ecology of Brazilian cave communities were performed in this region (e.g., Ferreira and Pompeu 1997; Ferreira et al. 2000b), among which we highlight those regarding ecology of guano communities.

Guano piles are widely considered as an important source of organic matter in caves (Harris 1970; Decu 1986; Ferreira and Martins 1999; Gnaspini 2012). In tropical caves, especially those permanently dry, bat guano may represent the most important source of organic matter, forming the trophic base for the structure of many invertebrate communities (Decu 1986; Ferreira and Martins 1998, 1999). The diversity of bats feeding habits in the tropics is remarkable (Herzig-Straschil and Robinson 1978). The three most common guano types found in the caves of the Lagoa Santa Karst are produced by frugivorous bats (with small undigested seeds), hematophagous bats (with a pasty consistency and reddish color when fresh, becoming black and often powdery when older), and by insectivorous bats (containing small chitinous parts of insects or other arthropods). Although other types also may occur, the most commonly found piles are produced by hematophagous bats (especially *Desmodus rotundus*), and this certainly has been caused by a historical replacement of the natural forests by pastures (see the topic "Threats").

Bat guano communities in caves are extremely interesting for ecological studies, especially due to their physical and chemical conditions (that are easily measurable and quite distinguishable when comparing different piles) and the great number of easily defined interactions with the overall cave environment (Fig. 3). However, during decades such communities were considered "isolated" from the cave environment as a whole, but in fact a high number of cave invertebrate groups associate and interact with them (Ferreira et al. 2000a).

Several guano piles traits act structuring the associated communities in the Lagoa Santa Karst (Ferreira et al. 2000b). Ferreira and Pompeu (1997) showed that the distance from the entrance was an important parameter determining the richness of guano communities in Taboa Cave (Sete Lagoas municipality) (Fig. 4b). Other studies performed later found similar (Ferreira et al. 2007) but also distinct results (Ferreira et al. 2000), indicating that the distance from the cave entrance is not always an important factor for the bat guano communities. Since most invertebrates occurring in guano piles are troglophiles (with some rare troglobitic species), the colonization of each deposit may occur from any place inside the cave, and not only from the entrance. On the other hand, the area of guano piles is always important, so that the richest and most diverse communities are always associated to biggest piles (Ferreira and Pompeu 1997; Ferreira and Martins 1998; Ferreira et al. 2000a; Bahia and Ferreira 2005; Ferreira et al. 2007) (Fig. 4c, d). The richness or abundance of species that use faecal deposits tends to be proportional to the availability of this resource (Doube 1986). Furthermore, one would expect some area effect of greater potential microhabitat variability over a larger surface. Hence, in caves of the Lagoa Santa Karst, larger deposits with a greater diversity of microhabitats (like small holes and cracks) have more associated species.

It is also important to mention that guano communities are structured over some physicochemical parameters, like pH and organic content. The reduction of guano pH over time is well known, since fresh guano is alkaline and becomes acidic due to ammoniac fermentation (Hutchinson 1950). However, pH does not always reflect guano age, since the piles are open systems subject to be affected by chemical (percolation water, floods, etc.) and physical (landslides, sedimentation, etc.) processes occurring in the cave environment (Ferreira et al. 2000a). In the caves of the Lagoa Santa Karst, the richest piles generally present moderate pH (Fig. 4c, d). The relationship between guano pH and richness of the associated communities is probably the result of a preference (by most species of the community) for an optimum and intermediate value of pH (Ferreira et al. 2000a). However, the same authors postulated that if guano pH reflects the piles age, fresh piles (more basic) may not have had enough time to be colonized, while old piles (more acidic) may have been exhausted as a food resource due to consumption or mineralization (Ferreira et al. 2000a). The organic content is also important, as shown by Ferreira et al. (2000a) in Lavoura Cave (Matozinhos municipality) located in the Lagoa Santa Karst. Such authors observed that richer communities were associated with guano piles with higher organic contents, demonstrating the importance of such parameters for these communities.

Finally, there are some evidence that larger piles can act as sources of colonization for smaller ones. In Lavoura Cave (Matozinhos municipality), the community similarities between one big guano pile and smaller piles surrounding it (unpublished data) were correlated. It was observed that smaller piles closer to the biggest ones are more similar to it than piles located far from it (Fig. 4a). This suggests that guano communities in a given cave may act as metacommunities. The concept of metacommunity was first proposed

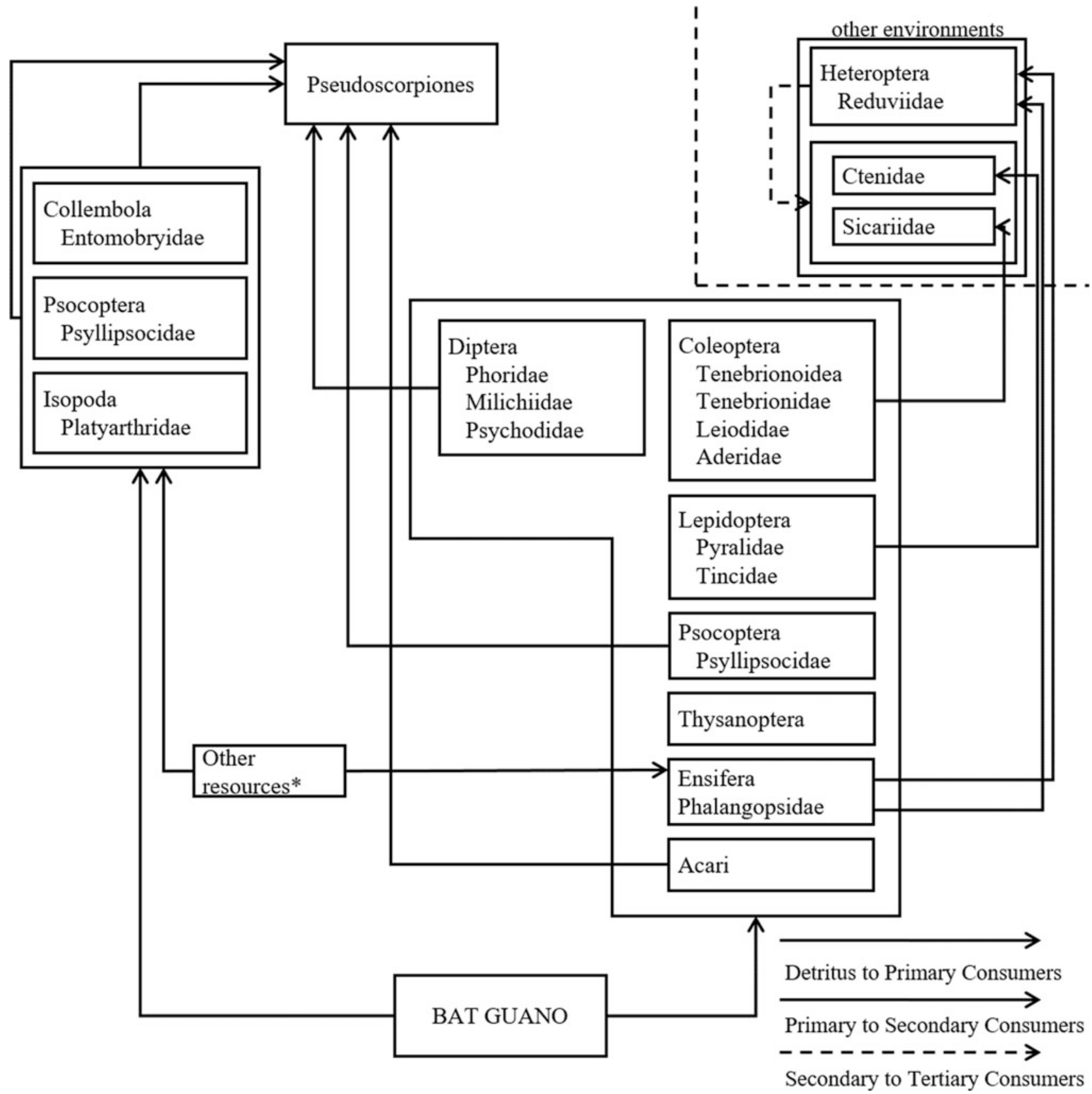

Fig. 3 Food web of a bat guano community in Lavoura Cave (Matozinhos municipality)

by Gilpin and Hanski (1991) to represent a set of local communities from different sites connected by dispersion of one or more of its components. A metacommunity follows the same dynamics of a metapopulation, and therefore is subject to local extinctions and recolonizations. The low abundance of organisms in some old guano piles enhances local extinctions. As the guano becomes older, its quality as an organic resource decreases, thus the community progressively leaves the pile and colonize others in order to maintain their populations. However, the dynamics of movements between guano piles remain largely unknown, certainly deserving further investigations.

Some studies performed in caves of the Lagoa Santa Karst focused on aspects of population ecology of some species. Ferreira et al. (2005) monitored a cave population of the brown recluse spider (*Loxosceles similis*) in the Lavoura Cave (located in Matozinhos municipality) and found some patterns especially regarding the displacement of such spiders inside the cave. *Loxosceles* species are usually considered sedentary having a life area restricted to the vicinities of

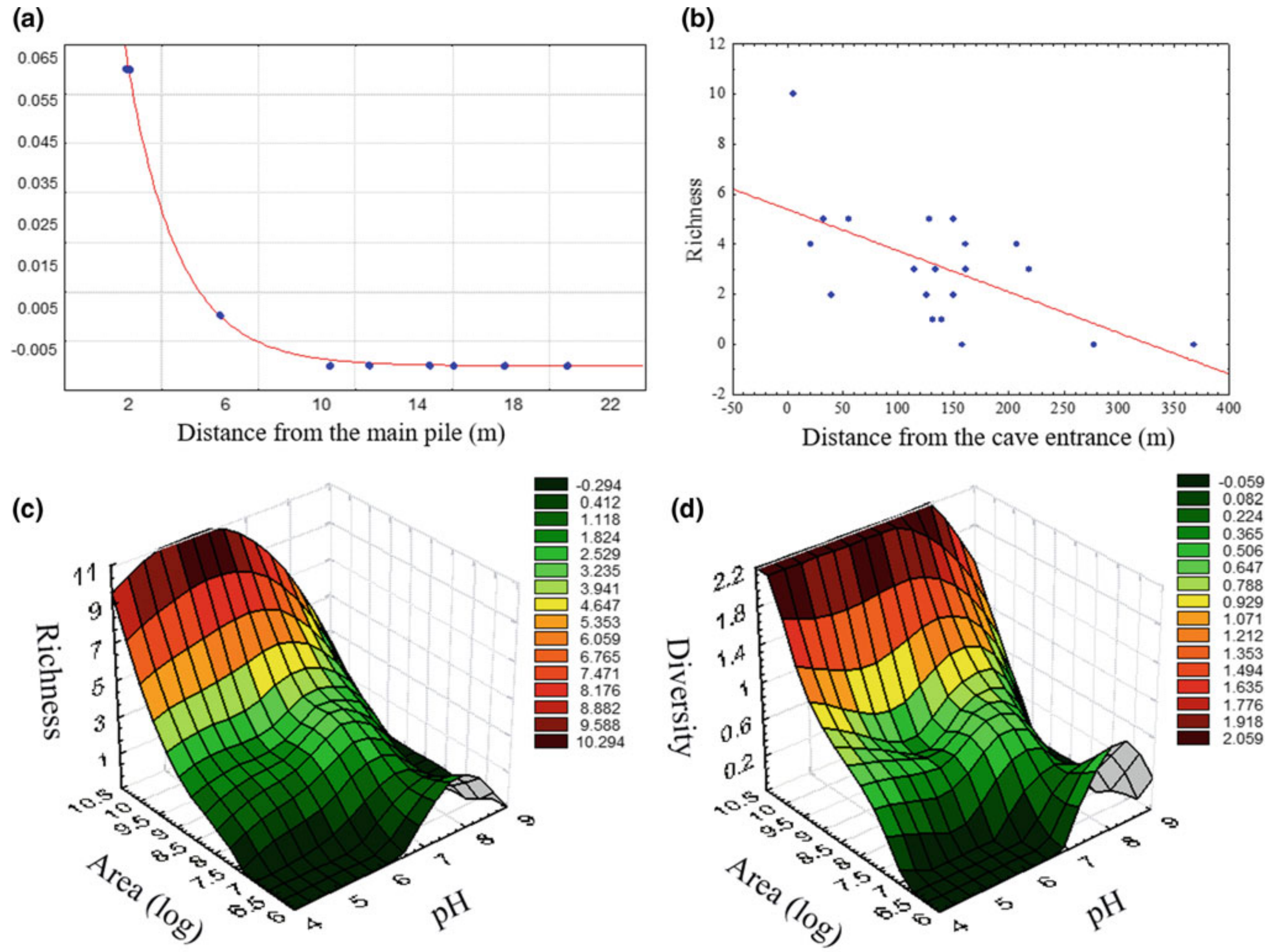

Fig. 4 **a** Similarity values (Renkonen index) between a larger pile (species "source") and small peripheral piles (species "sink") according to their distance in relation to the main (larger) pile in Lavoura Cave (Matozinhos municipality); **b** relation between the distance from the cave entrance and the richness of guano communities in Taboa Cave (Sete Lagoas municipality); **c** relation between the area, the pH of the guano piles and the richness of guano communities in Lavoura Cave (Matozinhos municipality); **d** relation between the area, the pH of the guano piles and the diversity of guano communities in Lavoura Cave (Matozinhos municipality)

their webs (Bücherl 1961; Foelix 1987). However, Ferreira et al. (2005) registered a great mobility of such spiders. Many individuals of *L. similis* were recaptured at distances from 20 to 80 m from the place where they were initially marked (a movement of 40 m was registered in only one week). These distances are much longer than those recorded for some species like *L. rufipes* (Lucas 1834) and *L. intermedia* Mello-Leitão, 1934 (around 2 m in one week, what was considered a significant mobility) (Delgado 1966; Fischer 1996). However, the cave environment presents different conditions from those found in external or anthropogenic environments. The scarcity and irregular distribution of food resources in a cave may result in lower prey availability, which may have led the spiders (in the Lavoura Cave) to move longer distances looking for preys.

Another important study performed in the Lagoa Santa Karst presented, for the first time for the tropical region, data regarding the responses of a cave population (of the moth *Hypena* sp.—Lepidoptera: Noctuidae) to seasonal variations in the epigean environments (Ferreira et al. 2015). Several studies demonstrated the effects of external climatic fluctuations on subterranean populations and communities in the temperate region (Bourne and Cherix 1978; Carchini et al. 1994; Novak et al. 2004; Tobin et al. 2013). Although such effects are expected in areas where external climatic fluctuations are more intense (Mitchell 1969), no studies were historically performed in tropical regions, maybe due to the false impression that both small temperature and humidity fluctuations (typical of the tropics) have little or no effect over the subterranean fauna. In this sense, Ferreira et al.

(2015) demonstrated that a cave population responds to seasonal external variations (in this case the Taboa Cave, municipality of Sete Lagoas). During the rainy seasons the population of *Hypena* sp. was closer to the cave entrance, while during the dry periods, the population peaks occurred slightly deeper inside the cave (Fig. 5). This study is important especially to demonstrate that patterns occurring in temperate caves can also be observed in the tropics. However, further studies are needed to actually understand how cave populations or communities from temperate and tropical regions differ or not, in terms of function and structure.

Although only few studies regarding general cave communities in the Lagoa Santa Karst were performed (Iniesta et al. 2012), some "patterns" were found, indicating that communities in this region present some similarities. In the Irmãos Piriás Cave (located in Matozinhos municipality), four collection events were conducted between 1999 and 2000. In all events, a reduction of invertebrate richness was observed from the entrance to deeper portions of the cave (Fig. 6a). This entrance-mediated effect was expected, especially in tropical regions, due to the remarkable richness of external communities, which represent an important source of organisms prone to colonize caves. Therefore, cave entrances in the tropics tend to present richer communities when compared to inner portions of the caves. However, although some species can establish themselves in the hypogean habitats, most of them cannot, due to their lack of preadaptive traits. Cave entrances are considered ecotones between epigean and hypogean environments (Prous et al. 2004, 2015). Hence, such regions tend to present intermediate conditions between those habitats. As an example, entrances are more stable than epigean environments (favoring the presence of many species), although they present less organic resources (preventing other species to colonize them). Prous et al. (2015) argued that ecotones in the cave entrances may function as selective permeability membranes acting differently over distinct species. According to Strayer et al. (2003), this "membrane" can act on matter, energy, or species in different ways and can partially transmit, transform, absorb, reflect, amplify them, or act neutrally. Moreover, filters present in these membranes can be biological or physical and the combination of both filters is responsible for the presence and distribution of species in the cave entrances and also within the caves (Prous et al. 2015).

However, although there is a tendency toward the reduction of richness from the entrance to deeper areas in caves, each species inside a cave can present a distinct pattern of distribution. In the Irmãos Piriás Cave, some species presents higher densities in regions closer to the entrance (as the spider *Plato* sp.—Theridiosomatidae) while for others the higher densities are observed on inner portions of the cave (e.g., the cricket *Endecous* sp.—Phalangopsidae) (Fig. 6b, c). Furthermore, such patterns of distribution vary not only in space but also throughout time. The community from Irmãos Piriás Cave varied considerably from 1999 to 2001. Richer communities were observed during rainy periods (89 and 94 invertebrate species in January 2000 and January 2001, respectively), while in the dry periods the communities reduced the number of species (44 and 64 invertebrate species in July 1999 and July 2000, respectively). The species turnover between the four sampling events corresponded to 54.18% indicating a considerable species replacement over time. The turnover was calculated using data of presence and absence through the index of Harrison et al. (1992); modified by Whittaker (1960), in order to compare samples of different sizes. $\beta_{Harrison} = \{[(S/a) - 1]/(N - 1)\}9100)$, where S = total species richness, a = average richness values, and N = number of samples. This measure ranges from 0 (no turnover) to 100 (each sample has a unique set of species) (Koleff et al. 2003).

In the Taboa Cave (Sete Lagoas Municipality) it was observed a similar pattern to the observed in the Irmãos Piriás Cave. In the rainy periods, not only the richness but also the diversity was higher than in dry seasons. In this cave, in both rainy periods the richness and diversity corresponded to 101 species and $H' = 3.04$ (January 2000) and 126 species and $H' = 3.29$ (January 2001), while in the dry periods those values corresponded to 35 species and $H' = 2.23$ (July 1999) and 75 species and $H' = 2.73$ (July 2000). However, the community equitability did not change considerably along the sampling period, corresponding to 0.63 in both dry periods and to 0.66 (January 2000) and 0.68 (January 2001) in the rainy periods. This indicates that although the community can vary along the time in richness, diversity and even in composition, the average distribution of population size is stable, and such "stability" can be the result of the oligotrophic conditions, which represents a limiting pressure upon the distinct populations inhabiting the cave.

Finally, the epigean landscape can also be important to determine the structure and composition of the cave fauna. It is well known that patterns of biodiversity usually respond to habitat disturbances and different land uses (MacDonald et al. 2000). However, until recently no study had demonstrated spatial-scale influences in subterranean terrestrial communities. In a study conducted in the Lagoa Santa Karst, Pellegrini et al. (2016) analyzed how land use and cave physical structure could influence the terrestrial cave invertebrate species composition. Such authors also determined the influence of different spatial scales under analysis on the composition of invertebrate cave fauna. For that purpose, they determined land uses at three different landscape scales, by gathering data into circular areas of different sizes (50, 100 and 250 m) with centroids in the cave entrances (Fig. 7). The authors found that the best explanatory variable

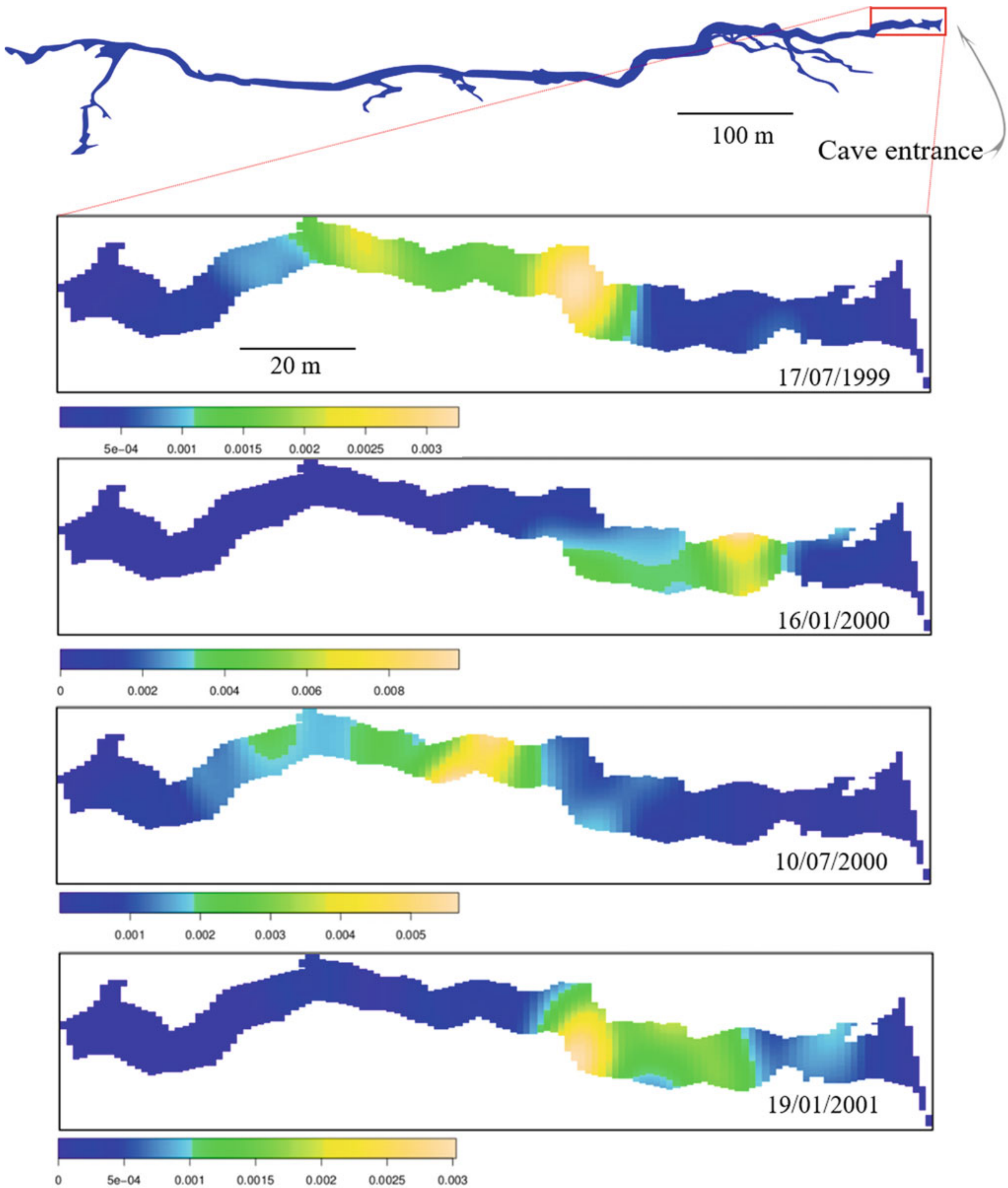

Fig. 5 Spatial distribution maps of *Hypena* sp. in Taboa Cave (Sete Lagoas municipality) demonstrating different densities between seasons. In the dry seasons (17/07/1999 and 10/07/2000) individuals are located far from the cave entrance, while during rainy seasons (16/01/2000 and 19/01/2001) individuals migrate to areas near the entrance. Blue colors indicate low densities while light yellow colors indicate high densities. Modified from Ferreira et al. (2015)

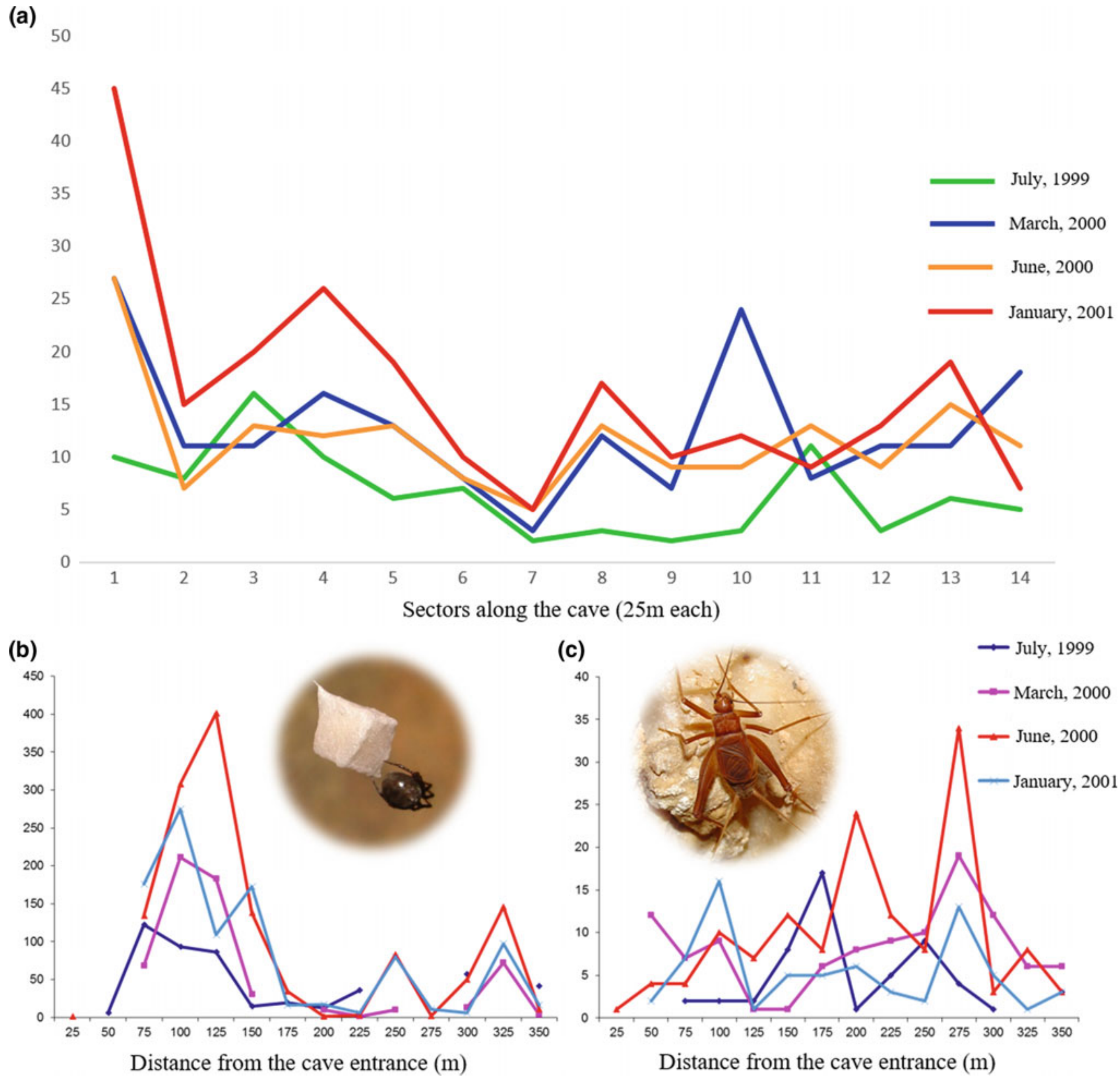

Fig. 6 **a** Relation between the distance from the cave entrance and the invertebrates richness (vertical axis) in different seasons in Irmãos Piriás Cave (Matozinhos municipality); **b** relation between the distance from the cave entrance and the density of the spider *Plato* sp. (Theridiosomatidae) in different seasons in Irmãos Piriás Cave; **c** relation between the distance from the cave entrance and the density of the cave cricket *Endecous* sp. (Phalangopsidae) in different seasons in Irmãos Piriás Cave

for cave invertebrate composition was the percentage of limestone outcrops covering the surface environments. Furthermore, they confirmed the scale-dependence hypothesis since the models generated during the study (by Distance Based Linear Modeling) became more precise as larger scales were analyzed to explain cave invertebrate composition. According to them, larger scales embrace more precisely more environmental traits that influence the cave fauna composition. In conclusion, Pellegrini et al. (2016) found a strong influence of limestone outcrops structuring cave communities independently of the scale under analysis (although the scale can enhance the precision of the analysis), demonstrating the major importance of preserving those outcrops for the maintenance of the cave fauna composition.

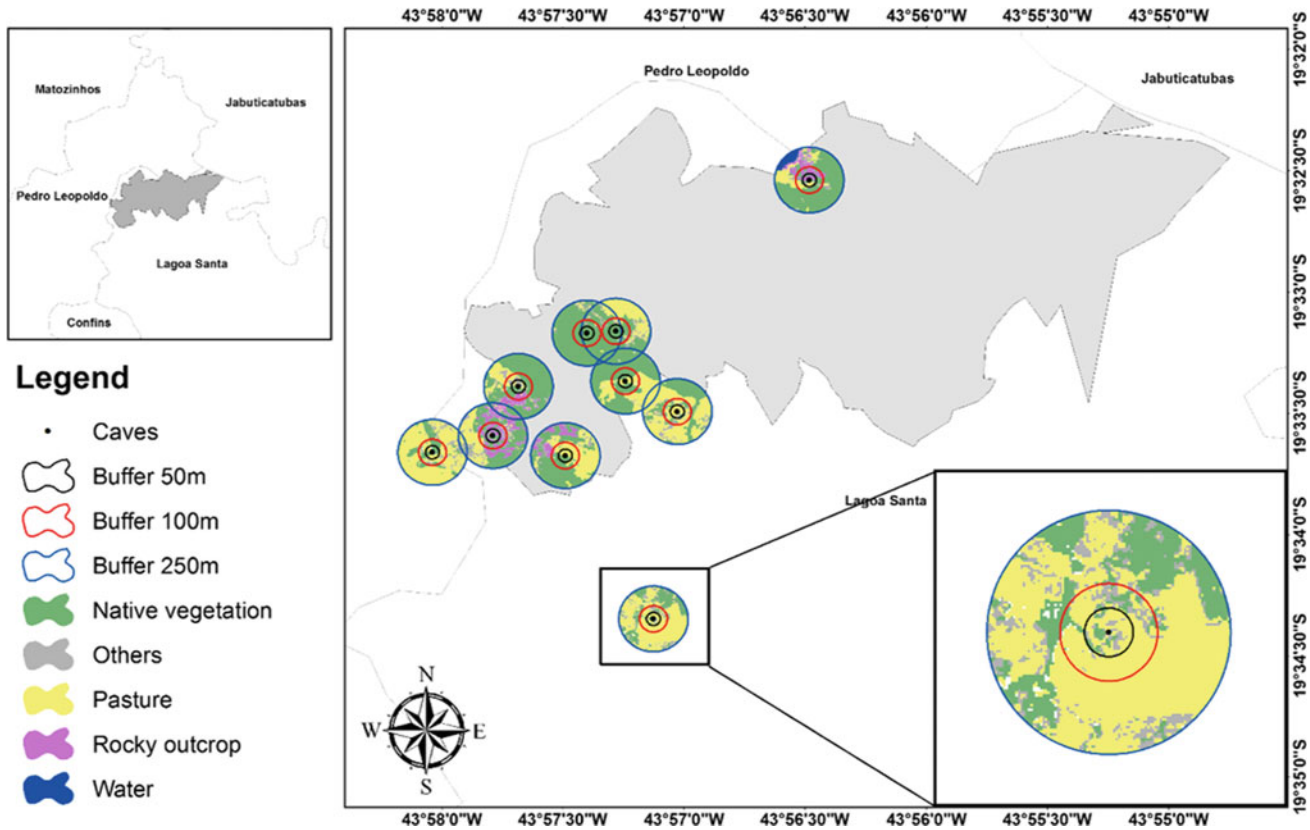

Fig. 7 Spatial characterization of the landscape at "Sumidouro State Park". Different colors represent distinct vegetation cover or land-use types. The black dots indicate the sampled caves, surrounded by the buffers of 50, 100, and 250 m for analyzing the effect of spatial scale on the explanatory power of environmental variables at the cave invertebrate communities. Modified from Pellegrini et al. (2016)

5 Tourism: Enemy or Ally to the Cave Life?

Several caves around the world present an extraordinary scenic beauty. Such caves historically attracted the attention of general public, which started to use them for touristic purposes. According to Hamilton-Smith (2004) tourist caves can be defined as those attracting the interest of the general people, thus generating some type of financial return, as charge for admission or sale of souvenirs. Several caves have been used worldwide for touristic purposes during decades. Many of these caves receive thousands of visitors every year. Culver and Sket (2002) attested that caves that receive large number of visitors could present a high diversity of species, despite the obvious alterations caused by tourism. Accordingly, the opening of a given cave to tourism does not mean that their biodiversity will necessarily be altered or lost, as in the cases of some show caves, as the Mammoth Cave (Kentucky, USA), Postojna-Planina Cave System (Slovenia), Baget-Sainte Catherine System (France), and Vjetrenica Cave (Bosnia and Herzegovina) (Culver and Sket 2002). However, one cannot assume that touristic use never has deleterious effects in caves, since alterations caused by such activities can affect distinct subterranean species in different ways.

In Brazil, there are many show caves with diverse infrastructure or use. In the Lagoa Santa Karst, two show caves can be highlighted, especially due to the large number of visitors they attract every year. Such caves are Rei do Mato Cave (located in Sete Lagoas municipality) and Lapinha Cave (Located in Lagoa Santa municipality). Both caves were inventoried regarding the fauna and at least in one of them (Lapinha Cave) it was possible to evaluate the effects of the touristic use on the cave communities.

In Rei do Mato Cave (Sete Lagoas municipality), a total of 204 invertebrate species were found during five sampling events (unpublished data from the authors). However, the species richness varied along the time, and richer communities were found during rainy periods, following the general pattern of the cave communities in the area (30 species on average in the dry periods contrasting with 67 species on average in the rainy periods). Most invertebrate species were troglophiles and trogloxenes, and only four species presented troglomorphic traits (two isopods, one springtail, and one harvestman). Furthermore, most species (more than 60%) were concentrated near the entrance during all

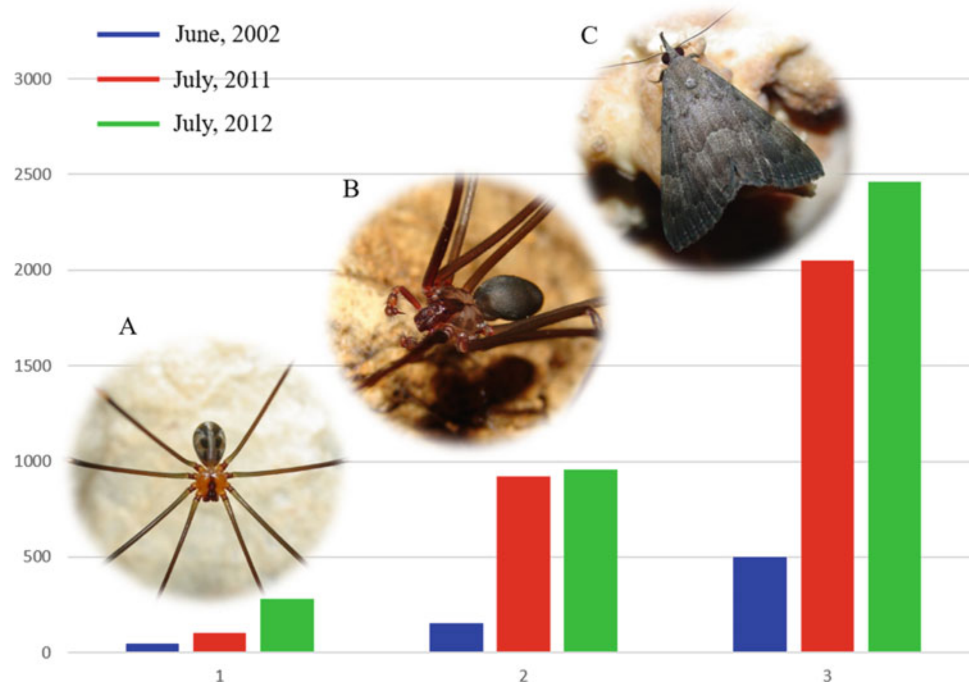

Fig. 8 Differences observed in population sizes of three species in sampling events conducted during touristic use (June 2002 and July 2012) and during non-touristic use (July 2011), in Lapinha Cave (Lagoa Santa municipality): **a** *Mesabolivar* sp. (Pholcidae); **b** *Loxosceles similis* (Sicariidae); **c** *Hypena* sp. (Noctuidae)

sampling events, indicating the importance of ecotone communities for this cave, or contrarily, the highly restrictive conditions observed in the inner portions of the cave (caused by natural and/or touristic factors).

In the Lapinha Cave (Lagoa Santa municipality), three sampling events were performed, all during dry periods (unpublished data from the authors). However, the sampling occurred in quite distinct situations. The first sampling (held in June 2002) occurred when the cave was under constant touristic use, since it was opened for this purpose in 1968. However, in 2009, touristic activities were interrupted due to the need of a management plan for the cave, and no tourists were allowed in. The second sampling event was performed in July 2011, 2 years after it was closed for tourism. After the second sampling, tourism was reestablished in the cave. The third sampling occurred in July 2012, one year after the reopening of the cave to tourists. Therefore, the samplings allowed a comparison regarding the direct effects of tourism on the cave communities of this cave. The most significant result observed was an increase in the invertebrate richness of the cave after the tourism ceased in the cave. The first sampling (during touristic use) revealed 58 invertebrate species, while the second event (no tourism in course) revealed 75. Hence, there was an increase of almost 30% in the richness during the period without tourism. The third collection (one year after the reestablishment of tourism) surprisingly revealed again 58 species, thus indicating that the tourism in this cave presented an obvious effect reducing the richness of invertebrate species.

However, diversity did not change considerably comparing the three events. In the first collection (during tourism), it corresponded to 2.3, in the second (after closing the cave) to 2.1, and in the third collection (after the reopening to tourism) it was 2.5. The increase in the diversity after the reestablishment of tourism resulted from a reduction in the dominance in this period (D = 0.14, compared to 0.21 and 0.22 from the first and second samplings, respectively). Furthermore, in general, the abundance tended to increase from the first to the last sampling events, and the highest values were observed after the reopening to tourism (8,141 individuals in the whole cave, compared to 4,966 and 1,210 individuals observed in the first and second samplings, respectively). Some common troglophilic or trogloxene species, as the cave moth *Hypena* sp. (Noctuidae) and the spiders *Mesabolivar* sp. (Pholcidae) and *Loxosceles* sp. (Sicariidae) presented the same pattern (Fig. 8).

However, it is important to highlight that the reopening of the cave to tourism occurred after the management plan, which indicated the necessity of preserving some areas (as the deeper chamber of the cave) for the fauna, especially due to the presence of a bat colony (*Phyllostomus* sp.). Accordingly, after the visitation ceased in this chamber, the bat colony increased (as the guano production), allowing more species to establish themselves and to grow their populations. Thus, the deleterious effects of tourism can be reduced by closing some areas to visitors, keeping them preserved and far from the direct effects of the visitation (such as lights, trampling, among others).

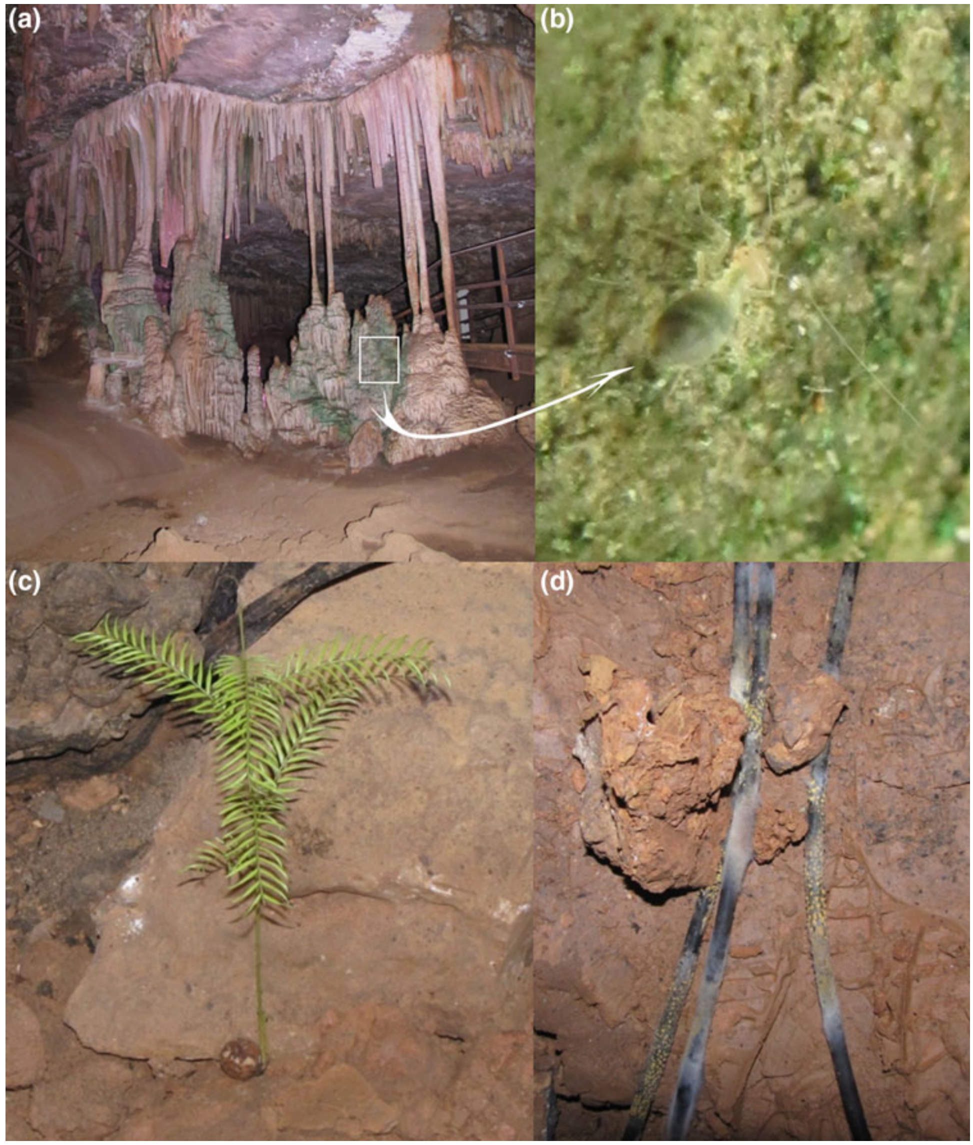

Fig. 9 **a** Algae growing on a speleothem in Rei do Mato Cave (Sete Lagoas municipality); **b** *Psyllipsocus falcifer* feeding on such algae (see the greenish color of the specimen's abdomen); **c** an angiosperm growing inside the Rei do Mato Cave; **d** fungi (especially *Fusarium solani*) growing associated with the electric cabling inside the Rei do Mato Cave

According to Hamilton-Smith (2004), the most severe impacts observed in tourist caves usually result from inappropriate use. However, the tourism, per se, can cause several modifications on the cave environment, most of them primarily produced by the introduction of artificial light, which creates a photoperiod in the pristine aphotic areas of the cave. Such photoperiod provides conditions for the growth of photosynthetic organisms (especially algae and moss, but sometimes ferns and other more complex plants) (Fig. 9a–c). In turn, those organisms represent organic resources that were absent in aphotic zones, thus attracting animals that would not be found in such areas. Furthermore, these organisms (Fig. 9c) can be consumed by cave species and the effects of such consumption on the populations (positive or negative) are unknown. Another important alteration caused by the touristic infrastructure in show caves of the Lagoa Santa Karst was the emergence of some fungi that started growing associated to the electrical wiring inside the caves (Fig. 9d). The most important species found in those cables were *Fusarium solani*, which are also commonly observed in soil. However, since there were no studies on the fungal community before the installation of those cables, it is not possible to evaluate whether those fungi already inhabited the cave soil or were introduced following the emplacement of such infrastructure. The concern lays over the fact that *Fusarium* species can cause opportunistic mycosis, thus offering risks to the visitors. Furthermore, hundreds of invertebrates (especially barklices and springtails) were observed feeding on those fungi colonies growing on the cabling. Accordingly, the fungi appearance may have caused a disproportional growth of some cave invertebrate populations, besides attracting those species to areas in which they are more exposed to trampling by visitors.

Finally, it is important to highlight the importance of tourism as a powerful tool for environmental education in the karst systems as a whole. Although such activities can produce deleterious effects on the caves and their fauna, such effects can be reduced by management plans and actions. On the other hand, one of the most effective approaches to promote the sustainable use of karst landscapes and caves is education. Show caves, in this context, are extremely important, since they can be used in instructive visits in order to provide a broader view of the environment for the cave visitors and incite more interest for the preservation of those unique and endangered habitats. Accordingly, show caves offer the opportunity to educate the general audience, since during visits technical information can be transmitted, thus providing a subtle inclusion of concepts, expanding the vision, as well as providing human interaction with the subterranean environment.

6 Threats

The Lagoa Santa Karst faces many environmental threats (see chapter "Environmental Problems in the Lagoa Santa Karst", this volume). The karst region of Lagoa Santa comprises one of the main areas of mineral exploitation of the state of Minas Gerais, with cement production as the main economic activity of the region. This mineral derivative represents an important economic pillar for the state, which is leader on the cement production of Brazil, with more than 14 million tons per year (CBIC 2013). According to Oss and Padovani (2003), for each ton of cement produced approximately 1.4 tons of limestone or similar rock is required. Thus, the accumulation of industries of such segment associated with the limited spatial distribution of Lagoa Santa karst constitutes relevant threats to the local subterranean environment.

The impacts of such economic activity over subterranean environments lead to the complete removal of bedrock for the production of commercial derivatives, alterations in groundwater routes of the local aquifer to access the mineral deposits and water supply of the industrial plant, besides the emission of gases and particulate sediments. The first mentioned impact promotes the complete alteration of landscape in function of the removal and processing of the rock mass. This process may cause the total or partial destruction of cavities and indirectly may interrupt the hydric flow responsible by the genesis and contribution of epigean trophic resources in the karst system. As it has been already demonstrated for other lithologies, the use of water during mining activities alters the balance between the aquifer recharge and the residence time of subterranean waters, limiting the capability of hydric resilience of the system (Gama and Matias 2015). In this sense, the lack of adequate management of the water resources may cause the extinction of many troglobitic amphibious species endemic of this karst area (Trajano and Bichuette 2010; Campos-Filho et al. 2014).

In relation to the emission of gases, studies demonstrate that this industrial sector is responsible for 5–7% of the total anthropic CO_2 emitted to the atmosphere (Chen et al. 2010). Additionally, the dust resulting from the process of cement production may accumulate in leaves of different vegetal strata, thus promoting necrosis and chlorosis in plants (Kumar et al. 2008). Considering the Lagoa Santa Karst, this is worrisome since the main trophic resources found in caves are allochthonous (Gomes et al. 2000; Pellegrini et al. 2016; Iniesta et al. 2012). Therefore, alterations on the quality and/or quantity of leaf litter carried into the caves may affect the fauna community, such as the local exclusion of species by inter or intraspecific competition.

The proximity of the Lagoa Santa Karst to a large metropolitan center makes the urban expansion and other anthropic activities possible threats to its conservation. The metropolitan region of Belo Horizonte, in which all the municipalities that compose the karst are included, is the third largest urban agglomeration of Brazil with population over 2.5 million people (IBGE 2016). Environmental impacts of the urban expansion vary from the excessive consumption and alterations of water quality, for modifications of the biodiversity and landscapes at different scales (Larson et al. 2009). According to White et al. (1986), the effects of urbanization over the karst are even more severe. The presence of urban centers affects the natural cycle of water infiltration in the soil, thus generating karst collapse through the increase of hydraulic gradient due to the lowering of the water table and alterations of the rainfall. The contamination of the water table by slurry and other anthropic wastes also occurs in some caves, given the proximity of dumps. One example occurred in a cave located in the municipality of Matozinhos (Meandro Abismante Cave). A faunal inventory conducted in 2002 revealed the presence of troglobitic fauna including an amphibious species of Styloniscidae (probably of the genus *Spelunconiscus*—Fig. 10b). After this inventory, a technical report was elaborated, which indicated a strong potential of contamination of the aquifer inside the cave given its proximity in relation to the municipal landfill of Matozinhos (Fig. 10a), what would have irreversible consequences for the fauna (especially for the troglobitic isopod that inhabited the small stream in the cave). This report also indicated the need to monitor such population in function of this potential impact. However, unfortunately, no attitude was taken by environmental agencies. In 2005, in a visit to the same cave, the presence of a dense biofilm was observed covering the entire

Fig. 10 **a** Landfill of the Matozinhos municipality (red arrows) located closely to the entrance of the Meandro Abismante Cave (white arrow); **b** *Spelunconiscus* sp. isopods present in the same cave before contamination; **c** dense biofilm covering the drainage bottom, as well as blackened fragments apparently from the contamination by the landfill

drainage bottom, as well as blackened fragments apparently from the contamination by the landfill (Fig. 10c). No specimen of the troglobitic Styloniscidae was observed during this visit. It is important to highlight that in 2002 dozens of individuals were seen along the accessible stretch of the drainage. Up to now, there is no more information about individuals of this species, and so it is possible that this important species, endemic and new to science, has been extinct even before it was described.

Furthermore, the economic and social development of the region results in a disordered exploration of natural resources and the substitution of important forest areas of Cerrado by grassland areas for livestock. This is the main threat to this biome, considered one of the hotspots for the conservation of world biodiversity (Myers et al. 2000). Nowadays, pastures for extensive livestock occupy almost 42% of the native area of Cerrado, and deforestation occurs at 30,000 km^2/year, a rate superior to those found for the Amazon region (Klink and Machado 2005). A recent study on different land use and its influence on the composition of terrestrial invertebrates from the Lagoa Santa Karst, pastures were present around all the studied caves, representing up to 76% of the buffer area (Pellegrini et al. 2016). In this work, the authors indicate the presence of limestone outcrops as the most determining factor for the composition of the subterranean community, as previously mentioned. Among other factors, this occurs due to the low anthropic influence, since the karst depressions in areas adjacent to the caves and outcrops are frequently used for crops and livestock (Pellegrini et al. 2016). The substitution of the native forests by monocultures generates a series of environmental problems like fragmentation, biodiversity loss, introduction of invasive species, erosion and soil degradation, water pollution, changes in the fire regime (natural impact of this biome), imbalances in the carbon cycle and probable modification of the regional climate (Klink and Machado 2005). Such alterations of epigean landscape may affect directly or indirectly the caves, thus hampering the maintenance of the environmental stability characteristic of subterranean environments.

Since the Lagoa Santa Karst lies close to large metropolitan areas, it presents a high density of roads and highways that makes possible the flow of people and services. Studies demonstrate that the establishment of a road network is among the main anthropic activities that affect directly or indirectly the dynamics of ecological processes, altering the physical, chemical, and biological properties of the environment (Coffin 2007; Forman and Alexander 1998). Direct impacts comprise the death of animals by trampling (Clevenger et al. 2003; Coelho et al. 2008) and isolation of populations (Shepard et al. 2008). Indirectly the roads favor the anthropic access and occupation in contiguous areas (Freitas et al. 2010) and alter the surface water runoff, thus promoting erosion in the soil and carrying the particulate material to other areas. Additionally, the facility of access makes marginal areas more susceptible to the fire (Laurance et al. 2009). The existence of these structures fractioning natural habitats interrupts the genetic flow, what may alter the permanence of populations in fragmented areas (Epps et al. 2005). Despite the absence of studies correlating the presence of roads and the effects of them over the hypogean fauna, it is likely that these anthropic actions may modify the structure of cave communities. Among the possible impacts, one may cite the alteration of the dynamics of trophic resources for the cave, what may severely influence the preservation and maintenance of the fauna. The proximity of roads may still generate constant vibrations in the caves, facilitate the accumulation of garbage and other anthropic wastes, besides altering the adjacent external landscape.

The presented threats represent only part of the risks to the maintenance of fauna and stability of subterranean environments. Since the Lagoa Santa Karst is inserted in an important Brazilian economic region and within the biome most used by agricultural activities, several other impacts may affect the caves and their surroundings (for example, forest fires, land invasion, pesticide contamination, vandalism and graffiti in caves, among others). Due to the social and economic plurality, preventing and mitigating the mentioned impacts is beyond the application of public policies and delimitation of areas for conservation. The awareness of the society and the assignment of value to the subterranean environment through environmental education are essential to guarantee the sustainable management of this karst.

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