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CAVE INVERTEBRATES IN NORTHWESTERN MINAS GERAIS STATE, BRAZIL: ENDEMISM, THREATS AND CONSERVATION PRIORITIES.

JAMSKI NEVRETENČARJI V SEVEROZAHODNEM PREDELU MINAS GERAIS, BRAZILIJA: ENDEMIZEM, OGROŽENOST IN VIDIKI VAROVANJA

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Matheus Henrique Simões, Marconi Souza-Silva & Rodrigo Lopes Ferreira: Cave invertebrates in northwestern Minas Gerais State Brazil: endemism, threats and conservation priorities

Due to their high economic value, karstic areas and caves have been affected for decades in Brazil. Accordingly, such systems have been receiving the attention of managers, environmental agencies and researchers, especially in recent years. The present study collected information regarding the cave invertebrate fauna of the Northwest region of Minas Gerais, Brazil, such as species richness and endemisms, besides the impacts and threats occurring in these environments, identifying caves and more vulnerable areas and proposing conservation actions. Three caves were identified as a priority for conservation: Lagoa Rica cave in Paracatu, and Lapa Nova and Lapa da Delza caves in Vazante. Another three areas were considered in need of conservation actions: regions of Arinos, Paracatu and Cabeceira Grande/Unaí. The main threat found in the area was the conversion of forests into pastures for cattle breeding, registered in the surroundings of 85% of the caves. The main recommendations were the recuperation of the surroundings, awareness raising of the population and biospeleological inventories in other caves of the area. The studied caves were very heterogeneous, presenting unique characteristics. Thus, the study of the highest possible number of caves of the region of interest is always recommended, to aid in conservation and action plans for cave fauna.

Key words: invertebrates, caves, conservation, endemisms.

Izvleček UDK 551.435.84:502.17(815.1)

Matheus Henrique Simões, Marconi Souza-Silva & Rodrigo Lopes Ferreira: Jamski nevretenčarji v severozahodnem predelu Minas Gerais, Brazilija: endemizem, ogroženost in vidiki varovanja

Kraška področja in jame v Braziliji so zaradi visoke gospodarske vrednosti že desetletja prizadeta. Posledično so, zlasti v zadnjih letih, pritegnila pozornost upravljalcev, okoljskih agencij in raziskovalcev. V pričujoči študiji so zbrani podatki o jamski favni severozahodnega območja Minas Gerais v Braziliji s poudarkom na bogastvu vrst in endemizmu, poleg ugotovljenih vplivov in nevarnosti, ki se pojavljajo v teh okoljih ter jam in drugih ranljivih predelov, za katere predlagamo ukrepe za njihovo ohranitev. Tri jame so bile opredeljene kot prednostne za ohranitev: jama Lagoa Rica v Paracatu in jami Lapa Nova in Lapa da Delza v Vazante. Poleg tega so bile prepoznane tri regije, kjer naj bi se izvajali ukrepi varovanja: Arinos, Paracatu in Cabeceira Grande/Unaí. Največja grožnja na teh območjih, kjer je registriranih 85% jam, je izsekavanje gozdov in sprememba v pašnike za vzgojo govedoreje. Glavna priporočila so zaščita področja, ozaveščanje prebivalstva in biospeleološke raziskave v drugih jamah na proučevanem območju. Vse raziskovane jame so heterogene, z edinstvenimi lastnostmi. Priporočene so raziskave v čim večjem številu jam, kot dodana vrednost pri načrtih za ohranjanje in varovanje jamske favne.

Ključne besede: nevretenčarji, jame, varovanje, endemizem.

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INTRODUCTION

Caves are habitats for several species that use them for the most diverse purposes (Culver & Pipan 2009). The troglobites, a strictly cave species, stand out in function of the frequent evolutionary modifications of morphological, physiological and behavioral character that make them highly specialized to live in these environments (Culver & Wilkens 2000). As such, caves are places of great importance for the study of evolutionary processes moulded by the selective pressures typical of these environments, such as permanent absence of light, shortage of food resources, high moisture/humidity and constant temperatures, among others (Culver & Pipan 2009).

Many troglobitic species occur in a single cave or a small group of caves. Once these environments have been extensively altered, especially in recent decades, it is possible that many species have disappeared without even having been described (Elliott 2000). Furthermore, caves are important for the maintenance of the ecosystems where they are inserted, because they frequently possess drains that supply the surface and are shelters of species that provide recognized ecological services to the external ecosystem, as for instance, the bats (Elliott 2000).

Although the importance of the subterranean habitats is evident, caves have been threatened over the years by anthropic interventions (Watson *et al.* 1997). These interventions are resulting in negative effects, such as hydric resource pollution and reduction, changes in the hydrologic regime, habitat alterations and local species population decline, among others (Gillieson & Thurgate 1999; Parise & Pascali 2003; De Waele & Follesa 2003; Neill *et al.* 2004; Van Beynen *et al.* 2007). Given these threats, karstic areas and caves are receiving the attention of managers, environmental agencies and researchers, mainly in recent decades, due to the great importance of those areas to science (geology, paleontology, archeology and biology), as well as to human values (spiritual, religious, aesthetic, recreational and educational) (Watson *et al.* 1997).

Due to the socioeconomic importance of karstic areas and the consumption increase of natural goods and products it is unlikely that some caves do not come to be affected, even those that present rare species (Gibert & Deharveng 2002). As such, to recognize locals with conservation priority is an important step for the creation of preserved areas and maintenance of the subterranean biodiversity.

In Brazil, studies with the objective of proposing areas that need emergency action for subterranean fauna conservation have been conducted, especially in recent years (Souza-Silva 2008; Zampaulo 2010; Bento 2011; Souza 2012). Such studies are based mainly on three aspects: (I) presence of troglobite species considered relevant in function of the "evolutionary status", knowledge inadequacy, restricted distribution and fragility facing random habitat alteration events (Culver & Wilkens 2000; Culver & Pipan 2009), (II) species richness, by enabling complex ecological interactions and processes (Ferreira 2004) and (III) the conservational state of the cave surroundings and interiors, which can reveal the impact degree and the threats imposed to the fauna (Souza-Silva 2008).

Recently a National Action Plan was published (PAN) for the conservation of the speleological patrimony in the karstic areas of the São Francisco river basin (Cavalcanti *et al.* 2012), the third largest hydrographic basin and one of the most important in Brazil. Among the three karstic areas within the scope of PAN, the Region I, located in Middle San Francisco Basin (karstic areas of the Paranoá Group, Bambuí Group and Vazante Formation), can be considered the most lacking in studies related to the cave fauna. The few works regarding the subterranean fauna were only made at one cave, Lapa Nova, located in the municipal district of Vazante, state of Minas Gerais (Pellegrini & Ferreira 2012a, b; Souza & Ferreira 2012). As such, the present study gathered information of the cave invertebrate fauna, such as species richness and endemisms, and the impacts and the threats occurring to the environment, identifying caves and more vulnerable areas and proposing conservation actions.

MATERIALS AND METHODS

STUDY AREA

The study was carried out in 47 caves distributed in eight municipal districts of the Northwest area of Minas Gerais, Brazil. The caves are inserted in Region I of the National Action Plan for the conservation of the speleological patrimony in the karstic areas of the São Francisco river basin (PAN Caves of São Francisco) (Cavalcanti *et al.* 2012) (Fig. 1).

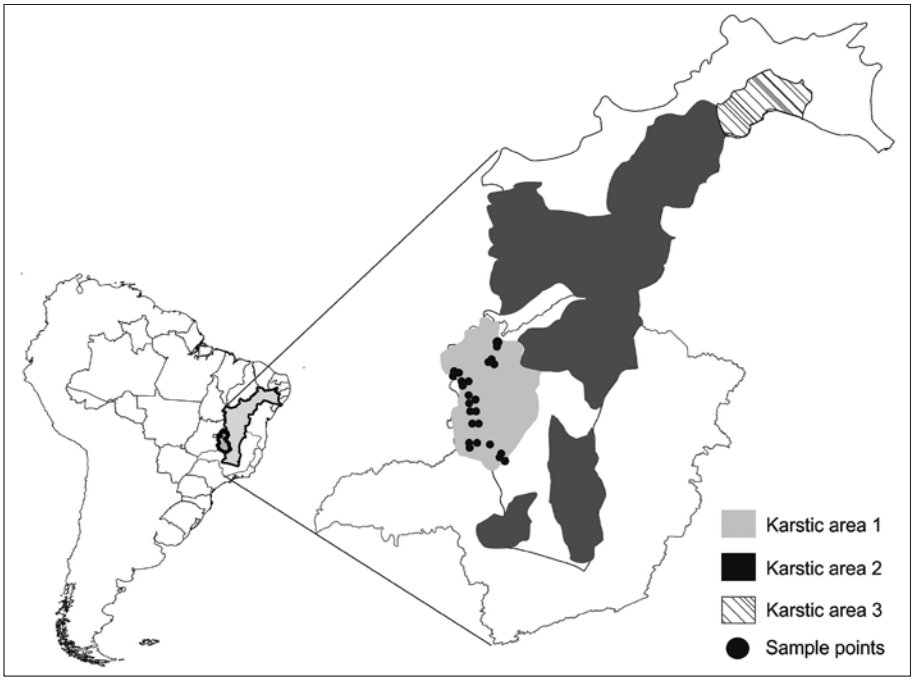

Fig. 1: Map of South America highlighting Brazil, Rio San Francisco hydrographic basin, and the state of Minas Gerais. Inside the San Francisco basin the karstic areas inserted in PAN San Francisco are highlighted. The caves of the present study are distributed through eight municipal districts of the Northwest area of Minas Gerais, belonging to the karstic area 1 of PAN Caves of São Francisco.

INVERTEBRATE SAMPLING

The collection of invertebrates was conducted through active searches throughout whole cave with the aid of tweezers, brushes and hand nets. During the collections, organic deposits were prioritized (plant debris deposits, carcasses, guano, etc.) and micro-habitats (under stones, moist soil, openings, speleothems, etc.). All of the collected specimens were conditioned in vials with 70% alcohol. The collection team was always composed of four biologists with experience in speleology and collection of invertebrates in caves, as recommended by Weinstein & Slaney (1995).

All of the organisms were identified until the lowest taxonomic level accessible and separated into morphospecies, as in other works (Souza-Silva 2011b; Oliver & Beattie 1996; Derraik *et al.* 2002; Ward & Stanley 2004; Derraik *et al.* 2010). All of the specimens are deposited in the subterranean invertebrate collection of Lavras (ISLA), at the Federal University of Lavras (UFLA).

The identification, in the specimens, of "troglomorphic" traits, was used for classification of potentially troglobitic species. Such characteristics vary among the groups, but are frequently represented by the reduction of pigmentation, reduction of ocular structures and appendage elongation (Culver & Wilkens 2000).

CAVE RATING TOOLS

The definition of the priority areas for conservation was based on the overlapping of the biological relevance, troglobitic species presence and impact degree in the caves as described below (modified from Souza-Silva 2008).

Biological relevance

The biological relevance categories were defined as extreme, high, medium and low, based on the total and relative species richness. The relative species richness in each cave was calculated through the ratio among the total richness, the horizontal projection of the cave and extension of the entrance (Souza-Silva 2008).

The highest value obtained for richness and relative richness was divided by four. Thus we obtained four categories of total and relative richness (extreme, high, medium and low) with intervals of number of species.

For the categorization of the biological relevance of the caves, weights were attributed to the total and relative richness categories. Caves with extreme total richness received Weight 8; high total richness Weight 6; medium total richness Weight 4 and low total richness Weight 2. Caves with extreme relative richness received Weight 4; high relative richness Weight 3, medium relative richness Weight 2 and low relative richness Weight 1.

It was defined that the total richness should receive the double the weight of the relative richness in function of the real and direct importance of the absolute number of species, as a parameter of preservation of a given system. In case only the relative richness was used, one would run the risk of preserving reduced caves, but with a relatively high number of species to the detriment of extensive caves and with high absolute richness (Souza-Silva 2008).

The biological relevance for each cave was determined through the sum of the weights of the total and relative richness for each cave. The highest biological relevance served as a basis for the inclusion of the caves in the categories of extreme, high, medium and low final biological relevance. Caves with *extreme* biological relevance received Weight 4; *high* final biological relevance received Weight 3, *medium* final biological relevance received weight 2 and *low* final biological relevance received Weight 1.

Troglomorphic species categories

The highest values of troglomorphic species richness found served as the basis for classification of the caves as extreme (Weight 4), high (Weight 3), medium (Weight 2) and low (Weight 1) troglomorphic species richness.

Characterization of impacts

Environmental impacts were defined for each cave in function of the presence or absence of alterations in their internal and external environments. The surveyed alterations were classified in relation to *uses* and *impacts*. Tourism and religious activities were considered uses, impacts being trampling, illumination, and the consequent alterations by these activities.

From the identification of the impacts in the caves we proceeded to a second analysis concerning the magnitude of these impacts that can cause alterations in the communities. Such analysis considered from impacts that could cause minimum alterations to those that would considerably affect the cave fauna.

In the impact definitions, three types of modifications were considered (*depletion*, *enrichment* and *alteration*). The first modification type is that which can lead to depletion, in other words, the reduction of trophic resources or the fauna in function of the anthropic activities and the second type, the alterations that lead to the enrichment in the availability of organic resources for the fauna. The third type of modification is that which modifies, in space and time, the physical structure of habitats or micro-habitats in the caves, called *alteration* impacts. It is emphasized that the same impact can lead to more than one type of these three modifications.

For attribution of the weights, the impacts were classified according to the potential, into *intense* (potentially the cause of intense alterations in the fauna – Weight 2) or *tenuous* (potentially the cause of reduced alterations on the fauna – Weight 1). A second classification added to the impact analysis the deals with their permanence. The permanence refers to the period of time the impact persists. Thus, the impacts were considered of *short* (Weight 1) or *continuous* duration (Weight 3). We opted for a weight attribution three times higher for continuous impacts for the fact that the continuity of the impacts can cause much greater damage than those of short duration. The last impact classification refers to the range of the impact. *Punctual* impacts received Weight 1, while those that occur over a wide range (*systemic* impacts) received Weight 2. The impacts that presented more than

Tab. 1: Valuation of the impacts to the caves. D: depletion, E: enrichment, A: alteration, I: intense; T: tenuous; CD: continuous duration; SD: short duration; GI: general impact; LI: localized impact; W: weigh of impacts; FIW: final impact weights (= $\Sigma w_{potencial} + \Sigma w_{permanence} + \Sigma w_{range}$*); *: impacts inside the caves (Modified from Souza-Silva 2008).*

Impacts	*Modification*	*Potential*	*W*	*Permanence*	*W*	*Range*	*W*	*FIW*
Mining	D + A	I	2 + 2	CD	3	GI	2	9
Garbage	E + A	I	2 + 2	CD	3	GI	2	9
Bare soil	A	I	2	CD	3	LI	1	6
Roads surroundings	A	T	1	CD	3	LI	1	5
Trail	A	T	1	CD	1	LI	1	3
Erosion	A	I	2	CD	3	LI	1	6
Siltation	A	I	2	CD	3	LI	1	6
Area burned	A	I	2	SD	1	LI	1	4
Deforestation	D	T	1	SD	1	GI	2	4
Impermeability of the soil	A	I	2	CD	3	LI	1	6
Livestock	A	T	1	CD	3	LI	1	5
*Destruction of speleothems	A	T	1	CD	1	LI	1	3
* Mining tailings	D + A	I	2 + 2	CD	3	GI	2	9
*Silting of drainage	D + A	I	2	CD	3	LI	1	6
*Graffiti	A	T	1	SD	1	LI	1	3
* trampling	A	I	2	CD	3	GI	2	7
*Constructions	A	I	2	SD	1	LI	1	4
*Bonfires	A	T	1	CD	1	LI	1	3
*Burning tire	D + A	I	2 + 2	CD	1	LI	1	6

one of the three alterations (depletion, enrichment or alteration) had the intensity weights added.

Tab. 1 shows some examples of impacts that were registered for the interior and surroundings of the caves and the weights attributed to each one. Note that the final weight can vary among the caves, because the same impact can present intensity, permanence and different range for each cave.

The categorization of the caves regarding the impact degree was conducted starting from the sum of the values obtained in each cave. The highest sum of impacts served as the basis for the separation of the caves regarding the degree of impacts into extreme (Weight 4), high (Weight 3), medium (Weight 2) and low (Weight 1).

Vulnerability and priority caves for conservation

The degree of vulnerability of the invertebrate communities of each cave was obtained from the sum of the weights of the final biological relevance, richness of troglomorphic species and the impacts present in each cave. The highest vulnerability value was used for the inclusion of the caves in the vulnerability categories extreme, high, medium and low.

Caves classified as extreme vulnerability were considered as priority caves for conservation. Regions with caves with high vulnerability were highlighted as areas of secondary priority and that need some conservation action.

RESULTS

A total of 1,348 invertebrate species was registered distributed in at least 170 families. The average richness was 63 (±29) species. The Lapa Nova cave presented the highest richness (155 species) and the V01 cave presented the lowest species richness (15 species) (Tab. 2).

Among the 47 caves, 4.26% were classified as of extreme total richness (117–155 species), 19.15% as high (78–116 species), 59.57% medium (39–77 species) and 17.02% low (less than 39 species) (Tab. 2). The highest relative richness registered was at the Gruta Nove cave (3.822) and lowest in the Lapa Nova cave (0.001). Thus, 2.13% of the caves presented extreme (2.868 to 3.822), 2.13% high (1.913 to 2.867), 8.51% medium (0.956 to 1.912) and 87.23% low relative richness (under 0.956) (Tab. 2).

The highest sum obtained through the weights attributed to the caves starting from the total and relative richness classifications was nine. As such, 25.53% of the caves were classified as with extreme (7 to 9), 57.45% high (5 or 6) and 17.02% medium (3 or 4) biological relevance (Tab. 2). No cave presented low biological relevance.

Thirty six troglomorphic species were distributed throughout 19 caves, all with at least one endemic species, representing 80% of endemic species for a single cavity. Some troglomorphic species are presented in Fig. 2. The caves with the highest troglomorphic species richness were the Lagoa Rica cave, in Paracatu, with seven species and the Lapa Nova cave, in Vazante, with six species. Therefore, 4.26% of the caves were classified as of extreme (6 or 7 species), 2.13% high (4 or 5 species), 21.28% medium (2 or 3 species) and 72.34% low troglomorphic species richness (0 or 1 species) (Tab. 2).

The main use of the surroundings was the pastures, registered in 85.11% of the cave surroundings. The main use of the interior was tourist visitation, observed in 23.4% of the caves. The main impact found in the cave surroundings were trails, registered in 72.34% of the caves surroundings. The main impact observed inside the caves was the trampling, registered in 38.3% of the caves. Mining was considered as the main potential impact in the surroundings, being likely to occur in the future in 34% of the caves. The pollution of water bodies stood out as the main impact inside the caves, being likely in 27.6% of the caves. Some impacts are presented in Fig. 3.

The highest sum of the weights attributed to the caves regarding the observed impacts was registered for the Lapa do Campo de Futebol, located in the municipal district of Matutina (61), it being the only cave with extreme impact degree (46 to 61). 12.77% of the caves presented high (31 to 45), 38.3% medium (17 to 30) and 46.8% of the caves presented low degree of impact (below 16) (Tab. 2).

The highest sum of the weights attributed to the three items considered in this study regarding importance for cave conservation (biological relevance, troglobitic species presence and conservation state) was 11, registered for the Lapa Nova, municipal district of Vazante. As such, 6.38% (three caves) of the caves were classified as those of extreme vulnerability (9 to 11), 68.09% as high (6 to 8) and 25.53% of medium vulnerability (3 to 5). No cave presented low vulnerability (below 3) (Tab. 2).

The priority caves for conservation were the Lagoa Rica cave (Paracatu municipality), Lapa Nova cave and

Tab. 2: List of the caves studied in the municipal districts of the Northwest area of Minas Gerais, Brazil, between the years 2009 and 2011. Location in UTM (X, Y, Z), total number of species (S), classification as to total number of species (SC), relative richness (RR), classification as to the relative richness (RRC), biological relevance (BR), troglomorphic species richness (RT), classification as to the troglomorphic species richness (RTC), degrees of impact (DI), vulnerability (V), extreme (E), high (A), medium (M) and low (B), presence of water (PW) (R: rivers, P: pools; PP: phreatic pounds; D: dry).

Municipalities	*Caves*	*X*	*Y*	*Z*	*PW*	*S*	*SC*	*RR*	*RRC*	*BR*	*RT*	*RTC*	*DI*	*V*
Arinos	Camila	353310	8240506	23L	R	115	H	0.192	L	E	2	M	L	H
Arinos	Capa	357713	8236358	23L	R	113	H	0.014	L	E	0	L	L	H
Arinos	Marcela	354261	8240358	23L	R	94	H	0.002	L	E	0	L	M	H
Arinos	Suindara	354162	8240098	23L	D	55	M	0.021	L	H	0	L	M	H
Arinos	Salobo	369279	8287176	23L	P	50	M	0.188	L	H	2	M	M	H
Arinos	Taquaril	369401	8295327	23L	R	78	H	0.104	L	E	1	L	L	H
Arinos	Velho Juca	354106	8240266	23L	D	46	M	0.093	L	H	3	M	M	H
Cabeceira Grande	Caidô	259885	8206642	23K	D	70	M	0.006	L	H	1	L	M	H
Cabeceira Grande	Porco Espinho	257418	8206250	23K	D	35	L	0.529	L	M	0	L	L	M
João Pinheiro	Sapecado	350114	8015342	23K	D	26	L	0.867	L	M	0	L	L	M
João Pinheiro	Tauá	350312	8015352	23K	D	22	L	0.055	L	M	0	L	L	M
Matutina	Cachoeira	399044	7874960	23K	P	61	M	0.229	L	H	0	L	M	H
Matutina	Nove	399102	7874933	23K	D	48	M	3.822	E	E	0	L	H	H
Matutina	Campo de Futebol	398585	7874853	23K	D	42	M	0.112	L	H	0	L	E	H
Paracatu	Lagoa Rica	309267	8102836	23K	PP	55	M	0.055	L	H	7	E	H	E
Paracatu	Tamanduá II	311508	8070394	23K	D	41	M	0.539	L	H	0	L	M	H
Paracatu	Cava	297248	8132338	23K	D	48	M	0.383	L	H	0	L	M	H
Paracatu	Santa Fé	297342	8133601	23K	D	30	L	0.018	L	M	0	L	H	H
Paracatu	Brocotó	308134	8083657	23K	D	72	M	0.533	L	H	0	L	M	H
Paracatu	Brocotó II	308165	8083812	23K	D	73	M	0.243	L	H	0	L	M	H
Paracatu	Santo Antônio	306536	8105656	23K	P	51	M	0.055	L	H	0	L	H	H
Presidente Olegário	Caieira	385073	7974405	23K	D	61	M	0.014	L	H	0	L	L	M
Presidente Olegário	Juruva	385747	7973888	23K	R	112	H	0.030	L	E	1	L	L	H
Presidente Olegário	Vereda da Palha	380964	7981211	23K	R	119	E	0.034	L	E	1	L	L	H
Unaí	Abriguinho	256233	8206485	23K	D	34	L	0.654	L	M	0	L	L	M
Unaí	Barth Cave	279196	8183910	23K	D	47	M	0.021	L	H	1	L	M	H
Unaí	Cachoeira do Queimado	251574	8205653	23K	D	57	M	0.007	L	H	2	M	M	H
Unaí	Encosta	255335	8206050	23K	D	52	M	0.650	L	H	0	L	L	M
Unaí	Mata dos Paulista	278976	8183510	23K	R	64	M	1.422	M	H	0	L	L	M
Unaí	Frangas	279221	8183417	23K	D	41	M	1.051	M	H	0	L	L	M
Unaí	Deus Me Livre	279976	8182900	23K	D	106	H	0.236	L	E	0	L	L	H
Unaí	Rio Preto	259263	8205827	23K	D	56	M	0.320	L	H	2	M	L	H
Unaí	Malhadinha	257965	8206112	23K	D	108	H	0.311	L	E	3	M	L	H
Unaí	Sapezal	297937	8141547	23K	P	71	H	0.041	L	E	0	L	L	H
Vazante	Abrigo da Escarpa	307964	8016869	23K	D	36	L	0.900	L	M	0	L	M	M
Vazante	Escarpa	307911	8016928	23K	D	62	M	0.332	L	H	0	L	M	H
Vazante	Urtigas	308192	8017657	23K	D	70	M	0.006	L	M	2	M	M	H
Vazante	Urubus	307785	8016598	23K	D	93	H	0.063	L	E	3	M	L	H
Vazante	Não Cadastrada	308230	8017482	23K	D	49	M	1.332	M	H	1	L	M	H
Vazante	V01	306704	8017075	23K	D	15	L	1.500	M	M	0	L	L	M
Vazante	V02	306618	8017108	23K	D	37	L	2.467	A	H	2	M	L	H
Vazante	Delza	298146	8010447	23K	PP	46	M	0.008	L	H	5	A	H	E
Vazante	Mata Velha	299617	8007387	23K	P	61	M	0.054	L	H	0	L	L	M
Vazante	Guardião Severino	300039	8010088	23K	D	47	M	0.063	L	H	0	L	L	M
Vazante	Lapa Nova	299765	8010652	23K	PP	155	E	0.001	L	E	6	E	H	E
Vazante	Lapa Nova II	299691	8010585	23K	D	55	M	0.020	L	H	3	M	M	H
Vazante	Sumidouro da Vaca Morta	306446	8016811	23K	D	72	M	0.639	L	H	0	L	M	H

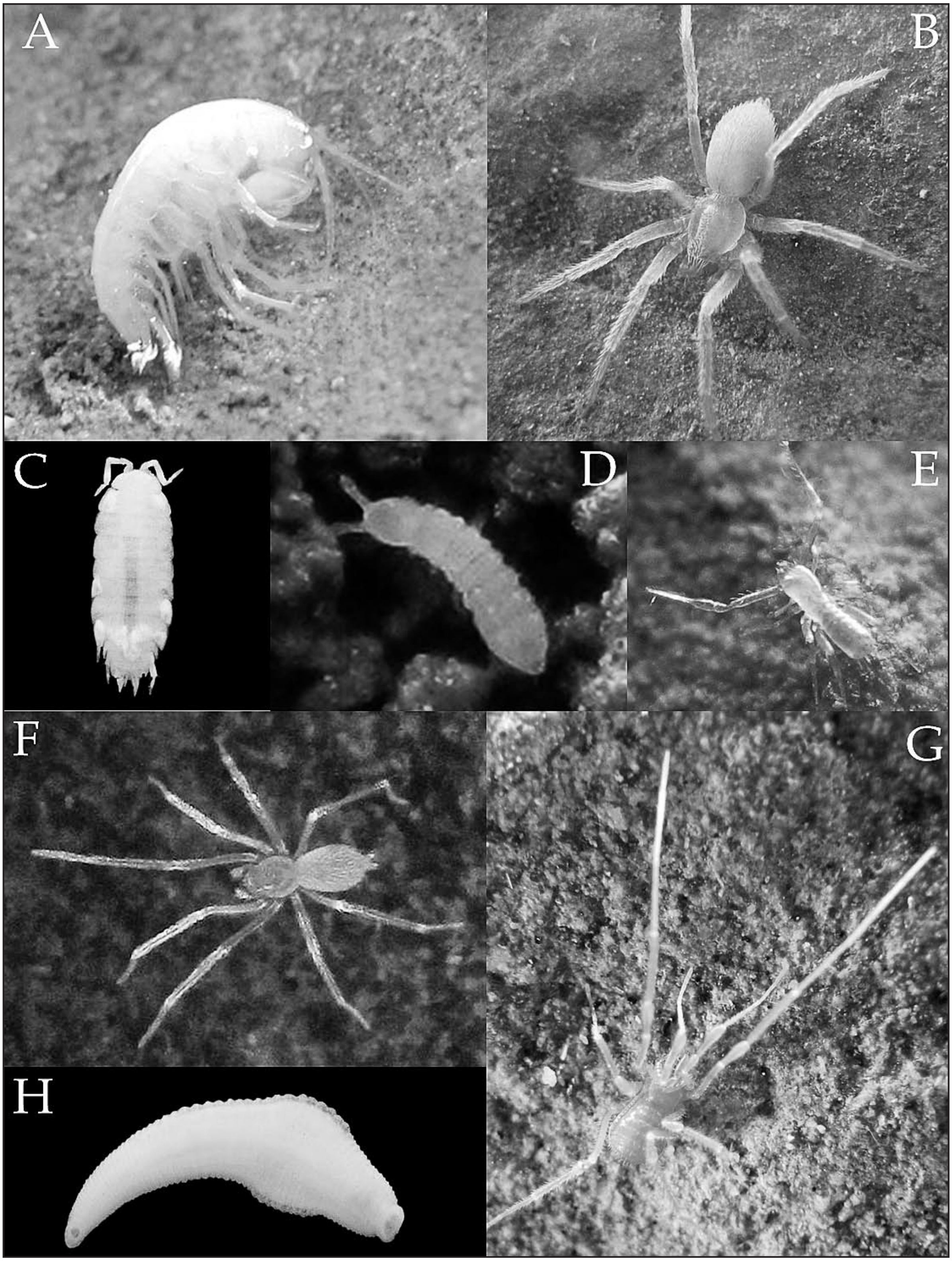

Fig. 2: Examples of troglomorphic species recorded in the Northwest region of the state of Minas Gerais, Brazil. A: Hyallela veredae (Hyallelidae). (Endemic to Vereda da Palha cave), B) Lygromma sp. (Prodidomidae) (Endemic to Cachoeira do Queimado cave); C) Trichorhina sp. (Endemic Camilo cave); D) Acherontides sp. and E) Chthoniidae sp. (Endemic to region of Vazante), F) Tetrablemmidae sp. and G) Speleoleptes sp. (Endemic Lagoa Rica cave), H) Hirudinea sp. (Endemic to Salobo cave).

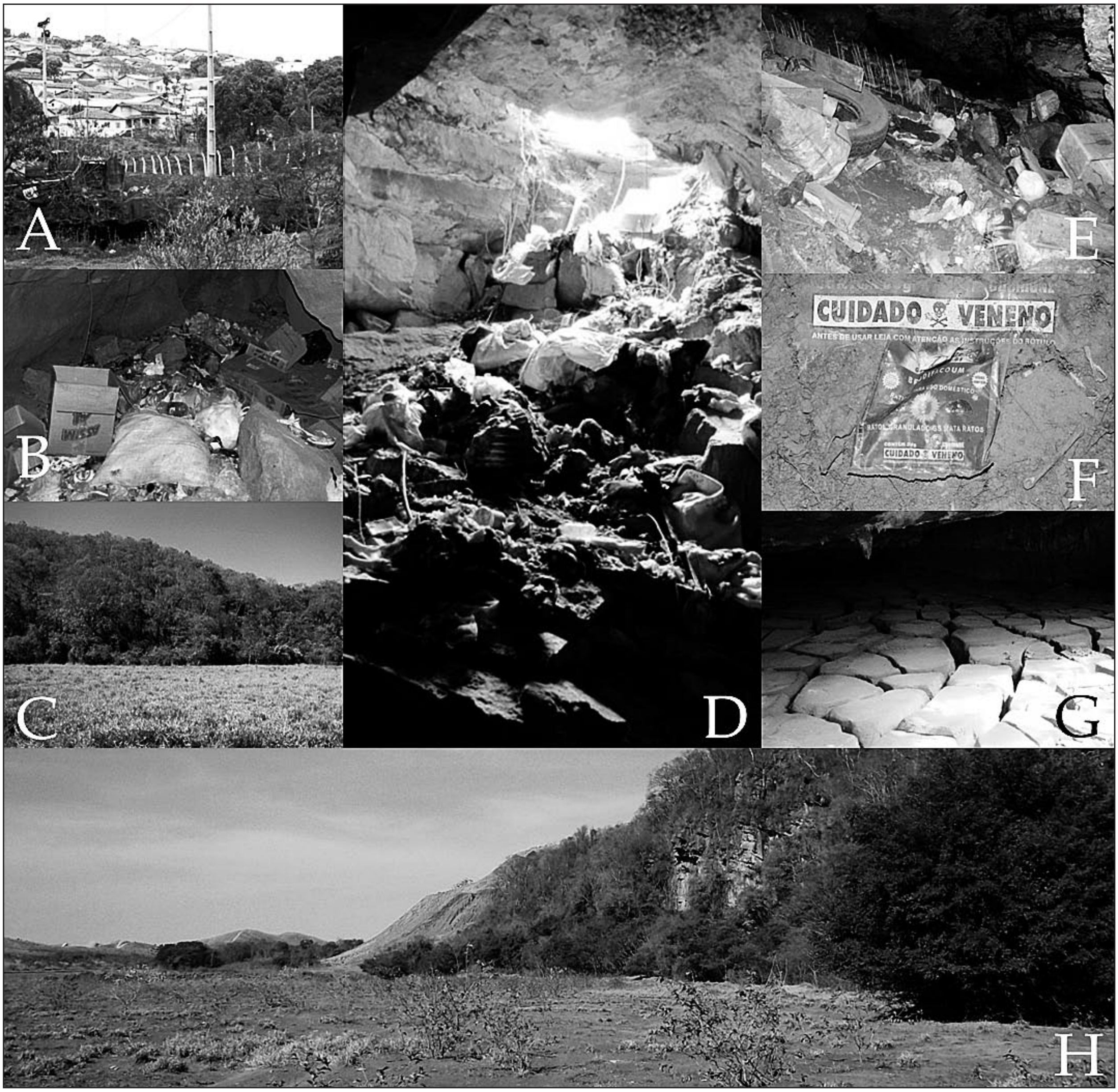

Fig. 3: Some impacts found in the surroundings and interior of the caves studied in the Northwest of the state of Minas Gerais, Brazil, between the years 2009 and 2011: A) Urban district on a cavity (Matutina); B) Discard of organic and veterinary trash (Paracatu); C) Removal of the external vegetation in the area of the surroundings (Paracatu); D) Discard of organic and veterinary trash (Paracatu); E) Discards of urban trash (Vazante); F) Discard of toxic waste (Paracatu); G) Silting of the cave by mining tailings; H) silting of the surrounding area by mining tailings (Vazante).

Delza cave, (both located in Vazante municipality) (Fig. 4, Tab. 3). Three regions were defined as priority for conservation: (1) the region of Arinos, (2) Cabeceira Grande and Unaí and (3) Paracatu (Fig. 4, Tab. 3). Table 3 summarizes the recommendations for the priority caves for conservation and the areas with need of conservation action, as well as the criteria used for indication.

Tab. 3: Caves and karstic areas in need of conservation action with the respective indication criteria, the main threats and the recommendations for conservation measures.

Site	***Indication criteria***	***Main threats***	***Recommendations***	***Endemic Species***
Lagoa Rica cave	High species richness and richness of troglomorphic species (seven species), six endemic to this cave.	Located in a mining area. Pollution of the groundwater lake.	Recovery of the cave surroundings. Constant supervision.	Tetrablemmidae sp.; Oonopidae sp.; Collembola sp.; Harpacticoida sp.; *Speleoleptes* sp. and Oniscodesmidae sp.
Lapa Nova cave	The biggest cave in this study and the higher observed richness (155 species); six troglomorphic species, two endemic to this cave.	Touristic cave, subject to impacts from such use.	Effective environmental protection of the reserve that exists around the cave and the execution of the management plan proposed by Pellegrini and Ferreira (2012).	Oonopidae sp. and Eukoenenia virgemdalapa Souza e Ferreira, 2012.
Delza cave	Five troglomorphic species, two endemic to this cave.	Inserted in the urban center of the municipality. Entrance used as a garbage dump by residents. Pollution of perennial water body.	Awareness of local residents not to throw garbage at the cave entrance.	*Lygromma* sp. and Oniscodesmidae sp.
Region of Arinos	Caves with great length, with rivers within, extreme biological relevance (25% of all species in the northwest of Minas Gerais studied), seven troglomorphic species recorded only in caves of this region.	Removal of native forest for pasture. Pollution of water bodies.	Recovery of the caves surroundings. Creation of a protected area in the region.	Hirudinea sp.; Collembola sp.; *Trichorhina* sp.; Styloniscidae sp.; Oniscodesmidae sp.; Polyxenida sp. and Turbellaria sp.
Region of Paracatu	Cave with the highest troglomorphic species richness registered in this study located in this region (Lagoa Rica cave) and other caves with high biological relevance and highly impacted.	Mining. Removal of native forest for pasture. Religious use.	Recovery of the caves surroundings. Biospelological inventories in other caves in the region.	Tetrablemmidae sp.; Oonopidae sp.; Collembola sp.; Harpacticoida sp; *Speleoleptes* sp. and Oniscodesmidae sp.
Region of Cabeceira Grande and Unaí	Caves with extreme biological relevance, seven troglomorphic species recorded only in caves of this region.	Removal of native forest for pasture. Construction of dams. Pollution of water bodies.	Recovery of the caves surroundings. Biospelological inventories in other caves in the region.	Trombidiformes sp.; Prodidomidae sp.; Ochiroceratidae sp. Pselaphidae sp.; Collembola sp.; *Trichorhina* sp.; and Oniscodesmidae sp.

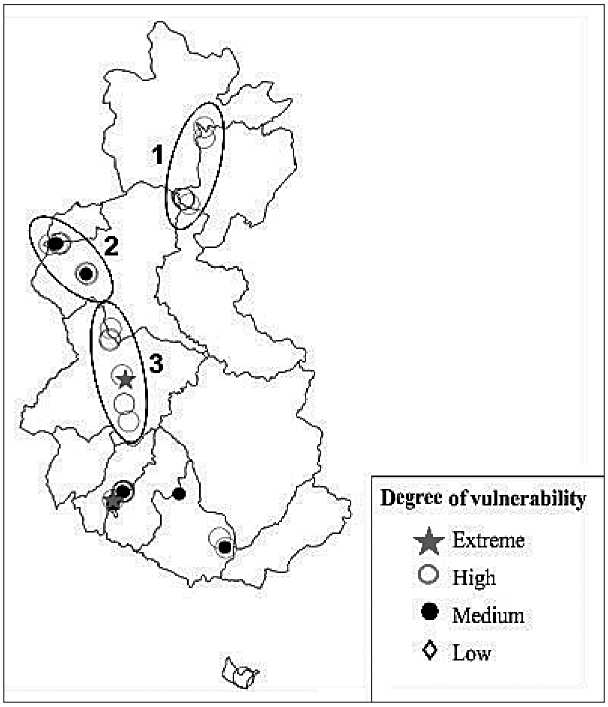

Fig. 4: Distribution map of the caves sampled in the Northwest area of the state of Minas Gerais, Brazil, between the years 2009 to 2011, and their respective classifications as to the vulnerability. The figure highlights the priority caves for conservation (red stars), as well as the regions in need of conservation actions (ellipses). 1: Region of Arinos, 2: Region of Cabeceira Grande and Unaí and 3: Region of Paracatu.

DISCUSSION

BIOLOGICAL RELEVANCE AND ENDEMISMS

Many studies regarding the subterranean fauna have been conducted in different regions of Brazil (Bento 2011; Bernardi *et al.* 2012; Cordeiro 2008; Ferreira 2004; Ferreira & Horta 2001; Ferreira *et al.* 2009; Ferreira *et al.* 2010; Santana *et al.* 2010; Souza 2012; Souza-Silva & Ferreira 2009; Souza-Silva *et al.* 2011a,b; Zampaulo 2010; Zeppelini Filho *et al.* 2003; Fundação Estadual do Estado de São Paulo 2010a,b,c,d). The average richness of those studies is 50 species (±20). In the present study the average found was higher than the general average for the Brazilian caves, but it is within the standard deviation. Therefore, the study area cannot be highlithed as one of the richer areas concerning cave fauna in Brazil. However, thirteen caves deserve prominence, because they present richness above average, plus the standard deviation, when compared to the other regions of Brazil (Tab. 2).

Regarding the troglobitic species, the distribution restricted to one or few caves, added to their potential low reproduction rate, make those organisms sensitive to alterations in the environment (Culver & Pipan 2009). Accordingly, they become an important tool for cave conservation (Elliott 2007; Borges *et al.* 2012). In the present study the troglobitis species presented a high degree of endemism and all of the caves that shelter troglobites possess at least one endemic species. Therefore, even if not being classified as the most vulnerable, these caves should be inserted in future conservation plans.

THREATS AND CONSERVATION STATUS OF THE AREA

The inadequate use of the land for agricultural activities, expansion of cities, surface and subterranean water use, mining activities, among others, have been the main threats imposed to the karstic areas (Watson 1997).

In the study region the main threat is the removal of forests for creation of pastures. Locally endemic cave species can become extinct if the surrounding area is deforested (Reboleira *et al*. 2011). Furthermore, the removal of the vegetation from the cave entrance surroundings can reduce the resource contribution and alter the environment in these areas, for instance, changing the local temperature and humidity/moisture. The entrances work as ecotones and they shelter a wide diversity of species that depend on the resource imported from the external environment (Prous *et al*. 2004).

The main potential threat for the caves of the studied region is the pollution of their water bodies, a fact that can result in severe alterations to the environment and cave fauna. As an example, the agricultural practices carried out in the surroundings of the Tumbling Creek cave, (Missouri, USA), are affecting the water quality and they may be decreasing the population of aquatic species sensitive to these changes (*Antrobia culveri*) (Neill *et al.* 2004).

Although the region, as are all the karstic areas of the world, is subject to impacts of anthropic origin, there are still places that are preserved, as is the case of the northern portion of the region, like the municipal district of Arinos. The caves of this municipal district are considerably preserved if compared to other caves of the study. A good example is the Lapa da Capa, where no visible impact was found, to the surroundings as well as to the interior the cavity. Nevertheless, the area is inserted in the Cerrado biome, known for high diversity and constant threats (Myers *et al.* 2000), always in need of conservation actions.

LEGAL PROTECTION AND PUBLIC EDUCATION

The lack of laws specifically dedicated to the karst is very common all over the world. Even when the legislation considers these environments, the potential benefits do not indeed exists, mainly due to the lack of enforcement on the part of the authorities (Parise & Gunn 2007).

Throughout the world, there are only few countries that possess some type of specific legislation for cave protection; some that do for instance, are the United States, France, Slovenia, Australia and Brazil (Tercafs 1992; Kepa 2001; Restificar *et al.* 2006; Ferreira *et al.* 2007). There are examples of legally protected caves and areas, as is the case of regions considered as World Heritage sites due to the characteristics of their karstic landscapes (Williams 2008). However, karstic areas and caves have been sometimes protected in an indirect way, mainly by the establishment of reserves for reasons that do not include the importance of their karstic characteristics, as in the case of Central American countries (Day 1996; Kueny & Day 2002) and some countries of Southeast Asian (Day & Urich 2000).

Brazil is the only country that has an agency devoted specifically to the study, protection and management of caves, which comprises the Centro Nacional de Pesquisa e Conservação de Cavernas (CECAV) *(National Cave Research and Conservation Center (CECAV).* Historically, the Brazilian caves could not be destroyed for being patrimonies of the Union (Federal Constitution 1998; Decree 99556/1990). However in 2008, the caves started to be susceptible to supression (Decree 6640/2008), as long as they were previously studied during the enterprise licensing process. During the study the caves should be classified, according to their relevance, as maximum, high, medium and low, according to criteria proposed in the Instruction Normative Number 2 of 2009. Caves with maximum relevance are not able, under any circumstances, to be suppressed, and caves included in the other categories are susceptible to irreversible alterations, including suppression.

Such a decree has been severely criticized and considered a setback for cave conservation in the country (Figueiredo *et al.* 2010). However, the rigidity of the previous law caused, in cases of strong social and economical demand, caves´ suppression (Auler 2006), many times without there being previous study.

It is important to point out that protection based only in laws is not enough. Real and efficient protection should count on the support of the population and a continuous program of public education regarding the protection of resources (Watson 1997). Furthermore, the appropriate use of the land can increase the sustainable development of the economy in these areas (Linhua 1999).

CAVES CONSERVATION IN THE WORLD

Different strategies for conservation of caves and karstic areas have been used all over the world. Indices have been used to evaluate the impact degree and threats, seeking to identify karstic areas most threatened and/or that deserve priority attention for conservation strategies (Elliott 2007; Van Beynen & Townsend 2005; 2012).

Van Beynen & Townsend (2005) created a karstic area disturbance index with different indicators, including the subterranean fauna, which has been used in works that seek to propose priority areas for conservation (Calò & Parise 2006; Van Beynen *et al.* 2007; Borges *et al.* 2012). Van Beynen & Townsend (2005), however, affirmed that the selection of individual species as indicators would be problematic because of disagreements about which species to use. Therefore, only in Borges et al. (2012) was the biological component used as indicator, based on the troglobite richness, endemism and rarity. Recently a karst sustainability index was created (KSI) (Van Beynen & Townsend 2012). This index is based on indicators that incorporate measurements of the three resources use domains: the social, the environmental and the economic.

The species distribution was used to identify places with threatened species and to propose conservation priorities by Culver *et al.* (2000) and Lewis *et al.* (2003), both in areas of the United States, and by Ferreira *et al.* (2007) in karstic areas of France.

Elliott (2007) used the species richness, troglobite richness and endemism as indicators for an index used to rank biodiversity relevance of caves in Missouri, United States, for conservation plans. Such index uses the expression B = SR×T×SE, where, B is: biodiversity, SR: species richness, T: troglobites richness, SE: local endemism.

In several regions of Brazil, studies are using methodologies similar to those used in this work to propose priority areas and caves for conservation (Souza-Silva 2008; Zampaulo 2010; Bento 2011; Souza 2012). Good results have been obtained, as is the case of the creation of the Parque Nacional da Furna Feia, in the state of Rio Grande do Norte, where 36% (205 caves) of all of the caves known to the state are inserted and legally protected. That area had been pointed out by Bento (2011) as priority for conservation in the State of Rio Grande do Norte in function of his work that used the same methodology as employed here.

CONSERVATION ACTIONS

Although protected areas, in themselves, do not guarantee the preservation of nature, they are fundamental tools, separating elements of the biodiversity from the processes that threaten Nature (Margules & Pressey 2000). In karstic landscapes the creation of buffer zones in between the preservation area and the neighboring lands is important, reducing the influences and consequences of environmental damage to the adjacent lands (Barany-Kevei 1999).

In Brazil, the creation of reserves faces serious problems. Caves inserted in preservation areas suffer visitation impacts, as for instance, trampling, garbage and speleothem depredation, among others (Lobo 2008; Souza-Silva & Ferreira 2009). Thus, the creation of nature reserves for the protection of caves or cave species should be very well appraised and elaborated, besides possessing an effective site management plan, integrating scientists, managers and tourism professionals, besides specific studies on each cave used for tourist visitation (Lobo *et al.* 2013).

Although direct impacts (e.g. mining) are the most worrisome, because they can cause immediate losses, other impacts can create countless problems for the fauna, although over the long term. The pollution of water bodies is an example. Karstic land possess discontinuities through which potential pollutants can be transported to remote locations, such as springs and caves with groundwater and rivers (Parise & Gunn 2007). Therefore, to reduce the exploration and water pollution on karstic land would be important for the maintenance of caves that possess groundwater and rivers (De Waele & Follesa 2003).

FINAL REMARKS

To study the subterranean biodiversity in the maximum number of caves in the Cerrado is of addition importance, because it is a highly diverse environment and under constant threat (Myers *et al.* 2000). As such, the present study presented results that can aid conservation actions in a little studied region in this biome. Furthermore, other karstic areas in the São Francisco river basin should be investigated regarding their conservation priority, providing subsidies for the National Action Plan for conservation of caves and cave fauna of that region.

Caves and karstic areas are being affected all over the world, mainly by anthropic action. Although probable, it is impossible to determine if such impacts have been causing the loss of species in these environments, mainly through lack of information of the primary characteristics of the communities prior to the impacts.

Even facing the difficulty of quantifying the cave biodiversity loss before alterations in the environment, it is certain that loss exists. Although the impacts that cause irreversible alterations in the caves, such as mining, are the main targets for environmentalists, others are also highly troubling.

In the study region, as well as throughout the world, the removal of forests appears as one of the most disturbing alterations, not only for the epigean biodiversity, but also for the subterranean. Cave species depend, largely, on the importation of resources from the external environment (Culver 1982) and the removal of forests can reduce that importation.

Another important fact is that tropical forests shelter a great diversity of species and they are subject to various impacts of anthropic origin, mainly linked to agricultural activities, that provoke, in almost all cases, high epigean biodiversity loss (Gibson *et al.* 2011). Once the epigean biodiversity is decreased, possibly fewer species will be using the cave environment.

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