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RESEARCH

Cave Conservation Priority Index to Adopt a Rapid Protection Strategy: A Case Study in Brazilian Atlantic Rain Forest

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Abstract Cave environments are characterized by possessing specialized fauna living in high environmental stability with limited food conditions. These fauna are highly vulnerable to impacts, because this condition can frequently be easily altered. Moreover, environmental determinants of the biodiversity patterns of caves remain poorly understood and protected. Therefore, the main goal of this work is to propose a cave conservation priority index (CCPi) for a rapid assessment for troglobiotic and troglophile protection. Furthermore, the troglobiotic diversity, distribution and threats have been mapped in the Brazilian Atlantic forest. To propose the CCPi, the human impacts and richness of troglobiotic and troglophile species of 100 caves were associated. Data related to troglomorphic/troglobiotic fauna from another 200 caves were used to map the troglobiotic diversity and distribution. The CCPi reveals extremely high conservation priority for 15 % of the caves, high for 36 % and average for 46 % of the caves. Fourteen caves with extremely high priorities should have urgent conservation and management actions. The geographical distribution of the 221 known troglobiotic/troglomorphic species allowed us to select 19 karst areas that need conservation actions. Seven areas were considered to have urgent priority for conservation actions. The two richest areas correspond to the "iron quadrangle" with iron ore caves (67 spp.) and the "Açungui limestone group" (56 spp.). Both areas have several caves and are important aquifers. The use of the CCPi can prevent future losses because it helps assessors to select caves with priorities for conservation which should receive emergency attention in relation to protection, management and conservation actions.

Keywords Biodiversity · Conservation priority · Cave fauna · Cave vulnerability · Cave conservation

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Introduction

Caves are subterranean spaces that can be penetrated by human beings, and present permanent darkness, constant temperature and high humidity values in their deepest zones. Temperature is the physical factor distinguishing abiotic environments in tropical versus non-tropical caves (Deharveng and Bedos 2012). Thus, subterranean habitats usually have strong environmental stability, without primary productivity from photosynthesis, and low organic debris availability (Culver and Pipan 2009). In general, the base of the the trophic chains are debris, moved by gravity, watercourses and animal feces produced by crickets, rodents, birds or bats (Culver and Pipan 2009). Specialized organisms can use subterranean environments as nighttime or daytime shelters (trogloxene) and/or also complete their whole life cycle inside or outside the caves (troglophile). However, some species are restricted to subterranean habitats, presenting behavioral, morphological and physiological specializations for exclusive survival within caves (troglobiotic) (Sket 2008).

Caves are important for the ecosystems in which they are located because they function as recharge sites for the subterranean drainage, and shelter species that carry out services in the external ecosystems (e.g., bats that pollinate, provide seed dispersion and predation of crop pests, etc.) (Elliott 2000). Caves are also important places for the study of ecological and evolutionary adaptation and speciation processes (Culver and Pipan 2009).

Karstic systems all over the world have experienced impacts from the increasing human population in their surroundings. These pressures have led to the need to evaluate and monitor the extent of these impacts (Parise and Gunn 2007; Fleury 2009; Van-Beynen 2011; BirdLife/FFI/IUCN/WWF 2014; Donato et al. 2014).

As such, some disturbance evaluation indexes in karstic and cave areas have already been produced and applied, revealing results that aid in the conservation and restoration of many threatened areas (Calo and Parise 2006; Van-Beynen and Townsend 2005; Gabriel et al. 2008; Biswas 2009; Borges et al. 2012; Van-Beynen et al. 2012; Donato et al. 2014). However, few of them have incorporated the caves' biological components into the analysis (Borges et al. 2012; Van-Beynen et al. 2012; Donato et al. 2014; Simões et al. 2014).

Appropriate criteria and techniques to be used to inventory cave fauna and monitor their alterations are largely unstudied. At least partly this is because the cave ecosystems are so little unknown, especially in the tropics (Souza-Silva et al. 2011; Deharveng and Bedos 2012; Culver and Pipan 2009). Another aspect that deserves mention is the existence of variations imposed by lithological differences among caves, which hinder the establishment of widely applicable criteria even more (Sharratt et al. 2000; Howarth 2004; Souza-Silva et al. 2011).

The Red List of threatened species from the International Union for the Conservation of Nature (IUCN) has been used to minimize biodiversity loss (Hoffmann et al. 2008; Pfab et al. 2011). However, current criteria may present serious deficiencies when applied to the majority of invertebrate groups (Sharratt et al. 2000; Cardoso et al. 2011a). Invertebrates are often neglected in biodiversity conservation programs, in part because their ecological services are mostly unknown to the general public, policymakers and stakeholders are mostly unaware of invertebrate conservation problems, and basic science on invertebrates is scarce and underfunded. Most species are undescribed and the distribution of the described species is mostly unknown, as are the abundance of species and their changes in space and time, as well as the species' ways of life and sensitivities to habitat change (Cardoso et al. 2011b).

Thus, the present work proposes a methodology for a rapid evaluation of the appropriate degree of cave community conservation using mainly cave invertebrate richness and the impacts/threats to determine the biological relevance and conservation priorities in the Brazilian Atlantic Rain Forest, a highly threatened biome.

Methods

Study Area

The Brazilian Atlantic Forest is a vast, heterogeneous area (1,481,946 km^2—about 17.4 % of the Brazilian territory) that includes a great variety of forest physiognomies distributed for more than 3,300 km along the Brazilian Atlantic coast, from sea level up to 2,700 m (Metzger 2009). The Atlantic Forest shelters human populations that live under different socioeconomic conditions, from large urban areas to rural regions (Valladares-Padua et al. 2002). Its diversity and endemism is remarkable, including more than 20,000 species of plants, 261 species of mammals, 688 species of birds, 200 species of reptiles, 280 species of amphibians, and many species that still require scientific description (Goerck 1997; Mittermeier et al. 1999). Despite the various studies conducted on this biome, very few works have been published referring to the biodiversity and conservation of caves (Trajano 2000; Trajano and Bichuette 2010b; Souza-Silva et al. 2011; Donato et al. 2014).

Caves and Invertebrate Species Surveyed

We assessed the invertebrate species richness (troglobiotic and trogophile) and impacts in 100 caves, formed in iron ore, limestone, quartzite and magmatic rock along the Atlantic Forest domain from Ceará to Rio Grande do Sul states. Information was obtained from the recent ecological literature (Souza-Silva et al. 2011), and from a database of the Center of the Subterranean Biology Studies (CEBS-UFLA 2014) (Table 1; Appendix Table 6). Data on richness of troglobiotic/troglomorphic species of another 200 caves were obtained from the literature (Appendix Table 6).

Cave Conservation Priority Index (CCPi)

The conservation priority of a cave was considered here as the association of its biological relevance (BR) and human impact (HI) (Tables 1, 2). The first variable represents the taxonomic singularity, biodiversity and potential for biological interactions and the second repesents threats from human changes (BirdLife/FFI/IUCN/WWF 2014). For each of these two variables (BR and HI), it is possible to suggest the following categories and weights: *extremely high* (Weight 4), *high* (Weight 3), *average* (Weight 2) and *low* (Weight 1) to facilitate valuations. Based on the highest sum value for these weights (8) (*extremely high*

Table 1 Evaluation according to cave conservation priority index (*CCPi*)

State	Cave name[impacts]	District	HI	$T_{g/b}R$	$T_{tf}R$	$R_{tf}R$	CCPi
AL	Toca da Raposa I[3, 16]	Murici	L		51	1.020	A
AL	Buraco do Cão[3]	Murici	L		31	0.310	A
AL	Toca da Raposa II[3]	Murici	L		30	0.250	A
BA	Gruta da Pedra Suspensa[9]	Pau Brasil	L	3	76	0.112	H
BA	Pedra do Sino[3, 11, 28]	Santa Luzia	L	2	74	0.247	H
BA	Lapão de Santa Luzia[25]	Santa Luzia	L	2	107	0.014	H
BA	California[3, 16, 28]	Pau Brasil	L	3	63	0.162	H
BA	Toca dos Morcegos[3, 28]	Pau Brasil	L	1	81	0.081	H
BA	Cova da Onca I[3, 16]	Ilha de Biopeba	L		38	1.086	A
BA	Corrego Verde[3, 9, 13, 16, 28]	Pau Brasil	H		50	0.050	H
BA	Milagrosa[1, 3, 7, 8, 9, 28]	Pau Brasil	H	1	65	0.018	E
BA	Cova da Onça II[1, 3]	Ilha de Biopeba	L		28	0.747	A
BA	Praia da Cueira I[3, 26]	Ilha de Biopeba	L		19	2.375	A
BA	Praia da Cueira II[3, 26]	Ilha de Biopeba	L		7	0.875	A
CE	Ubajara[2, 6, 7, 8, 12, 14, 16]	Ubajara	E	2	74	0.013	E
CE	Morcego Branco	Ubajara	L		54	0.099	A
CE	Farias[8, 10]	Arajara	H		35	0.250	H
CE	Mocós	Ubajara	L		24	0.103	A
ES	Huschi	Santa Tereza	L	2	79	0.878	H
ES	Fazenda Paraiso	Ecoporanga	L	1	40	1.026	A
ES	Mirante[14]	Vargem alta	L		45	0.188	A
ES	Didi Vieira	Afonso Cláudio	L		64	0.101	H
ES	Santa Bárbara[1, 2, 3, 8]	Venda N. dos Imigrantes	H		61	0.191	E
ES	Archimides Panssini[3, 6, 7, 28]	Vargem alta	H	1	66	0.073	E
ES	Evald[3, 28]	Domingos Martins	L		17	0.246	A
ES	Limoeiro[1, 2, 3, 5, 6, 7, 8, 9, 11, 12, 14, 21, 22, 28]	Conceição de castelo	E	1	78	0.013	E
ES	Michele[6, 28]	Pancas	L		73	0.122	H
ES	Casa Branca[1, 3, 7, 8, 9, 12, 17, 21]	Itaimbe- itaguaçu	E		41	0.182	E
ES	Henrique Altoé[3, 28]	Jaciguá	L		50	0.139	A
ES	Rio Itaúnas[3, 8, 10, 28]	Pedro Canário	H	1	49	0.120	H
ES	Represa[3, 8, 28]	Santa Teresa	L		43	0.096	A
ES	Fazenda do Dr Saulo[3, 10, 28]	Ecoporanga	A		46	0.077	H
ES	João Buteco[3, 28]	Ecoporanga	L		17	0.340	A
MG	Serra da Moeda Sul-31	Itabirito	L	5	40	1.333	H
MG	Serra da Moeda Sul-29	Itabirito	L	11	75	0.652	E
MG	Mina do pico 08[15, 17, 18, 19, 20]	Itabirito	A	14	78	0.030	E
MG	Serra da Moeda Sul-04	Itabirito	L	3	58	0.853	H
MG	Mina do pico 11[15, 19, 20]	Itabirito	A	8	46	0.613	E
MG	Mina do pico 09[15, 17, 18, 19, 20]	Itabirito	A	8	37	0.587	H
MG	Mina do pico[12]	Itabirito	L	4	37	0.500	H
MG	Serra da Moeda Sul-25[16]	Itabirito	L	10	57	0.246	E
MG	Mina do pico 04[16]	Itabirito	L	4	43	0.239	H
MG	Mina do pico 10[16]	Itabirito	L	9	39	0.152	H
MG	Mina do pico 01	Itabirito	L		11	0.917	A
MG	Mina do pico [17, 18, 19, 20, 21, 22]	Itabirito	L		12	0.800	A
MG	Mina do pico 13[15]	Itabirito	A	1	17	0.654	H
MG	Mina do pico 02[18, 19, 22]	Itabirito	L	3	20	0.500	A
MG	Mina do pico 16[21]	Itabirito	L		15	0.469	A

Table 1 continued

State	Cave name[impacts]	District	HI	$T_{g/b}R$	$T_{tf}R$	$R_{tf}R$	CCPi
MG	Mina do pico 03[17, 21]	Itabirito	L	3	18	0.257	A
MG	Mina do pico 07[15, 17, 18, 20]	Itabirito	A	1	26	0.133	A
MG	Pico do pião[2, 7]	Lima Duarte	H	1	34	0.067	H
MG	Sete Salões[6]	Santa Rita do Itueto	L	1	49	0.047	A
MG	Bromélias[18]	Lima Duarte	L	2	96	0.019	H
MG	Casas[18, 23]	Lima Duarte	L	3	47	0.010	H
MG	Moreiras[2, 7]	Lima Duarte	H	1	75	0.002	E
MG	Fonte Samuel[2, 7, 9]	São Sebastião do Paraíso	L		57	0.089	H
MG	Coelhos[9]	Lima Duarte	H		66	0.083	E
MG	Ribeirão do Anastácio[28]	Novo Oriente de Minas	L		22	0.440	A
MG	Monjolinho[2, 7]	Lima Duarte	H		22	0.210	H
MG	Martiniano I	Lima Duarte	L		22	0.138	A
MG	Martiniano II	Lima Duarte	L		18	0.090	A
MG	Córrego da americaninha[3, 28]	Novo Oriente de Minas	L		32	0.057	A
MG	Serra do Jardim[28]	Novo Oriente de Minas	L		23	0.051	A
MG	Zé Branco[3, 28]	Novo Oriente de Minas	L		30	0.020	A
MG	Fugitivos[2, 7]	Lima Duarte	H		34	0.003	H
MG	Gruta dos Viajantes[2, 7]	Lima Duarte	L		33	0.002	A
MG	Palhares[1, 2, 3, 6, 7, 8, 9, 10, 12]	Sacramento	E		21	0.021	H
MG	Baixada dos Crioulos II[3]	Itambé do Mato Dentro	L		79	0.013	H
MG	Vaca Parida[3, 7, 9, 28]	Teófilo Otoni	L		39	0.120	A
MG	Corrego dos Vieira[3, 9, 28]	Padre Paraiso	L	1	48	0.053	A
MG	Boa Vista[1, 3, 6, 8, 9, 10, 28]	Padre Paraiso	H		48	0.050	H
MG	Rio Suaçui[3, 28]	Santa Maria do Suaçiu	L		36	0.045	A
MG	Cachoeira do Reinaldo I[3, 28]	Felisburgo	L		23	0.307	A
MG	Lavra do Cristal[3, 28]	Teófilo Otoni	L		23	0.288	A
MG	Cachoeira do Reinaldo II[3, 28]	Felisburgo	L		5	0.208	A
MG	Tião Lima[3, 15, 17, 28]	Poté	H		22	0.147	H
MG	Manga da Pedra[3, 28]	Nacip Raydan	L		10	0.050	A
MG	Ponte de pedra[3, 4, 9, 19, 23]	Ouro Preto	E		29	0.025	E
MG	João Matias[3, 28]	Ataléia	L		19	0.018	A
MG	Baixada dos Crioulos I[3]	Itambé do Mato Dentro	L		26	0.017	A
RJ	Pedra Riscada[9]	Lumiar	L	1	35	0.109	A
RJ	Pedra Santa	Cantagalo	L		31	0.103	A
RJ	Furnas[3, 28]	Cambuci	L	1	71	0.118	H
RJ	Pirozzi[3, 28]	Varre e Sai	L		56	0.267	H
SE	Pedra Branca[9]	Laranjeiras	L		24	0.080	A
SE	Urubu[3, 28]	Divina Pastora	L		12	0.050	A
SP	Quarto Patamar disfótica	Santo André	L		81	0.540	H
SP	Quarto Patamar2	Santo André	L	4	56	0.124	H
SP	Paraná	Altinópolis	L	1	49	0.033	A
SP	Itambé[1, 2, 6, 7, 8, 9]	Altinópolis	E		59	0.008	E
SP	Olho de Cabra	Altinópolis	L	1	58	0.005	H
SP	Edgar[28]	Altinopolis	L		26	0.058	A
SP	Serraria[9, 27]	Ilha Bela	L		29	0.015	A
SP	Toca[3]	Itirapina	L	1	27	0.004	A
PR	Andorinhas[3, 28]	Ponta grossa	L	2	–	–	A
PR	Agua Boa[3, 5, 15, 17]	Almirante tamandare	H	3	47	0.313	H

Table 1 continued

State	Cave name[impacts]	District	HI	$T_{g/b}R$	$T_{tf}R$	$R_{tf}R$	CCPi
RS	Furna da Lagoa Itapeva I[3, 9, 22]	Torres	H		35	0.583	A
SC	Furna do Posto I[1, 2, 3, 6, 7, 8, 9, 20, 22]	Sombrio	E		39	0.39	A
SC	Gruta de Cinema[3, 17, 28]	Vidal Ramos	H		31	1.476	A

Key to impacts (numerical superscripts): [1]religious use, [2]touristic use, [3]deforested surroundings, [4]drainage pollution, [5]alterations by detonations, [6]graffiti or lithography, [7]trampling by humans in the caves, [8]construction sites, [9]trash, [10]drainage exploitation, [11]speleothem water used as holy water, [12]electric illumination in the caves, [13]killing of bats in the caves, [14]vandalism to speleothems, [15]mining activities near caves, [16]alien ants in the cave and guano, [17]chamber destruction, [18]collapse in the cave [19]silting in the caves, [20]road traffic vibrations or explosion vibrations, [21]excavation to increase cave entrances, [22]roads near caves, [23]domestic sewage, [25]sporadic tourism, [26]erosion, [27]marron community shelter, [28]agropastoral practices surroundings

HI human impact; $T_{g/b}R$ troglomorphc/troglobiotic richness; $T_{tf}R$, $R_{tf}R$ total and relative troglophile richness; *E* extremely high; *H* high; *A* average; *L* low

Table 2 Criteria used in defining cave priorities for conservation actions based on a cave conservation priority index (CCPi)

Priority	Degree	Criteria
1	Extremely high	Expected occurrence of more than 11 troglobite/troglomorphic species of wide or narrow distribution; total species richness more than 84 species; relative richness more than 2 (biological relevance greater than 10 points) and sum of impact weights more than 21 points.
2	High	Expected occurrence between 7 and 10 troglobite/troglomorphic species of wide or narrow distribution, total richness between 56 and 83 species; relative richness between 1.4 and 1.9 species (biological relevance between 7 and 9 points) and the sum of impact weights between 11 and 20 points.
3	Average	Expected occurrence between 4 and 6 troglobite/troglomorphic species of wide or narrow distribution; total richness between 28 and 55 species; relative richness between 0.7 and 1.3 species (biological relevance between 4 and 6 points) and the sum of impact weights between 6 and 10 points.
4	Low	Expected occurrence of less than 3 troglobite/troglomorphic species of wide or narrow distribution; total richness less than 27 species; relative richness less than 0.6 species (biological relevance less than 3 points) and the sum of impact weights less than 5 points.

BR $_{weight}$ + *extremely high* HI $_{weight}$), four cave conservation priority categories were created. Such categories include *extremely high* (≥6), *high* (4–5.99) *average* (2–4.99), and *low* (≤1.99).

Determination of the Biological Relevance (BR)

The biological relevance of the caves was determined through the superimposition of three variables: troglomorphic/troglobiotic species richness ($T_{g/b}R$) and total and relative species richness (T_{tRf} and $R_{tf}R$). The inherent morphological and evolutionary adaptations restrict distribution and special habitats requirement by troglobitcs species requires separate analysis to the rest of the community because they contribute strongly to cave protection. Accordingly, the highest troglomorphic/troglobiotic richness per cave found was divided by four (14 spp./4), creating the richness categories of: *extremely high* (≥11 spp.), *high* (7–10 spp.), *average* (4–6 spp.) and *low* (≤3 spp.). Each category received a weight as *extremely high* (4), *high* (3), *average* (2) and *low* (1).

The total species richness ($T_{tf}R$) were found by inserting the highest total species richness into four categories (107 spp/4): *extremely high* (≥84 spp.), *high* (56–83 spp), *average* (28–55 spp) and *low* (≤27 spp). Each category received a weight: *extremely high* (8), *high* (6), *average* (4) and *low* (2). The total species richness ($T_{tf}R$) is relevant because it enables ecological interactions (Ferreira 2004). Therefore, caves of highly conservation priority should include those with high species richness.

The relative species richness ($R_{tf}R$) classifies the number of species in relation to the cave area and the entrance area (Souza-Silva et al. 2011). As such, this variable seeks to reduce the excessive contribution of para-epigean communities when considering the entrance extension in this analysis (Prous et al. 2004). It is expected that there exists a large contribution of para-epigean communities in caves with large entrances, due to their higher contact with the external environment (Prous et al. 2004). The relative species richness ($R_{tf}R$) was calculated using the index: $R_{tf}R = [(T_{tf}R/\text{ca})/\Sigma\text{cea}]$, where ca = cave area and cea = cave entrance area (Ferreira 2004; Souza-Silva et al. 2011). The relative species richness ($R_{tf}R$) was found by inserting the highest relative species richness into four categories (2.37 spp/4): *extremely high* (≥2 spp.), *high* (1.4–1.9 spp.), *average* (1.3–0.7 spp) and *low* (≤0.6 spp.). Each category received a weight: *extremely high* (4), *high* (3), *average* (2) and *low* (1).

It was determined that total species richness ($T_{tf}R$) was allocated double the weight of the relative richness, because of the real and direct importance for the absolute number of species as a preservation parameter of a cave. If cases where only the relative richness was used, smaller caves, but with a relatively high number of species (in relation to their small extent), could be preserved to the detriment of extensive caves, with high absolute richness.

The *biological relevance* (BR) of caves was considered by summing the troglomorphic/troglobiotic richness ($T_{g/b}R$), the total species richness ($T_{tf}R$) and the relative species richness ($R_{tf}R$) weights (Table 1). BR was found by inserting the highest sum into four categories (12/4): *extremely high* (≥09.1), *high* (09–6.1), *average* (6–3.1) and *low* (≤3) biological relevance. Each category received a weight: *extremely high* (4), *high* (3), *average* (2) and *low* (1).

Determination of the Degree of Impacts

The changes surveyed in this study were classified in relation to *uses* and *impacts*. Tourist (except caving) and religious activities were considered uses while real impacts were trampling, illumination and construction resulting from these activities (Table 3). Impacts were determined for each cave as a function of the presence or absence of modifications inside the cave and in the surroundings (CONAMA law 347, from September 10th, 2004; Donato et al. 2014). This law prohibits any environmental impact activities in the surrounding area within a 250-m radius projected from the cave entrance.

The impacts were considered those modifications that could potentially lead to *depletion*, *enrichment* or *modifications* in the microhabitats, organic resources and/or cave fauna (Table 3). Depletion is understood as the reduction of organic debris or biological diversity in function of the human activities inside the cave. Trophic enrichment are human activities that promote the increase in the availability of organic resources (debris). Modifications are those human uses that spatially and temporally modify the physical structure of habitats or microhabitats in the caves without trophic enrichment or depletion. They were classified according their *potential to modify*, *spatial extension modified* and *time of permanence* within the cave, receving weights 1, 2 or 3.

Intense potential refers to modifications causing great disturbance to the fauna and physical structure of the cave (weight 2). *Tenuous potential* (weight 1) refers to modifications potentially causing small disturbance to the fauna and physical structure. *Short spatial extension* (Weight 1) refers to specific modifications of potentially low spatial amplitude and that should probably locally affect the physical structure and the fauna of the cave. These impacts can bring minor modifications to the fauna when compared to the *Ample spatial extension* modifications (Weight 2). *Permanence* refers to the time interval of the impact persistence on the cave environments. Impacts from *occasional permanence* received weight 1 and those impacts from *constant permanence* received weight 3. Tenuous potential human impacts, short spatial extension and occasional permanence can minimally affect the environment of the caves and allow a fast recovery of the fauna after the modifications have stopped.

Table 3 Results of assessment of human impact

Impacts	Alt	Pot	W	Per	W	Ext	W	Σ
Alien ants in the cave and guano	a+c	I	2+2	S	1	L	1	6
Alterations by detonations in caves	c	T	1	S	1	L	1	3
Chamber destruction	c	T	1	S	1	L	1	3
Collapse in the cave	c	T	1	S	1	L	1	3
Construction sites in caves	c	I	2	S	1	L	1	4
Deforested surroundings	c+a?	–	–	–	–	–	–	1
Agropastoral practice surroundings	c+b?	–	–	–	–	–	–	1
Domestic sewage in caves	b+c	I	2+2	C	3	G	2	9
Drainage exploitation in caves	a	I	2	C	3	L	1	6
Drainage pollution in caves	c	I	2	C	3	G	2	7
Electric illumination in caves	b	I	2	C	3	G	2	7
Erosion	a	T	1	C	3	G	1	5
Excavation to increase cave entrances	c	I	2	C	3	L	1	6
Garbage/trash in caves	c	I	2	C	3	G	2	7
Graffiti or lithography in caves	c	T	1	S	1	L	1	3
Killing of bats in caves	a+c	I	2+2	S	1	L	1	6
Marron community shelter	a+b	I	1+2	C	3	G	2	8
Mining activities near caves	a+c	I	2+2	C	3	G	2	9
Road near caves	c	T	1	C	3	L	1	5
Silting in caves	c	I	2	C	3	L	1	6
Speleothems water used as holy water	a	T	1	S	1	L	1	3
Trampling by humans in caves	c	I	2	C	3	G	2	7
Vandalism to speleothems	c	T	1	S	1	L	1	3
Vibrations from road traffic or from explosions near caves	c	I	2	C	3	G	2	7
Final impact weight								125

The impacts were considered those Alterations (*Alt*) that could lead to *depletion* (*a*), *enrichment* (*b*) or *modifications* (*c*) in the microhabitats, organic resources and/or cave fauna, and they were classified according to potencial (*pot*) weights (*W*) *1* or 2, permanence (*per*) *1* or *3*, and extension (*ext*) *1* or *3* within the cave. *Final impact weight* $= \Sigma wI_{potencial} + \Sigma wI_{permanence} + \Sigma wI_{extension}$

I intense, *T* tenuous, *C* continuous, *S* short, *G* general and *L* localized (L), *?* means doubts about the weigth of the impact

Table 4 Priority actions suggested for the conservation of 14 caves in the Brazilian Atlantic Forest, as results of the cave conservation priority index (CCPi)

State	Cave	Municipality	L	CCP	$T_{g/b}R$	Actions
BA	Milagrosa	Pau Brasil	li	E	1	MP, RS
CE	Gruta de Ubajara	Ubajara	li	E	2	MP
ES	Gruta do Limoeiro	Conceição de Castelo	li	E	1	MP, RS
ES	Archimides Panssini	Vargem Alta	li	E	1	MP, RS
ES	Gruta da Santa Bárbara	Venda N. dos Imigrantes	ma	E		MP, RS
ES	Casa Branca	Itaimbe-Itaguaçu	ma	E		RS, RS
MG	Mina do Pico 08	Itabirito	io	E	14	RCS
MG	Serra da Moeda Sul-29	Itabirito	io	E	11	RCS
MG	Serra da Moeda Sul-25	Itabirito	io	E	10	RCS
MG	Mina do Pico 11	Itabirito	io	E	8	RCS
MG	Gruta dos Moreiras	Lima Duarte	si	E	1	MP
MG	Gruta dos Coelhos	Lima Duarte	si	E		MP
MG	Gruta da Ponte de Pedra	Ouro Preto	si	E		IER, RS
SP	Gruta Itambé	Altinópolis	si	E		MP

L lithology: *li* limestone, *ma* magmatic, *si* siliciclastic, *io* iron ore, *CCP* cave conservation priority, *E* extremely high, ($T_{g/b}R$) troglomorphic species richness, *MP* management plan, *RS* recuperation of surroundings, *RCS* reserve creation in the surroundings, *IER* internal ecological restoration

The rank of the caves as to the impact weight was conducted based on the sum of the points obtained by each cave through the amount of observed modifications (Table 3). The highest value found for the sum of impacts (40 points) served as the basis for the categorization of the caves into impact degrees: *extremely high* (≥21), *high* (11–20), *average* (6–10) and *low* (≤5). In this case, "irregular" categories were created with the intention of not reducing the contextual importance of caves that received impact weights above 20, although this cut-off value was arbitrary. Each category received weight as *extremely high* (4), *high* (3), *average* (2) and *low* (1).

The deforestation and agropastoral practices on cave surroundings were considered as weight 1. Such a consideration was made because these activities represent external impacts (Gillieson 1996). Actually, it is impossible to evaluate the real effects of deforestation on the cave communities, because detailed studies do not exist on this theme in tropical caves. Ants exploiting guano were considered as an impactful agent.

Caves for Conservation Priorities

It is understood that caves are environments that naturally require preservation or conservation action because of their inherent fragility. However, those with troglobiotic species and more threatened by human alterations would be a priority for the implementation of conservation measures (Tables 1, 2).

Accordingly, all the caves or karstic areas in the study need conservation actions. However, only caves with an *extremely high* impact, the highest priority obtained in the CCPi, were considered emergency areas to receive conservations actions. For these places, emergency conservation actions were suggested (Table 4).

Karstic Areas for Conservation Priorities

The results of the CCPi and troglomorphic/troglobiotic species richness data from the literature have indicated karstic areas that deserve attention with respect to conservation needs, but that are not necessarily the most urgent (Fig. 1; Appendix Table 6).

Results

The human impacts in caves and surroundings (HI) are shown in Tables 1 and 3. Caves have mainly secondary forest (38 %) and pastures (34 %) as surrounding vegetation. The main human modifications were deforestation (40 %), mining (15 %), trash (13 %), trampling (12 %), tourist use (10 %), specific construction (10 %), graffiti (8.5 %), exotic species (8.5 %) and religious use (7.5 %).

A total of 216 troglomorphic/troglobiotic invertebrate species plus 5 cave fish species have been documented in the literature. Until now, 221 troglomorphic species have been registered in 300 caves in the Brazilian Atlantic Forest (Appendix Table 6). Most of the troglomorphic/troglobiotic species present in the Atlantic Forest caves are outside conservation units (63 % of the species).

Caves with *extremely high* troglomorphic/troglobiotic species richness ($T_{g/b}R$) represented only 2.02 %, high 4.04 %, average 4.04 % and low 89.9 %. Caves with *extremely high* total species richness ($T_{tf}R$) represented 2.13 %, high 27.66 %, average 39.36 % and low 30.85 %. Caves with *extremely high* relative species richness (R_{tf}-R) represented 1.06 % of the sample, high 0 %, average 12.77 % and low 86.17 %. The biological relevance was *extremely high* for 5.32 % of the caves, high for 37.23 % and average for 57.45 % of the caves. The impact was *extremely high* for six caves (6 %), high for 13 (14 %), average for 6 (6 %) and low for 69 caves (73 %).

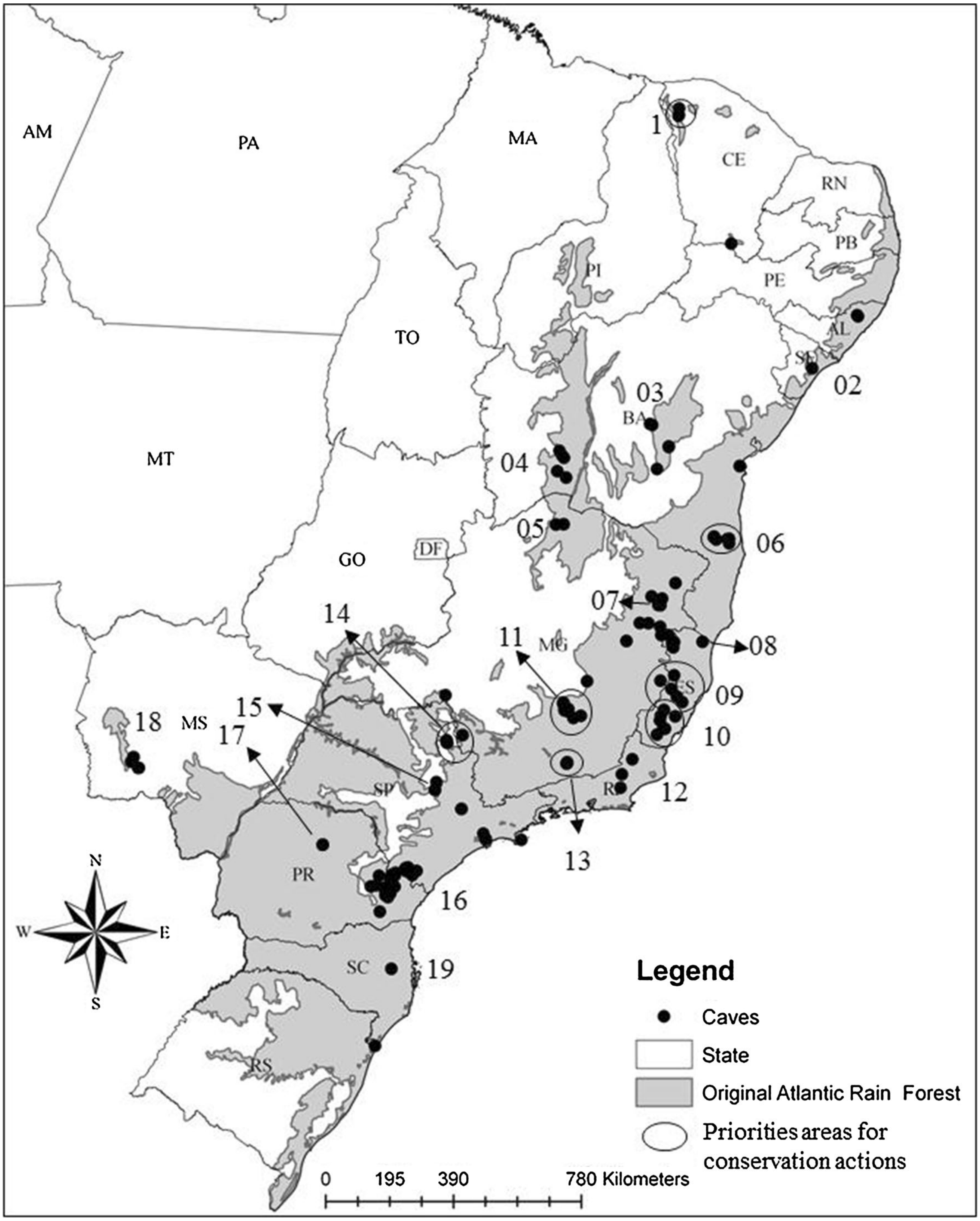

Fig. 1 Areas of Brazilian Atlantic Forest (www.conservation.org.br), distribution of 300 caves, with records of troglophile and troglomorphic/troglobiotic invertebrates and/or vertebrates. There are 19 areas in need of conservation actions and 7 priority areas for cave invertebrate conservation actions (numbers *1*, *6*, *9*, *10*, *11*, *13*, *14*) (For details, see Appendix Table 6)

Table 2 shows results of the cave conservation priority index (CCPi). Fifteen percent of the caves (14 caves) had a score framing them in the highest conservation priority, or *extremely high*, because they presented more than 11 troglobiotic/troglomorphic species, more than 84 invertebrate species, relative richness more than 2 species, biological relevance greater than 10 points and sum of impact weights more than 21 points. Thirty-six percent of the caves (34 caves) had a score placing them in high priority, because they presented between 7 and 10 troglobiotic/troglomorphic species, total richness between 56 and 83 species, relative richness between 1.4 and 1.9 species, biological relevance between 7 and 9 points and the sum of impact weights between 11 and 20 points. Forty-nine percent of the caves (46 caves) had a score placing them in conservation average priority, because they presented between 4 and 6 troglobiotic/troglomorphic species, total richness between 28 and 55 species, relative richness between 0.7 and 1.3 species, biological relevance between 4 and 6 points and the sum of impact weights between 6 and 10 points There are no caves with low conservation priority (Tables 1, 2).

Those 14 caves in the *extremely high* vulnerability were considered of extreme priority for conservation purposes and need emergency conservation management plans (Table 4). The creation of reserves in the surroundings is a priority for 4 of these caves. The formulation and execution of a tourist use management plan are priority actions for 8 caves. The recovery of the surrounding vegetation was considered a priority for 6 caves. One cave needs an ecological restoration plan (Table 4). It is important to emphasize that these priority actions do not exclude each other and nor exclude other actions of secondary importance (e.g., biological inventories and monitoring, among others). Furthermore, those caves that are not included in Table 4 also need action; however, none is priority one.

Considering the data obtained in this study and using literature data, 19 karstic areas were considered for conservation need (Appendix Table 6; Fig. 1). Many locations are noteworthy due to the occurrence of still unprospected areas (potential water resources and new caves with specialized fauna), groundwater resources presence and undescribed troglomorphic species. However, insufficient knowledge and the lack of conservation actions for most of the areas are also of note.

Seven karstic areas were picking out to be of major priority for conservation action due to the presence of caves with *extremely high* vulnerability. Such areas correspond to the Ubajara limestone outcrop, Rio Pardo limestone area, the granitic outcrop in the central part of Espírito Santo state, Limestone caves in southern Espírito Santo state, the iron ore outcrop in the "iron quadrangle" in central Minas Gerais state, quartzitic caves in southern Minas Gerais state, and sandstone caves in northern São Paulo and western Minas Gerais state. From 19 highlighted areas, only 7 are within conservation units (Appendix Table 6; Fig. 1).

Discussion

Protecting Cave Fauna in Brazilian Atlantic Forest

The Brazilian Atlantic Forest is one of the most threatened ecosystems on the planet, and more than 85 % of its original area has been deforested. In consequence of the historical changes in the biome, many populations have been eliminated, and genetic diversity of several species has been potentially eroded (Terborgh 1992; Morrelato and Haddad 2000).

Only Donato et al. (2014) report methods dedicated directly to the conservation of the subterranean invertebrate fauna in Brazil. Some other studies present lists of troglophile, troglobiotic and/or threatened species in caves of the Atlantic Forest (Trajano 2000; Sessegolo et al. 2001; Machado et al. 2008; Trajano and Bichuette 2010a).

Machado et al. (2008) used the IUCN criteria for evaluation of the species conservation status and they listed 26 troglobiotic species threatened by extinction in the Brazilian Atlantic Forest (24 species of invertebrates and 2 fish species) (Table 5). However, only the formally described species were considered, which represent about 12 % of the total troglomorphic species known for the Atlantic Forest. Furthermore, even the troglobiotic species included in integral protection units and on "Red Lists" in Brazil still continue to be threatened by the contamination of water bodies and habitat modifications (Machado et al. 2008).

General View of Cave Protection Around the World

Another aggravating factor is linked to the fact that the subterranean biodiversity is usually little considered in the current national and international legislation. Few conventions can be applied to the theme of cave biodiversity and habitat preservation, because they deal with protection of threatened species and terrestrial and aquatic ecosystems (Tercafs 1992a, b; Baillie and Groombridge 1996; Culver and Pipan 2009; Fleury 2009; Pipan and Culver 2012).

Some countries throughout the world have specific cave protection laws (Tercafs 1992a, b; Juberthie 1995; Day 1996; Van-Beynen and Townsend 2005; Fleury 2009).

In North America, the Cave Protection Resource Act in the USA guarantees protection of caves (Tercafs 1992a; Huppert 1995) and the Endangered Species Act protects threatened or endangered species (McFarlane 1988; Orndorff 2005). Land use policies on karstic terrains occur throughout the United States, although the specific forms these ordinances take can vary widely from place to place, and in some municipalities there are no codes or ordinances that manage the interactions between humans and karst systems (Fleury 2009). Van-Beynen and Townsend (2005) made references to cave protection in Central America, showing that there protection for caves in some countries, but not in others.

In South America, the problem is even more serious, because only Brazil possesses advanced cave protection legislation. Currently, the National Conservation Unit

System (Law 9.985 of 2000—SNUC) supports the creation of protected areas of variable size and use, which may or not contain caves. However, for all the Brazilian conservation units with caves (more than 10 conservation units), geology, not the subterranean fauna, was considered as a main objective of their creation.

Federal agencies (CECAV and ICMBio) and specific legislation are dedicated to protect subterranean habitats and their fauna. The possible suppression of caves is allowed according to Environmental Impact Assessment (EIA) decisions, based on Decree 6640, of 2008, and Normative Instruction 02, of 2009 (Brazilian resolution 001 of 1986; Ferraz 2012). The evaluation prevents the suppression of caves that are essential shelters for threatened species populations, are endemic, contain relicts or rare species, as well as those caves where unique ecological interactions are observed.

In Europe, Asia and Oceania, a few countries such as France, Slovenia and Australia possess specific legislation for the protection of natural monuments that include karstic areas and caves (Juberthie 1995; Tercafs 1992a; Kepa 2001; Van-Beynen and Townsend 2005; Restificar et al. 2006; Ferreira et al. 2007). In 2010, during the 20th International Symposium on Subterranean Biology, an official letter supporting the petition to stop the trade, import and export of objects removed from caves was signed by 54 representatives from 18 countries (Valsegno 2010). To date, the represenative national caving associations of many European countries have officially signed this petition (Austria, Belgium, Bulgaria, Croatia, Czech Republic, France, Germany, Greece, Hungary, Netherlands, Ireland, Italy, Luxembourg, Monaco, Portugal, Romania, Slovakia, Slovenia, Spain, Switzerland, UK, and Ukraine). However, what the actual conservation perspectives are is effectively unknown.

Cave Conservation Priority Adopted in a Rapid Assessment Cave Index

According to Deharveng and Bedos (2012) and Donato et al. (2014), cave fauna in the tropics are threatened by human activities, such as pollution, tourism and mining, and these threats are aggravated when they affect bats, an important agent in food supplies and endemic species.

Many of the obligate cave species have a restricted distribution and limited dispersion. Consequently, they can even be affected by moderate human alterations in their environments, thus being considered vulnerable to extinction events (Culver and Pipan 2009).

The main threats arise from the destruction of their habitats by deforestation, agriculture, forestry (Van-Beynen Van-Beynen 2011; Van-Beynen and Townsend 2005), engineering activities, quarrying and mineral exploitation (Van-Beynen 2011; Biswas 2009), tourism, (Gillieson 1996; Cigna and Forti 2013; Gillieson 2011), vandalism, and pollution by heavy metals, herbicides or pesticides, eutrophication and biological invasions (Reboleira 2007; Tercafs 1992a; Simon and Buikema 1997).

The main impact observed for the Atlantic Forest caves consists of the deforestation of the surrounding areas, which certainly reflects the high historical fragmentation undergone by this biome. According to Reboleira et al. (2011), the change of native forest to pasture can easily lead to the extinction of locally endemic populations often limited to a single cave, with the corresponding loss of this biological endemic heritage. Troglobiotic planthopper populations, which depend on the presence of tree roots for survival inside the caves, can be especially affected (Hoch and Ferreira 2012, 2013).

Furthermore, the risks of deforestation have to be highlighted because of the dependence of a contribution of allochthonous organic resources (Souza-Silva et al. 2011, 2012). Deforestation can intensify the oligotrophic state of the caves, which can significantly alter the structure and composition of the communities. Deforestation of areas surrounding caves may have a detrimental effect on the trogloxene invertebrate cave fauna, because they have to go out to get food (Machado et al. 2003; Taylor et al. 2005). In addition, the modification of the vegetation surrounding the cave entrances can degrade the habitat of para-epigean communities (Prous et al. 2004) and can increase sedimentation (Gillieson 1986). Since many obligate cave fauna are considered endangered, that means that the protection of the cave itself is not enough to ensure their survival; there is also a need to protect the surrounding areas (Culver et al. 2000).

For most of the other uses and impacts in the caves of the Atlantic Forest, their occurrence can be considered a direct or indirect influence of the population growth, rural exodus and urban expansion in the biome (livestock, agriculture, mining, inorganic trash, tourist use, construction, graffiti, exotic species, religious use, water exploitation, etc.).

More than 100 million people live in more than 300 cities that depend and exploit the components and environmental services of this biome (Morrelato and Haddad 2000), and they can directly or indirectly affect the karst, caves and aquifers.

The protection of the karst caves and their aquifers should be based on a land use policy design such as geographical units of regional planning, which comprise a mosaic of land uses and key conservation areas established by a central protection area near springs or pristine recharge areas and surrounding core areas of the immediate protection area that require severe protection and restriction (Ford 2005). The groundwater protection in karstic areas depends on knowledge of important factors such as aquifer recharge, hydrogeological anisotropy and

Table 5 Troglobite fauna of the Atlantic Forest constantly on the Brazilian Red List of species threatened with extinction according to the IUCN

Giupponia chagasi Pérez and Kury 2002	*Yporangiella stygius* Schubart 1946
Pachylospeleus strinatii Silhavy 1974	*Coarazuphium cessaima* Gnaspini, Vanin and Godoy 1999
Spaeleoleptes spaelus H. Soares 1966	*Coarazuphium tessai* Godoy and Vanin 1990
Aegla microphthalma Bond-Buckup and Buckup 1994	*Schizogenius ocelatus* Whitehead 1972
Aegla leptochela Bond-Buckup and Buckup 1995	*Arrhopalites amorimi* Palacios Vargas and Zeppelini 1995
Aegla cavernícola Turkay 1972	*Arrhopalites gnaspinius* Palacios Vargas and Zeppelini 1995
Hyalela caeca Pereira 1989	*Arrhopalites lawrenci* Palacios Vargas and Zeppelini 1995
Potamolithus troglobius Simone and Moracchioli 1994,	*Arrhopalites papaveroi* Zeppelini and Palacios Vargas 1999
Charinus troglobius Baptista and Giupponi 2003	*Arrhopalites wallacei* Palacios Vargas and Zeppelini 1995
Iandumoema uai Pinto da Rocha 1996	*Trogolaphysa aelleni* Yosii 1988
Maxchernes iporangae Manhert and Andrade 1998	*Trogolaphysa hauseri* Yosii 1988
Leodesmus yporangae Schubart 1946	*Pimelodella kronei* Ribeiro 1907
Peridontodesmella alba Schubart 1957	*Trichomycterus itacarambiensis*

Reference: Machado et al. 2008 and http://www.icmbio.gov.br/portal/biodiversidade/fauna-brasileira/lista-de-especies.html. (Accessed in March 2013)

depurative capacity, among others. Hydrogeological maps and tracer tests in different hydrogeological conditions and during the different positions of the water table in the aquifer are an unavoidable basis for defining the protection zones (Ford 2005).

Caves are important as tourist and/or religious attractions in many places around the world (Hamilton-Smith 2004; Cigna 2005; Pellegrini and Ferreira 2012; Cigna and Forti 2013). Among these caves in the Atlantic Rain Forest, Ubajara cave in Ceará state, Limoeiro cave in Espirito Santo State, and some caves located in a mosaic of natural protected areas covering the Upper Ribeira river Valley, in the southeastern of São Paulo state, have received many vistors throughout the year (Souza-Silva 2008; Lobo et al. 2013). The traffic of people inside caves can generate negative impacts because of the possibility of soil compaction, changes in the concentration of atmospheric gases, and the introduction of microorganisms and food resources (Pulido-Bosch et al. 1997; Hamilton-Smith; 2004; Barton 2006; Pellegrini and Ferreira 2012; Taylor et al. 2013). However, the use of a cave for tourism or religious activities is not incompatible with preserving its biodiversity if there is a previous definition of the criteria to be used, and the environmental change monitoring is continuous (Gunn et al. 2000; Pellegrini and Ferreira 2012; Cigna and Forti. 2013).

In Brazil, as well as around the world, the conservation measures frequently suggested are the interdiction of visits to caves with threatened species, creation of conservation units based on the occurrence of endemic species, and improvement of the legislation and environmental education actions (Lino and Allievi 1980; Tercafs 1992a; Trajano 2000; Sessegolo et al. 2001; Hamilton-Smith 2006; Trajano and Bichuette 2006; Donato et al. 2014). However, all these authors only evaluated limestone caves, and other lithologies such as granite, quartzite and iron ore were not considered. Furthermore, none of these authors consider the broader context of ignorance of the effective biodiversity, the stress of impacts, and the conservation status of the caves. Another factor that has not been suggested is the need for management plans, and the restoration of caves already impacted.

General Conclusions

The lack of information about where to focus efforts for subterranean biodiversity conservation is a major obstacle to be overcome by conservation agencies facing the rapid industrial, economic and populational growth in Brazil (Loyola et al. 2007). The use of the CCPi can prevent future losses because it helps to select extremely high and high priority caves, which should receive emergency attention in relation to protection, management and conservation actions. Such a fact does not exclude the need for the conservation of the other caves that should also have recovery, management and/or conservation plans coordinated by the environmental supervisory agencies.

However, this study does not provide information to assist with strategies for biodiversity conservation on a large scale such as selecting areas for the creation of large biological reserves, but to identify areas with caves of high biodiversity conservation value and that are significant in a global, continental or regional context. Once identified, more detailed conservation assessments should then be directed to these areas.

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Appendix

See Table 6.

Table 6 Nineteen karstic areas in Atlantic Rain Forest, Brazil that need major conservation actions, with indication criteria, and recommendations for protection

Local	Indication criteria	Main threats	Recomendations	Source
Carbonate caves in Northwest Cearense meso-region and Ibiapaba micro-region. State of Ceará (Fig. 1 N. 1). UTM—24 M-286854/9578741. 893 to 230 m asl	Ubajara National Park on the Ibiapaba plateau. It presents 11 limestone caves, only 3 sampled. It has 2 troglomorphic species, a new species of Schizomida (Santos et al. 2013) and insufficient knowledge	Intense tourism in the Ubajara show cave. No specific biological management plan	Biological inventories, proposing and implementing a management plan in the Ubajara cave and environmental education	This study, Souza-Silva et al. (2011), Santos et al. (2013), CEBS/UFLA
Carbonate caves in the eastern Sergipe state. Municipalities of Laranjeiras and Divina Pastora (Fig. 1 N. 2). UTM—24L-705979/8815882. 30 m asl	Region with limestone caves that have populations of bats and invertebrates composed of thousands of individuals (bat caves) and insufficient knowledge	Deforestation, garbage and proximity to urban centers (800,000 inhabitants in greater Aracaju)	Biological inventories, recovery of the surroundings and creation of conservation units in the vicinity of the caves	This study, Souza-Silva et al. (2011), CEBS/UFLA
Carbonate caves in the center of the state of Bahia, Chapada Diamantina Region (Fig. 1 N. 3). UTM—24L-240080/8610663. 483 m asl	Quartzite and limestone caves with insufficient knowledge. It has 18 troglobite/troglomorphic species. Karstic areas with water resource and high speleological potential	Moderate to intense tourism, mining, deforestation	Biological inventories, environmental education. Management plans	Auler et al. (2001), Trajano and Bichuette (2010b), Machado et al. (2011), CEBS/UFLA
Carbonatic caves in the South Center of the state of Bahia. Karstic area of the Serra do Ramalho. (Fig. 1 N. 4). UTM—23L-633258/8418161. 451 m asl	Presents limestone caves with inadequate knowledge. It possesses 12 troglobite/troglomorphic species. Karstic area with water resource and high speleological and biological potential (Auler et al. 2001, Trajano and Bichuette 2010a, b). It occupies an area of more than 2,000 km^2	Deforestation Agriculture Potential mining	Biological inventories, creation of conservation area	Auler et al. (2001), Trajano and Bichuette (2010b), CEBS/UFLA
Carbonatic caves in the North of the state of Minas Gerais (Rio Peruaçu basin and surroundings). Municipal districts of Itacarambi/Manga/Januària (Fig. 1 N. 5). UTM—23L-614944/8368379. 449 m asl	Presents limestone caves with inadequate knowledge. Possesses 11 troglobite/troglomorphic species. Karstic area with high speleological potential (Auler et al. 2001, Ferreira 2004, Trajano and Bichuette 2010a, b)	Moderate tourism Deforestation Agriculture and livestock	Biological inventories	Ferreira (2004), Trajano and Bichuette (2010b), Auler et al. (2001)

Table 6 continued

Local	Indication criteria	Main threats	Recomendations	Source
Carbonatic caves in the extreme south of the state of Bahia. Municipal districts of Pau Brasil/Santa Luzia/Mascote (Fig. 1 N. 6). UTM—24L-420374/8296354. 242 m asl	Presents limestone caves with inadequate knowledge. Possesses 11 troglomorphic species	Deforestation Agriculture and livestock Potential tourism	Biological inventories, recovery of surroundings and creation of conservation units	This study, Trajano (2000), Auler et al. (2001), Pinto-da-Rocha et al. (2002), Trajano and Bichuette (2010b), Souza-Silva et al. (2011)
Granitic caves in the Northeast of Minas Gerais. Municipal districts of Novo Oriente de Minas, Teófilo Otoni, Padre Paraiso and Ataléia. (Fig. 1 N. 7) UTM—24 K-228366/8028692. 334 m asl	Region with granitic caves that have insufficient knowledge A new species of Opiliones (*Mitogoniella mucuri*) and 2 of Palpigradi, one of them troglomorphic, besides the rare occurrence of Uropygi in a granite cave. Granitic areas with speleological potential	Deforestation Materials deposit Corral Livestock	Biological inventories, recovery of surroundings	This study, Souza-Silva et al. (2011), Ázara et al. (2013)
Granitic caves in the extreme north of Espírito Santo state. Municipalities of Pedro Canário, and Ecoporanga (Fig. 1 N.8). UTM—24 K-395452/7977430. 300 m asl	Area with granitic caves that present 3 troglomorphic species	Deforestation Agriculture Livestock Exploitation of subterranean water	Biological inventories, recovery of surroundings	This study, Souza-Silva et al. (2011)
Granitic caves in the Central Serrana region of Espírito Santo state. Municipality of Santa Teresa (Fig. 1 N. 9). UTM—24 K-339370/7791692. 671 m aslasl	Region with granitic caves which have 2 troglomorphic species	Deforestation Agriculture Livestock Subterranean drainage alteration	Biological inventories, recovery of surroundings and creation of conservation units	This study, Souza-Silva et al. (2011)
Carbonatic cave in southern Espirito Santo state. Municipalities of Castelo, Vargem Alta and Cachoeiro do Itapemirim (Fig. 1 N. 10). UTM—24 K-285168/7711062. 650 to 170 m asl	Region with limestone caves and marble and that have 2 species of troglobite/troglomorphic Opiliones and 1 of Palpigradi	Religious tourism Deforestation Marble extraction Materials deposit	Biological inventories, recovery of surroundings, management and creation of conservation units	This study, Souza-Silva et al. (2011), Souza and Ferreira (2011)
Fourteen municipalities in the meso-region of Minas Gerais state (http://www.codemig.com.br), (Fig. 1 N. 11). UTM—23 K-607918/7765858. 1300 m asl	Region with iron ore caves that have at least 67 species troglobite/troglomorphic species and insufficient knowledge. Iron ore areas with high speleological and biological potential and water resource (Iron quadrangle area)	Mining, real estate development, proximity to urban centers (800,000 inhabitants in Belo Horizonte and 4 million in other municipalities) .	Biological inventories and creation of conservation units	This study, Ferreira (2004, 2005), Trajano and Bichuette (2010b), Souza-Silva et al. (2011), Brescovit et al. (2012), Hoch and Ferreira (2012), Zeppelini et al. (2014), CEBS/UFLA

Table 6 continued

Local	Indication criteria	Main threats	Recomendations	Source
Carbonatic caves in the Northwest Fluminense in the municipalities of Cambuci, Itaocara and Cantagalo. Granitic cave in the mountainous Fluminenese region in the municipality of Lumiar (Fig. 1 N. 12). UTM—23 K-779553/7524950. 900 to 130 m asl	Region with granitic and limestone caves and two troglomorphic species. Insufficient knowledge	Sporadic visitation Deforestation	Biological inventories, recovery of surroundings and creation of conservation units	This study, Souza-Silva et al. (2011)
Quartzite caves in the Campos das Vertentes and Zona da Mata, Minas Gerais. Ibitipoca State Park municipality of Lima Duarte (Fig. 1 N. 13). UTM—23 K-614323/7598762. 1300 m asl	Region with quartzite caves that present 7 troglobite/troglomorphic species and insufficient knowledge. Quartzite areas with water resource and speleological potential	Intense tourism in some caves Trampling Erosion Trash	Biological inventories and management plans	This study, Auler et al. (2001), Souza-Silva et al. (2011), Brescovit et al. (2012)
Sandstone caves in the north of São Paulo (municipality of Altinópolis) and West of Minas Gerais State (municipality of Sacramento) (Fig. 1 N. 14) UTM—23 K-248688/7670137. 630 m asl	Show sandstone caves with mass tourism and two troglomorphic species. Water resource	Religious tourism Construction Ground water exploitation	Biospeleological inventories, management plans and creation of conservation units	This study, Souza-Silva et al. (2011)
Sandstone caves in the north of São Paulo state (municipality of Itirapina) (Fig. 1 N. 15). UTM - 23 K-216647/75442614. 750 m asl	Sandstone caves with a troglomorphic species. Insufficient knowledge. Water resource	Deforestation	Biological inventories	This study, Cardoso et al. (2011), Souza-Silva et al. (2011)
Carbonatic caves in the south of Sao Paulo state and north of Paraná and also a few granitic caves in Serra do Mar. (Figure 1 N. 16). UTM—22 J-648265/7299288. 100 to 1000 m asl	Region with limestone caves that have at least 56 troglobite/troglomorphic species and insufficient knowledge. Water resource	Intense tourism Mining	Biological inventories and management plans	This study, Sessegolo et al. (2001), Abrantes et al. (2010), Trajano and Bichuette (2010b), Ázara Ferreira (2013), Rodrigues et al. (2014), CEBS/UFLA
Caves in the center of Parana state. municipality of Tibagi, Castro, Ponta Grossa (Fig. 1 N. 17). UTM—22 J-584647/7224181. 1000 m asl	Region with sandstone and limestone caves that have 2 troglomorphic species, but insufficient knowledge. Water resource	Deforestation Agriculture and livestock Visitation	Biological inventories and management plans	This study, GUPE (2013), Cardoso et al. (2014)

Table 6 continued

Local	Indication criteria	Main threats	Recomendations	Source
Karstic region of Corumbá in Bodoquena Range, Mato Grosso do Sul state. (Fig. 1 N. 18). UTM—21 K-429364/7899377. 300 m asl	A region with large limestone caves accessing lakes and subterranean rivers that extend under the water table (Auler et al. 2001). The very few caves known and studied there present at least 16 troglobite/troglomorphic species and insufficient knowledge	Tourism Deforestation Pasture Mining	Biological inventories and management plans	Trajano and Bichuette (2010b)
Carbonatic caves of Brusque formation. Municipality of Botuverá, Brusque and Vidal Ramos, state of Santa Catarina (Fig. 1 N. 19). UTM—22 J-706293/7001104. 20 m asl	Region with limestone caves that have at least 4 troglomorphic species and Insufficient knowledge	Intense tourism Deforestation Mining	Biological inventories and management plans	Trajano and Bichuette (2010b), Sessegolo et al. (2001)

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