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A conservation status index, as an auxiliary tool for the management of cave environments

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Abstract: The conservation of the Speleological Heritage involves bioecological, geomorphological and anthropogenic studies, both from inside the caves and from the external environments that surround them. This study presents a method to rank caves according to their priority for conservation and restoration. Nine caves were evaluated: indicators related to the environmental impacts and the vulnerability status presented by those caves (intrinsic features) and the values scored in a 'Cave Conservation Index' (CCI) were established. We also used a rapid assessment protocol to measure cave vulnerability for prioritization of conservation/ restoration actions (RAP-*cr*) comparing natural cavities with the same lithology, due to "*strictu sensu*" peculiarities. Based on the protocols applied in caves of the municipality of Laranjeiras, Sergipe, Northeastern Brazil, we concluded that the present method attended to the needs for the classification of the caves into categories of conservation/restoration status, using little time and financial effort, through rapid diagnostics that facilitate the comparisons. In this perspective, the CCI can be used to indicate areas that should be protected and caves that should be prioritized to have initiated activities of conservation and restoration.

INTRODUCTION

The success for the conservation of cave environments is directly associated with an accurate diagnosis of their intrinsic characteristics and their risk or vulnerability situation. In Brazil, most studies that conduct environmental assessment of caves tend to only characterize them qualitatively and indicate possible consequences and ways of reparation (e.g. Lino, 2001; Ferreira & Horta, 2001; Ferreira, 2002; Lobo et al., 2009; Ferreira, 2010). These studies present either rapid or ascertained assessments as methodologies, but are not liable for comparison regarding the indication of vulnerability, extinction risk or the relative degree of stability of a particular cave in relation to others with similar characteristics. The pursuit of appropriate methodologies has been proposed by Bovet & Ribas (1992) and recently by Hardt (2008), but these approaches still present difficulties with regard to the comparison of results from different localities. More recently, Gomes (2010)

made use of new techniques to characterize vulnerable sites using map overlap and GIS data. However, this methodology is useful when assessing large areas, even those which were not personally visited. Its negatives are the lack of qualified professionals to use these new technologies and the time spent preparing the maps and the possible absence of pre-existing data generating a margin of inaccuracy.

The use of an index to prioritize conservation of Brazilian karst systems began with the creation of the 'Importance Value for Cave Conservation' (Borges et al., 2012). This index is composed by indicators and statistics in order to rank the caves but this approach is limited, because they attribute to all the caves the same weight and importance, which would not be the most appropriate.

Such studies present the caves concerning its impacts or characteristics, but require long-term studies. To assist the regional management of caves with same lithology, this study proposes the use of the 'Cave Conservation Index' (CCI), which

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analyses the environmental impacts, pressures and vulnerability of intrinsic characteristics presented by caves. The function of the CCI is to classify the caves into categories to provide quick diagnosis, thus facilitating comparisons, and indicating priority areas to be protected.

The need of development and application of an practical and rapid index that could be more appropriated to Brazilian caves is evident (Donato, 2011), thereby the aim of this study is to present a methodology for a new CCI, for which were defined criteria regarding the geological, geomorphological, biotic, archaeological, paleontological, hydrological and environmental impact aspects for the evaluation of a pilot area, a set of nine caves found in the municipality of Laranjeiras, in Sergipe State, Brazil.

METHODS

Study area

The 'Cave Conservation Index' was developed to evaluate nine caves located in the microregion of the Cotinguiba, in the County of Laranjeiras (Fig. 1) (Correia, 2004). The rainy season is concentrated from May to August, and the driest months range from September to February. The average rainfall is 1300 mm per year, comprising the megathermal dry and sub-humid climate (Bomfim et al., 2002).
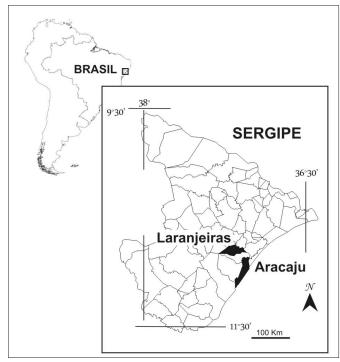

Fig. 1. Map of municipality of Laranjeiras, Sergipe, Northeastern Brazil. Source: Dantas et al. (2009).

The municipality is situated in the Rio Sergipe basin, represented mainly by the Cotinguiba and Buri rivers. Regarding the geomorphology, the study area is composed by river surfaces and remnants of coastal plain and coastal tablelands. Geologically, the County is in the Sedimentary Basin Sergipe/Alagoas, which is divided into two sections: Cotiguiba and Riachuelo. The Cotinguiba section (Cenomanian to Coniacian of Upper Cretaceous) consists of argillaceous limestone with stratified

layers. The Riachuelo section has regions with clay sediments interspersed with micaceous rock in medium and thin layers. Another region comprises a sequence of microcrystalline and pisolitic limestone (Araujo & Santos, 2013). The soils are classified according to both the new Brazilian soil classification (Jacomine, 2009) and the old classification (Correia, 2004), indicating the predominance of Argisoil (red and yellow Podzolic and the variation of reddish Brunizem), while the Organosoil (indiscriminate halomorphics) originated from the mangrove. The soil formation process presents major bands of limestone, that naturally favors the presence of caves and the deployment of cement and lime industries in the region, which cause environmental problems.

As the index of Caves Conservation should be applied in caves in the same region, we chose the nine caves of this municipality because they are in an area with massive opencast mines, Thus at greater risk of destruction. The set of caves from the municipality of Laranjeiras was chosen due to: (i) the assembly of the largest collection of nearby caves registered in the State of Sergipe (CECAV, 2013); (ii) the differences in the karst formation of its caves; (iii) Due to the formation of limestone caves in the municipality, these cavities suffer great pressure from mining, as well as threats and environmental impacts arising from these activities (Donato et al., 2012).

The proposed method was tested in nine caves: Aventureiros (10°48'11.5"S 37°10'49.3"W), Raposa (10°48'51.6"S 37°10'45.4"W), Matriana (10°48'04.0"S 37°10'46.8"W) Pseudomatriana (10°47'51.6"S 37°10'55.7"W), Janela (10°49'22.2"S 37°10'28"W), Tramandaí (10°49'03.5"S 37°10'12.5"W), Orixás (10°49'04.6"S 37°10'25.5"W), Raposinha (10°48'48.9"S 37°10'27.8"W) and Pedra Furada (10°49'14.7"S 37°10'40.2"W) in the municipality of Laranjeiras, State of Sergipe, Brazil.

Study methodology

The developed method is divided into three stages: environmental impact and pressure analysis, through the rapid assessment protocol of cave environmental impact; vulnerability analysis of the cave, through the rapid assessment protocol for prioritization of conservation and/or restoration actions; and comparison of results. The rapid assessment protocols should be filled out using secondary data and/or field trips. The results, obtained in percentage, are compared in the last stage, in which the final value is classified into a specific category.

Rapid assessment protocol of cave environmental impact (RAP-*cei*)

The protocol was built based on the structural model "Pressure-State-Response" (PSR), developed by the Organization for Economic Co-operation and Development (OECD, 1993), removing the response indicator from the table and using it only on proposals of resolutions for pressures and changes in the environmental status.

The indicators are qualitative and quantitative, in order to improve comparisons of existing data

from different environmental impact studies. The parameters that were used as indicators were adopted according to information obtained in previous environmental impact studies in Brazilian caves (e.g. Lino, 2001; Ferreira, 2010; Cavalcanti et al., 2012) and studies about the cave fauna (Souza-Silva, 2008). The categories of impact were formulated based on the methodology used by Carmo (2010).

Possible pressure activities causing impact were separated into: mining, agriculture, tourism, disorderly visitation, water damming, urbanization, scientific research and engineering work. A single cave may present impacts coming from one or many of the described activities (Table 1).

causing changes in the environment and ecological processes. Score: 62 to 84 points;
e. Critically Endangered (CR): outcrops with extremely high risk of extinction. Major changes in the surrounding landscape, or matrix, compromising the maintenance of native species and ecological processes. Score: 85 to 99 points;
f. Extinct (EX): cave that despite having been assessed in previous protocols do not exist anymore. Score: 100 points.

The final result is the value obtained in the RAP-*cei* protocol, which is already presented in percentage. In possession of the values, each cave can be compared with one another, the sorting and classification of the caves in ascending order, from the least to the most impacted, according to the total of points obtained for each natural cavity due to the observed impacts.

Table 1. Rapid assessment protocol of environmental impact related to caves (RAP-*cei*).

Activity(ies) causing impact		
( ) Mining	( ) Agriculture/Ranching	( ) Tourism/disorderly visitation
( ) Damming	( ) Urbanization	( ) Engineering work

Score refers to the magnitude of the impact, which indicates the severity of the impact on the environment. The magnitude can be of four types:
1 – Threats to natural resources is negligible regarding its depletion and the environment and community degradation, being reversible in a short term (up to 1 year); add 2 points.
2 – The use of natural resources is considerable but the depletion of the natural reserves is not possible, being the degradation of the environment and the community reversible in the medium term (1 to 10 years), if immediate actions take place; add 4 points.
3 - The use of natural resources is considerable and the depletion of the natural reserves is possible, being the degradation of the environment and the community reversible in the long term (10 to 50 years), if immediate actions take place; add 6 points.
4 – When the action caused the scarcity of natural resources, and the degradation of the environment and the community does not have many chances of reversibility; add 10 points.
5 – If there are more than one component to be evaluated in each indicator, consider the sum of the scores, for values below 10 and/or give the highest score (10) if the sum of values is greater than 10.

Type of impact	Estimated Score	Achieved Score
Complete destruction of the cave (in this case, there is no need of continuing analysing the impacts, scoring closes here).	0 / 100	
Partial destruction of the cave.	0 / 2 / 4 / 6 / 10	
Changes in water dynamics: lowering of the aquifer; partial or complete flooding; drying of karstic lakes and ponds; destruction of cargo areas; obstruction of ducts and consequent flooding or drying.	0 / 2 / 4 / 6 / 10	
Karst changes: cracks, detachments, broken speleothems, collapse of karstic structures.	0 / 2 / 4 / 6 / 10	
Alterations of subsurface soil: trampling of delicate formations, pavement compaction.	0 / 2 / 4 / 6 / 10	
Sound pollution: acoustic overlap and vibration.	0 / 2 / 4 / 6 / 10	
Pollution of groundwater: eutrophication, presence of pollutants (i.e. oil, suds)	0 / 2 / 4 / 6 / 10	
Natural vegetation deforestation by fire, reduction of organic resources, increase of exotic species, spread of pollutants, soil acidification.	0 / 2 / 4 / 6 / 10	
Masonry work: lighting, walkways, microclimatic changes.	0 / 2 / 4 / 6 / 10	
Disorderly visitation/vandalism: garbage, graffiti, and other types of vandalism.	0 / 2 / 4 / 6 / 10	
Range of impact, taking into account the most impactful action: If there is no impact – add 0 points. If the impact is local – add 5 more points. If the impact is regional – add 10 more points. Note: Local – when the effect is restricted to the site of action; Regional – when the effect is spread over an area beyond the immediate vicinity of where the action takes place.	0 / 5 / 10	
Total Score		

According to the cave's situation, it can be classified into six different categories concerning the presence of environmental impact:
a. Intact (I): natural communities, populations and ecological processes apparently intact, without anthropic alterations or threats. Score: ≤ 7 points;
b. Stable (S): noticeable anthropic alterations possibly leading to local declines of natural populations. Integrity of the landscape maintained, ecological processes apparently intact. Score: 8 to 34 points;
c. Vulnerable (VU): outcrops with risk of extinction if adequate protection and management measures are not adopted. Loss and degradation of habitat. Score: 35 to 61 points;
d. Endangered (EN): outcrops with high extinction risk. Landscape alteration with habitat loss

Rapid assessment protocol of cave vulnerability for prioritization of conservation and/or restoration actions (RAP-*cr*)

For the vulnerability analysis of the intrinsic characteristics of the caves, sixteen indicators were used, distributed among the internal and external environments, since both are interrelated, but have distinct characteristics. There are indicators with either more general and more specific features. The protocol has a quantitative assessment regarding the presence/absence of features at different levels.

The indicators from the internal (i) and external (e) environments are organized in three categories: biotic environment (BE; score = 3), abiotic environment (AbE; score = 2) and anthropic environment (AnE; score = 1) (Table 2), which generate the Equation 01 of the RAP-*cr*, as follows:

$$\text{RAP-}cr = \{[(BE_i + BE_e) \times 3] + [(AbE_i + AbE_e) \times 2] + [(AnE_i + AnE_e) \times 1] / 60\} * 100$$
Equation 01

The values range from 0% to 100% and values equal to or smaller than 35% indicate low priority for conservation/restoration, values ranging from 36% to 75% suggest medium priority for conservation/restoration, and values from 76% onward explicit high priority for conservation/ restoration. For the case of scores between 35% and 40% or between 75% and 80%, small differences in assessment between two observers could occur. But this problem exists in established protocols (North et al., 2009; Van Beynen & Bialkowska-Jelinska,

Table 2. Rapid assessment protocol of cave status (RAP-*cr*).

Environment	Analyzed Characteristic	Classification	Estimated Score
Internal	**Biotic Environment**		
	Occurrence of animals with troglomorphism (i.e., depigmentation, absence of eyes, elongated appendages, etc.), possible troglobian – animals restricted to caves, not being found in external environments.	Yes	1
		No	0
	Group of animals found in the caves *(if there is no internal fauna, don't score = 0 points)*	Invertebrate *or* vertebrate	1
		Invertebrate *and* vertebrate	2
	Invertebrate richness (the higher the richness the better status – tends to increase the diversity index). The score should be given from the number of morphospecies found. *If there is no internal fauna, don't score = 0 points. (*)*	1 to 5 species	1
		6 to 10 species	2
		≥ 11 species	3
	Bat richness (observe the existence of guano inside the cave and the possibility of identifying the species). The score should be given from the group with the higher value. *If there aren't any bats, don't score = 0 points.*	Hematophagous	1
		Carnivorous	2
		Insectivorous	3
		Nectarivorous / Frugivorous	4
	Paleontological site: Fossil presence (whole or fragmented animals or plants) and/or ichnofossils (traces of vital activity of ancient organisms, such as footprints and drillings).	Yes	1
		No	0
	Anthropic Environment		
	Visible mischaracterization of the environment (agents such as: grids, garbage, graffiti, artificial lighting, pest control, stairs, predatory collection of biological components, etc.).	Yes	0
		No	1
	Archaeological sites – sites with traces of human activity (paintings, bonfires, graves, chipped stone tools, etc.) that lived before the beginning of our civilization.	Yes	1
		No	0
	Scenic beauty (aesthetic quality of a landscape to the eyes of the population that visits it).	Low	0
		Medium	1
		High	2
	Cultural heritage (the set of all material or immaterial goods that, for its own intrinsic value, are considered of relevant interest to the permanence and cultural identity of a nation).	Yes	1
		No	0
	Abiotic Environment		
	Speleothems: the number of different types that are well preserved	0	0
		1-2	1
		3-4	2
		≥ 5	3
	Presence of permanent water bodies (rivers, ponds, underground and/or internal superficial lakes).	Yes	1
		No	0
External	**Biotic Environment**		
	Type of occupation found around the cave (main activity	Natural vegetation (characteristic biome of the region)	2
		Pasture, Agriculture, Monoculture, Reforestation	1
		Residential, Commercial, Industrial	0
	Abiotic Environment		
	Karstic environmental heterogeneity (presence of other karstic environments in the surroundings of the cave – such as lapiaz, sinkholes, uvalas and poliés)	Yes	1
		No	0
	Anthropic Environment		
	Location inside a Conservation Unit (UC)	Full Protection	2
		Sustainable use	1
		Outside UC	0
	Visible anthropogenic alteration of urban domestic or industrial origin (garbage, sewage, factories, steel mills, fires, exotic plants, predatory collection of biologic components).	Yes	0
		No	1
	Presence of buildings or environmental changes (such as roads, urban core, mining, agriculture/ranching, etc.) near the cave area (a map could be necessary).	< 1000	0
		1000 - 1500	1
		1500 - 2000	2
		> 2000	3

(*) – In case of karst regions with low richness of invertebrates, or in case of difficulty in separating the samples into morphospecies, the score can be obtained by the number of orders, using the same scoring criteria.

2012). Thus, for cases where marginal values are found, we suggest the use of additional criteria that could be easy to visualize, to help in determining the most representative category. For example, one can observe whether among biotic, abiotic and anthropogenic characteristics evaluated are there any that stand out, such as high species richness of invertebrates, or speleothems as well as the presence of an important archaeological site. These features can only be observed in situ and can be an useful tool to deal with observed marginal values.

Cave Conservation Index (CCI)

To obtain the 'Cave Conservation Index' (CCI), the results of both rapid assessment protocols (RAP-*cei* and RAP-*cr*) were combined, as shown in Equation 02. The value of the vulnerability status of the cave (RAP-*cr*) is reduced from the environmental impact value (RAP-*cei*), giving a final value which classifies the caves into five classes of conservation priority (Table 3).

$$CCI = (RAP\text{-}cei) - (RAP\text{-}cr)$$
$$\text{Equation 02}$$

Table 3. Cave classification according to the 'Cave Conservation Index' (CCI), indicating priority for conservation and/or restoration actions.

Conservation Index	Cave Classification (Priority)
81-100%	Intense
61-80%	High
41-60%	Medium
21-40%	Moderated
0-20%	Low

RESULTS

In general, we found four pressure activities causing impacts: mining, agriculture, tourism/disorderly visitation and urbanization. However, not all of these impact-causing activities were witnessed at the same time in each cavities. The agriculture, urbanization and tourism/disorderly visitation caused impacts in all studied cavities. The mining had impacted Janela, Orixás and Pedra Furada.

These actions caused different types of impacts, with different intensity and range in each of the studied caves. The range of the impacts varied from local to regional. The results presented refer to field observations made from July 2010 to July 2011, thus some attributes may vary in values over time.

There were eight main types of impacts found: karst changes (cracks, detachment and broken speleothems); soil alterations (erosion, landfill, rubble, trampling of delicate formation sand pavement compaction); natural vegetation loss (deforestation, fire, reduction of organic resources, increase of exotic species and pollution); sound pollution (acoustic overlap and vibration); engineering works (mine steps); disorderly visitation/vandalism (trash, graffiti and microclimatic changes); and partial destruction of the cave (internal mining for removal of lime).

After using the RAP-*cei*, the caves were divided into two groups according to their respective scores:

Aventureiros (9%), Matriana (21%), Raposa (23%), Pseudomatriana (23%), Janela (25%), Tramandaí (27%) and Orixás (29%) are stable with regard to their environmental characteristics and faunal communities, while Raposinha (41%) and Pedra Furada (55%) are vulnerable (Table 4).

Table 4. Assessment of the environmental impacts, cave status, value of the *'Cave Conservation Index'* (CCI) and priority ranking for conservation/restoration actions in the caves from Laranjeiras/Sergipe/Brazil.

Cave Code	Richfau	Richveg	CEI	CS	CCI	CP
CAV1	57	12	S	Me	Me	1
CAV2	79	14	S	Me	Mo	3
CAV3	78	4	S	Me	Me	2
CAV4	78	15	S	Me	Mo	5
CAV5	91	7	S	Me	L	8
CAV6	89	14	S	Me	Mo	4
CAV7	70	14	S	Me	Mo	6
CAV8	49	9	VU	Me	L	7
CAV9	141	15	VU	Me	L	9

Notes: Aventureiros (CAV1), Janela (CAV 2), Raposa (CAV 3), Tramandaí (CAV 4), Matriana (CAV 5), Pseudomatriana (CAV 6), Orixás (CAV 7), Raposinha (CAV 8), Pedra Furada (CAV 9); Richness of the internal fauna (Richfau); Richness of the external flora (Richveg); Cave classification according to the environmental impact (CEI); Cave classification according to the intrinsic characteristics status (CS); Cave priority ranking for conservation/restoration actions (CP); Cave Conservation Index (CCI); Stable (S); Vulnerable (VU); Low (L); Moderated (Mo); Medium (Me).

The state of vulnerability analysis of the caves (RAP-*cei*) indicated that no troglomorphic species were found in the internal biotic environment (that is, possessing morphological characteristics of a troglobian species, such as depigmentation, absence of eyes, elongated appendages, etc.), but other specimens of vertebrates and invertebrates were successfully found. All the caves have specimens of frugivorous and nectarivorous bats, except for Matriana, which does not have a bat population. Only Raposa presents a paleontological site. The internal anthropic environment of all the caves presents some sort of visible mischaracterization, does not have archaeological sites and holds low or medium scenic beauty, although Matriana and Pedra Furada are considered cultural heritage sites. The internal abiotic environment of the caves does not present permanent water bodies, except for the Aventureiros. All the studied caves have some sort of speleothems.

The external biotic environment presents pasture, agriculture, monoculture or reforestation around all the caves. All studied caves don't have an external abiotic environment presenting environmental heterogeneity, except for the Matriana which is standing amid a field of lapiaz. The external anthropic environment of all caves states that they are not included in a conservation area, since there are visible anthropogenic alterations from domestic urban or industrial origins, besides the presence of buildings or major environmental modifications from, at most, fifteen hundred meters away from the entrance of the caves.

Regarding the intrinsic characteristics related to the vulnerability status of the studied caves, all were classified as medium priority for conservation/restoration, as follows: Raposa (70%) and Aventureiros (65%), Janela (60%), Orixás (58%), Raposinha (58%), Pedra Furada (57%), Tramandaí (57%), Pseudomatriana (55%) and Matriana (37%) (Table 4).

The results obtained with the 'Cave Conservation Index' (CCI) classified the caves following their order of priority of conservation or restoration: Aventureiros (56%), Raposa (47%), Janela (35%), Pseudomatriana (32%), Tramandaí (30%), Orixás (29%), Raposinha (17%), Matriana (16%) and Pedra Furada (2%). Therefore, the Aventureiros and Raposa have priority of conservation/restoration in relation to other caves (Tables 3 and 4).

DISCUSSION

After analysis of the protocols, it was observed that all studied natural cavities are under some extent of pressure and present environmental impacts affecting their internal environments, while also containing heterogeneous environmental conditions. These conditions mainly reflect the presence of a large population of bats (Janela, Raposa and Pseudomatriana) and the availability of microhabitats and trophic resources (presence of guano from hematophagous, frugivorous and insectivorous bats; fallen blocks; watercourses; roots; and litter in the various natural cavities). Previous studies have demonstrated the importance of considering the biota as a factor to increase the utilization of the disturbance indexes (van Beynen & Townsend, 2005; van Beynen et al., 2007).

Given the pressures and impacts posed by these caves, we suggest the development of an environmental management plan at the municipality level, consisting of five programs for the conservation of the speleological collection of Laranjeiras, which should focus on: (i) surveillance and environmental monitoring to restrain impacts; (ii) environmental restoration and landscape recovery of sites where mining occurred and containment of fires and deforestation; (iii) environmental education with focus on the principles of local culture, conserving myths and legends about the caves which can help maintaining the original characteristics of the Atlantic forest; (iv) a specific plan for waste disposal in caves; (v) a plan to ensure resources for environmental compensation and land use planning.

For the restoration of the epigeal environment, it is necessary to implement the current legislation, which indicates a minimum perimeter of maintained native vegetation with a radius of 250 meters around each cave (Brazil, 2004). Furthermore, the agricultural and livestock in the area should be avoided or suspended, the non-native species should be gradually removed and the native vegetation should be restored using agroforestry or native species. All actions above mentioned will assist in the restoration of the surround environment and will help conserving the caves.

The creation of ecological corridors after restoration of the cave surroundings is possible, due to the proximity between them, thus enhancing the conservation of the influence areas of the caves (Marra, 2008). Encouraging the creation and implementation of Private Natural Heritage Reserves (RPPN), a model of environmental conservation in accordance with Brazilian legislation, in the area of caves with high hypogeal fauna richness and possessing natural or recovering vegetation is also a relevant option (Souza-Silva, 2008).

Caves considered as Cultural Heritage by the surrounding population can be listed as such, like the Pedra Furada and Matriana. The National Institute of Historic and Artistic Heritage (IPHAN) is the Brazilian institute responsible for registering a determined patrimony (environmental, cultural, historic or architectural) as a public heritage, intending to protect its physical integrity and safeguard its memory. This process does not turn the patrimony unavailable and its use is allowed if authorized and accompanied by personnel of the relevant government body. Therefore, tourism can still occur at these sites (Marra, 2008).

All the caves that have been impacted by human activities, including tourism, should have implemented recovery and management plans. To assist restoration of the karst environment, it is required intervention and management through the removal of garbage, cleaning of speleothems and painted walls (Hildreth-Werker & Werker, 2006).

The proposed protocols for the classification of caves according to the experienced pressures and environmental impacts and for the prioritization of conservation/restoration actions also serve as parameters for the conservation of the associated fauna and flora. Through the use of the presented indicators, it is possible to identify the pressures causing the environmental impact in the caves, the effects and magnitude of these impacts, which cave should be restored and which should be preserved, and which of them should receive the conservation/restoration actions first.

The ranking according to the vulnerability resulting from the impacts, and to the prioritization of actions can assist the decision making of which caves deserve more attention at first. However, it should be stressed that this study does not suggest that the remaining cavities should be put aside; it only indicates a general rank of action.

The presented protocol can also be used to indicate caves that must have management plans prepared more urgently, and which should not be suppressed while still having a high relevance inside an area with other high relevance caves that need rapid restoration of their attributes. Besides, the methodology presented in this study can be used to assist managers in making decisions about which caves can be used for tourism and recreation activities while others would be kept closed or used only in research or conservation. Furthermore, this protocol may be useful in studies of implementation of national parks and other protected areas in a given lithologic region, indicating the vulnerabilities and needs for conservation or restoration of karst ecosystems.

This protocol was initially performed to be used by evaluators from karst regions in Atlantic Forest complex and other Tropical environments, due to the rapid urban development and the high degree of disturbance in these environments associated to the great importance of biota in the scoring. With regard to the application of this study elsewhere, it is worth mentioning the need to adapt the indicators in light of local circumstances. Other indicators that may seem obvious to other locations did not appear in the obtained results due to the characteristics of the studied area.

Through the refinement of the index, the aim is to increase its applicability to resource managers. Thus, before applying the protocol here presented to another region, certain factors must be considered. Part of that refinement encompass: 1) the use of aerial photographs to improve the accurance in the determination of environmental impacts in the vicinities of the caves rather than relying on topographic or Cap maps; 2) for temperate regions, the indicators of species richness of invertebrates and their abundance needs to be adapted; and 3) the broadening of the indicator descriptions (including scores) to encompass a greater diversity of possible scenarios.

This reformulation is crucial to adjust the utility of the protocol to the reality of the new study sites. However, we stress that when determining an indicator's score, the evaluator should not only rely on the indicator descriptor but also on the overall characterization of the score. Further research is also necessary, in this sense, to validate the identified criteria in other localities, as well as to expand this material to obtain a methodology that can be applied also in more varied environmental contexts.

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