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ORIGINAL ARTICLE

Caves Geodiversity Evaluation as an Instrument to the Management of the Campos Gerais National Park, Southern Brazil

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Abstract
This paper aims to evaluate the geodiversity of sandstone caves in the *Campos Gerais* National Park, Southern Brazil. The subject of the research was the inventory, quantification, and classification (ranking) of geodiversity features and biological elements, in order to identify which caves are fragile, vulnerable, and demand priority management action. The inventory proposes a data plan template with 11 characteristics for evaluation of 33 caves and generated a set of speleological information for the *Campos Gerais* National Park. The quantification and classification of the caves were based on five factors: (a) underground geodiversity features, (b) vulnerability, (c) expropriation priority, (d) sensibility, and (e) potential to scientific use. A case study shows topics that may influence the relevance of the sandstone caves, such as (a) karstification process in non-carbonate siliciclastic rocks, (b) geological function of the caves, (c) interactions between geodiversity and biodiversity, and (d) recent changes in Brazilian laws about cave protection and speleological relevance. The results showed that cave geodiversity evaluation through inventory, quantification, and classification (ranking) is an effective instrument to identify which caves must be prioritized in conservation actions. The evaluation can directly contribute to the management plan and other conservation actions in the *Campos Gerais* National Park. It can be applied in other areas for the analysis of eventual enlargement or creation of new protected areas.

Keywords Caves · Geodiversity inventory · Protected areas · Geoconservation strategies

Introduction

The identification of priority areas for conservation in Brazil is mainly based on biological aspects of the landscape, such as the presence of fauna, forests, natural fields, and other flora elements. The main Brazilian legislation about protected areas is the law no. 9.985, July 18, 2000, has created the *Sistema Nacional de Unidades de Conservação* (National System of Protected Areas) (Brasil 2000). This law rarely approaches anything about geological heritage, and themes like geodiversity and geoconservation are not mentioned.

This reflects the low visibility and importance that the geodiversity elements receive in Brazilian protected areas, as reported by Pereira et al. (2008). Even in national parks, where the mainly natural attractive are landscapes that present relevant geological and geomorphological aspects, the geodiversity does not have the necessary highlight. As example of this case, the Iguassu Falls National Park (UNESCO World Heritage), situated on the border between Brazil and Argentina, there is a monumental waterfall ensemble formed on Mesozoic basaltic spills; however, there is few information about it in interpretative panels, folders, and other promotion materials of the protected areas, as indicated by Moreira (2012).

The lack of attention involving not promoting information about geological and geomorphological phenomena, geodiversity features, and the evolutionary processes that have

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transformed the landscape is recurrent in many protected areas all around the Brazilian territory.

However, virtually, many protected areas (UC - portuguese acronym) present landscapes with unique geodiversity features. This remarkable presence should not be ignored and such as the biodiversity aspects, geodiversity features need studies, divulgation and conservation aiming the management. The geodiversity should be widely discussed in studies for the identification of priority areas for conservation, as also in researches focused in environmental control and monitoring the protected areas that already exist.

In this sense, the geoconservation have practices that can contribute directly to the management of the Brazilian protected areas. Geoconservation strategies, according to Brilha (2005, 2016), include inventory, quantification, classification, conservation, evaluation, and divulgation, and geodiversity monitoring is an important instrument of management to the protected areas.

Caves constitute environments of meaningful geodiversity and biodiversity (Culver and Sket 2000; Ford 2006; Palmer 2007; Melo et al. 2011; Galão and Bichuette 2015; Souza-Silva et al. 2015; Souza-Silva and Ferreira 2016). Cave geological features are evidence of genetic and evolution processes and unique interactions between biotic and abiotic elements, besides being intrinsically correlated with superficial and underground water action, as large aquifers recharging zones.

In spite of that, studies about geodiversity still are insufficient, mainly in caves formed by siliciclastic sandstone, for example, the *Campos Gerais* National Park (PNCG) caves, located in Southern Brazil. Recent research has given attention to this type of caves and its geological features (Melo and Giannini 2007; Pontes et al. 2010; Melo 2009; Massuqueto et al. 2011; Melo et al. 2011; Pontes and Melo 2011; Melo et al. 2015; Pontes 2016; GUPE 2017). These studies show geodiversity features developed by quartz dissolution process in ambient temperature, microbial action record in the siliceous speleothem formation, and quartz sandstone dissolution, as indicated by Pontes (2017), as well as interactions between biodiversity and geodiversity and geosystemic functions of the caves as aquifer recharge.

The recent decree law no. 6.640/2008 (Brazil 2008) provides that every cave in the Brazilian territory must undergo a process of determining the speleological relevance, which will define the possibility of its total suppression or not. This decree law presented a method that classifies the caves in maximum; high, medium, and low relevance; and has received heavy criticism from the academic community (Marra 2008; Ganem 2009; Figueiredo et al. 2010; Trajano and Bichuette 2010; Berbert-Born 2010). Previously, there was a "broad protection" of the caves (although sometimes it did not happen), but the demand for natural resources resulted in exploration of areas with caves and their destruction, if necessary. For this reason, legislation has been amended.

The great challenge of a law like decree law no. 6.640/2008 (Brazil 2008) is to define how to evaluate which method, parameters, and elements should be evaluated without prejudicing the object under analysis. For this reason, it is important to have proposals that aim to answer these questions, which search for references of parameters, values, and numbers that better represent natural singularities, interactions, and dynamics.

Attributing numerical values to the geodiversity elements will always be subjective; there is always a risk of assigning high or very low values to a parameter, altering the final result. However, the quantification is necessary, once there are legal provisions in Brazil, which require the geological heritage quantification, based on the attribution of numerical values.

Thus, the sandstone caves geodiversity of PNCG constitutes an important parameter to be evaluated in geoconservation strategies. Therewith, this paper presents a method to evaluate the caves geodiversity of this protected area. The research involved inventory, quantification, and classification (ranking) of the geodiversity features and biological elements, in order to identify which caves are fragile, vulnerable, and priority to the management actions. In the same way, this method can be applied in analysis to aim determination of speleological relevance, according to the Brazilian laws.

Study Area

The *Campos Gerais* National Park is a protected area classified as an integral protection, located in the municipalities of Ponta Grossa, Castro, and Carambeí, State of Paraná, Southern Brazil (Fig. 1). Created in 2006, with 218.26 km^2, this protected area aims to protect the last remaining of natural fields and forests with Araucaria pine, beyond archaeological heritage and singular geological and geomorphological formations. Currently, the *Campos Gerais* National Park is initiating the expropriation process, which requires studies indicating priority areas for conservation.

Among these geological and geomorphological features, the caves are among the highlights. These cavities can be of several types, such as caves, grottos, rock shelters, abysms, and doline (sinkhole), and they vary from few meters to more than 1 km of linear extension. The largest cave in the park is the *Sumidouro do Córrego das Fendas* (Flügel Filho et al. 2011; Flügel Filho 2012; GUPE 2017). This underground system has 1300 m of extension mapped, and it is the fourth longest Brazilian cave developed in sandstone. According to GUPE (2017), there are new galleries known in this system; nevertheless, they are not yet accounted in the total length.

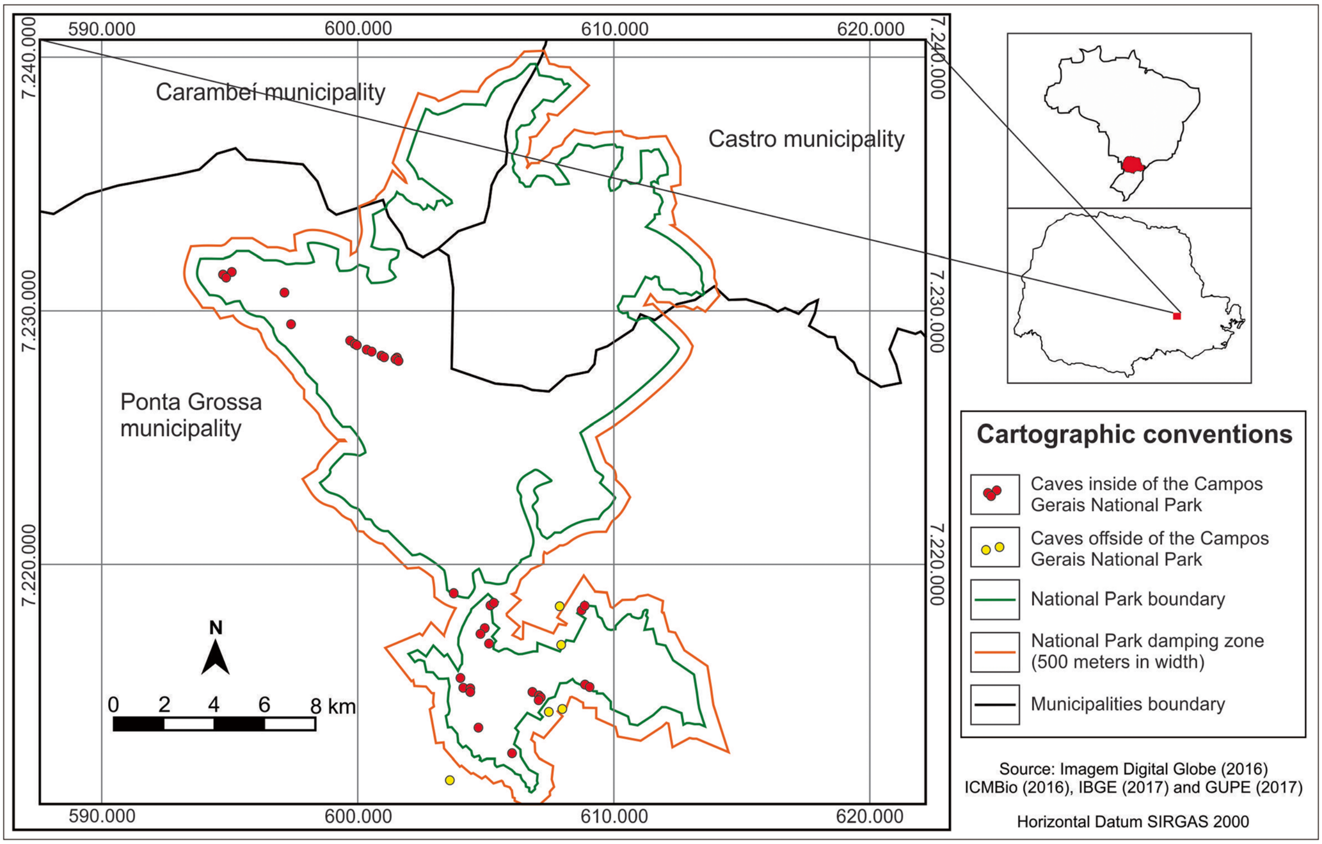

Fig. 1 Location of the *Campos Gerais* National Park and distribution of the caves

In the total, 38 caves are under jurisprudence of *Campos Gerais* National Park, 35 situated inside the UC, and three in the damping zone (Fig. 2). There are two more cavities near to damping zone limit included in the evaluation due to geological singularities present in these environments. Thus, besides providing methodological subsidies to the management actions inside of UC, this study enables the identification of priority areas to conservation in places near the park.

All PNCG caves are formed in sandstones of the Furnas Formation. These rocks appearing on the east edge of the Paraná Sedimentary Basin, with age between 395 and 421 My (Silurian/Devonian) (Borghi 1993; Assine 1999; Milani et al. 2007). According to Assine (1996), Melo and Giannini (2007), and Milani et al. (2007), this formation is predominantly compounded by quartz sandstones of medium to coarse gran-size, cemented by kaolinite and illite, showing different stratifications and presenting layers of silty and clay of thickness usually decametric.

The PNCG landform and hydrography as well as the caves and other geological features are controlled by remarkable tectonic structures related to Ponta Grossa Arc. This rupture structure reflects a huge regional crustal arching and according to Zalán et al. (1990) was active since the Paleozoic, but with apex during the Mesozoic. This is the record of a trend of continental break in the interior of the state of Paraná during the separation between South American and African plates.

Methods

In order to identify which PNCG caves are priorities for management actions, the research was developed in four stages: (1) fieldwork to explore, identification, and data collect, (2) the application of geodiversity inventory in all caves, (3) systematization of data and the formatting of a complete inventory of the cavities and (4) quantification and classification (ranking) based on the inventory to define underground geodiversity features, vulnerability, expropriation priority, sensibility, and potential of scientific use to each cave.

There are several proposals for geodiversity inventory and quantification, applied in areas ranging from small localities to large territorial extensions, such as regions and countries (Brilha 2005, 2016; Cendrero 1996, 2000; Pereira 2006; Lima 2008; Trueba and Cañadas 2008; Pereira 2010). This work is pioneering to carry out an inventory for the geodiversity quantification specifically of subterranean environments. To understand the fragility and vulnerability of the underground geodiversity, the analysis at smaller scales is more adequate, being possible to identify specific characteristics of these

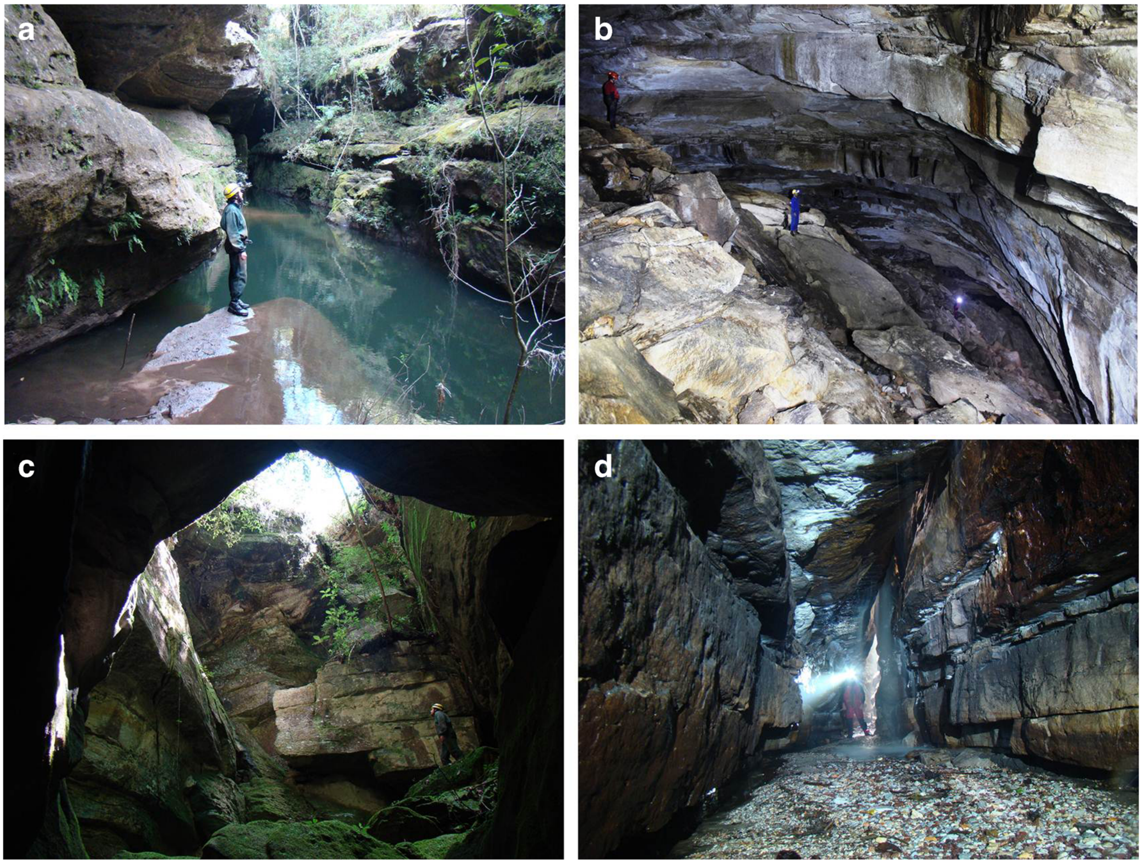

Fig. 2 *Campos Gerais* National Park caves. **a** *Sumidouro do Rio Quebra-Perna* cave. **b** *Andorinhas* cave. **c** *Sumidouro do Córrego das Fendas* cave. **d** Zé cave. These caves had the best classification in the geodiversity evaluation

environments. Therefore, this research was conducted from surveys in caves, constituting small areas of analysis.

The inventor form of the caves geodiversity applied in the PNCG was elaborated based on proposition of Dias (2003) and Gray (2004). The first author showed a field form designed to standardize data from caves collected in the field for the registration purpose. The second one proposes the inclusion of functional value for geodiversity, including utility and geosystemic and ecosystem functions, among others. The final inventory form was adapted for application in the study area considering the physical and biological characteristics of the local caves.

The inventory was divided into two parts, one for filling in during fieldwork and another to be filled in the office. The first part involved an analysis of the caves characteristics and its surroundings, during the fieldwork. The second one, which aims the urgency to protection and the identification of the cave functional value, according to Gray (2004), was developed with a technical team of researchers from the *Grupo Universitário de Pesquisas Espeleológicas*—GUPE (University Group of Speleological Research). These meetings enabled a multidisciplinary discussion and an integrated analysis of data obtained during the fieldwork.

The inventory form presented 11 topics, which are the following: (a) general information, (b) aspects of the access until the cave, (c) speleometric data, (d) hydrographic data, (e) geological data (including the caves geodiversity features), (f) biospeleological data (observation only, without specimen collection), (g) immediate surroundings characterization, (h) potential of scientific use of the caves, (i) general observations, (j) urgency to protection of the caves, and (k) functional value.

With the inventory of the geodiversity, it was possible to quantify and classify (establish a ranking) the PNCG caves and its immediate surroundings. This step served to indicate which caves are priorities for protective actions, identify areas for expansion of the protected area, and define which places are urgent for expropriation.

To quantify and classify the caves, five items of the inventory form filled were evaluated, which are the following: (a) underground geodiversity features, (b) vulnerability, (c) expropriation priority, (d) sensibility, and (e) potential to scientific use. The classification (ranking) is obtained from the sum of the values assigned for each item evaluated in the inventory, as exemplified in Table 1.

The use of 0.25, 0.5, 1.0, 2.0, and 4.0 is a criterion adopted for the method presented in this paper; however, as presented

Table 1 The quantitative method used to evaluate the cave geodiversity

Evaluated items	Value attributed	Maximum value added	Inventory topics used in integrated analysis
Underground geodiversity features	0.5 point for each feature identified	7.0 points	Geological data
Vulnerability	Very high level = 4.0 High level = 2.0 Intermediary level = 1.0 Low level = 0.5 Very low level = 0.25	4.0 points	Hydrographic, geological and biospeleological data, immediate surroundings characterization, and functional value
Expropriation priority	Very high level = 4.0 High level = 2.0 Intermediary level = 1.0 Low level = 0.5 Very low level = 0.25	4.0 points	Speleometric, hydrographic, geological and biospeleological data, immediate surroundings characterization, potential of scientific use, urgency to protection of the caves, and functional value
Sensibility	Yes = 4.0 Not = 0.0	4.0 points	Aspects of the access until the cave, hydrographic, geological and biospeleological data, and immediate surroundings characterization
Potential to scientific use	0.5 points for each feature identified	4.0 points	Speleometric, hydrographic, geological, and biospeleological data

by Brilha (2016), the application of weights in the quantification process demands more discussions. The maximum value in the evaluation of each item is 4.0 points, only the underground geodiversity features the total score that can reach 7.0 points. This difference is intentional, because the exposed method seeks to value the presence of this item in the caves.

The existence of 14 underground geodiversity features were evaluated, such as (a) ghost-rock, (b) speleothems, (c) dissolution conduit, (d) dissolution dome, (e) balance chimney, (f) alveoli (honeycomb), (g) ceiling half-tube, (h) plunging-pool (Fig. 3), (i) anastomosis, (j) incrustation, (k) scallops, (l) clastic deposits, (m) ichnofossil, and (n) vertical grooves in thin granulation layers (whale's tooth) (Fig. 4). For each features of cave geodiversity that were presented, it was added the value of 0.5 point.

The vulnerability and the expropriation priority have five different context levels and to each one was added different values, which are the following: 4.0 points to very high level, 2.0 points to high level, 1.0 point to intermediary level, 0.5 point to low level, and 0.25 point to very low level. To identify the vulnerability, the main topic analyzed was the characterization of the cave surroundings, involving the following subtopics: (a) activities near the caves (considering a radius of 250 m from the horizontal projection of the cave), (b) immediate surroundings vegetation, and (c) vegetation conservation status. To classify the expropriation, priority was considering the cave vulnerability and sensibility.

In this work, vulnerability is related to the presence of geodiversity features which can be degraded or exposed to total suppression by any kind of disturbance resulted by anthropic activities (considering a radius of 250 m from the horizontal projection of the cave). Sensibility is the fragilities of the caves that are susceptible to degradation and if there is general divulgation that can generate negative impacts, for example, speleothems can be easily destroyed. This analysis also considered the elements of biodiversity, involving abundance, diversity, or rarity of species. The value 4.0 was applied to the cave with sensibility present and 0.0 when it was not present.

For each potential to scientific use that the cave presents, it was added the 0.5 value. The potentials of scientific use analyzed to each one were the following: (a) geomorphological, (b) paleontological, (c) stratigraphic, (d) tectonic, (e) hydrogeological, (f) speleogenetic, (g) geochemical, and (h) biological.

The method of caves geodiversity evaluation included topics which can influence the determination of relevance in sandstone caves, either for the management in protected areas or to the identification of priority areas for conservation, which are:

a) There is no complete understanding about the karstification process in non-carbonate siliciclastic rocks, mainly on dissolution of quartz and other silicates.

Fig. 3 Geodiversity features in the *Campos Gerais* National Park caves. **a** Ghost-rock. **b** Speleothems. **c** Dissolution conduit. **d** Dissolution dome. **e** Balance chimney (source: Rubens Hardt). **f** Alveoli (honeycomb). **g** Ceiling half-tube (author: Rubens Hardt). **h** Plunging-pool

b) The caves present an important geosystemic function, since they are great areas to aquifer recharge.
c) These environments present important interaction between geodiversity and biodiversity, what is shown by features such as speleothems formed by microbial action.
d) With the changes in Brazilian legislation regarding cave protection, it became mandatory to determine speleological relevance in the environmental license process, that is, the natural heritage quantification based on the attribution of numerical values.

Results and Discussions

This research was based in the inventory form about the caves geodiversity applied in 33 caves: 28 of them inside the PNCG and the other 5 in its immediate surroundings (*Andorinhas*, *Poço das Andorinhas*, *Dos Trezentos*, *Fenda Guacharos* and *Sumidouro do Rio Quebra-Perna* caves).

Seven caves were not inventoried (*Abrigo do Campo Minado*, *Toca da Catinga*, *Fenda dos Morcegos*, *Abismo Cercado Grande 1*, *Abismo Cercado Grande 2*, *Abismo Cercado Grande 3* and *Gruta Nova Holanda* caves) due

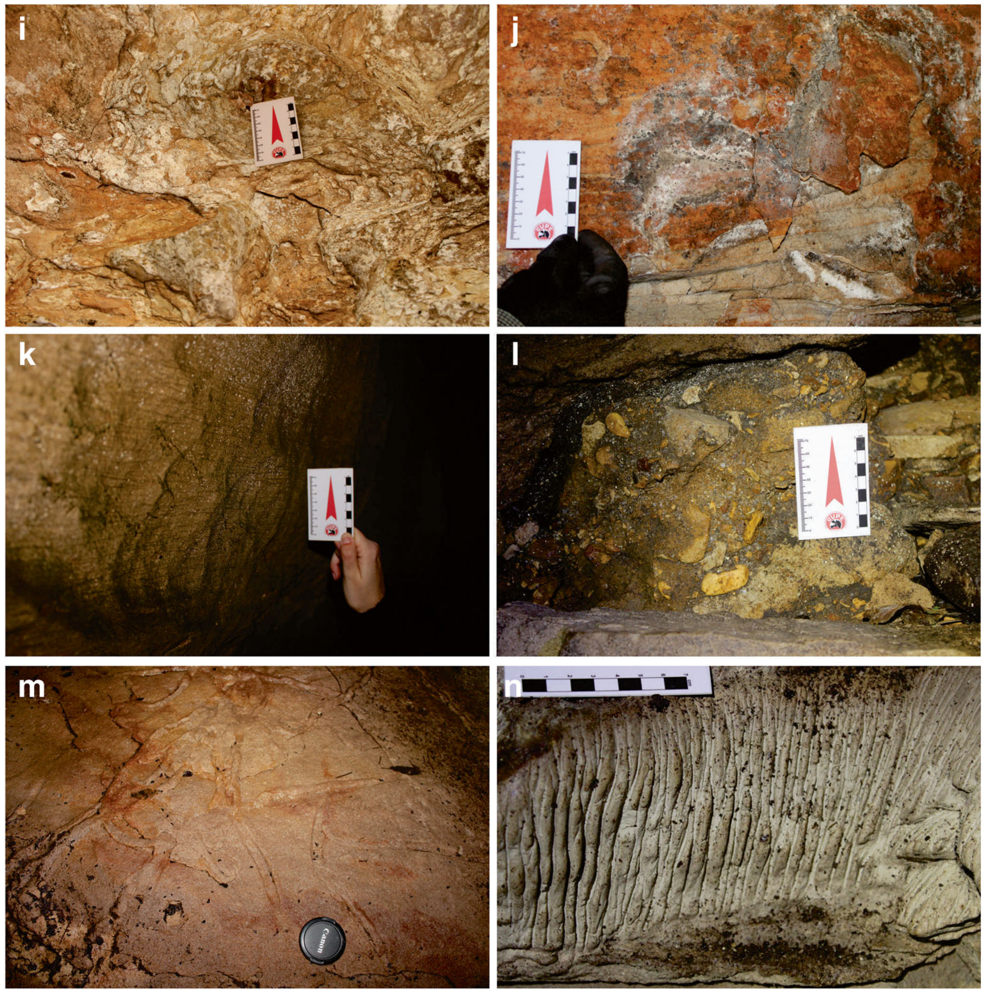

Fig. 4 Geodiversity features in the *Campos Gerais* National Park caves. **i** Anastomosis. **j** Incrustation. **k** Scallops. **l** Clastic deposits. **m** Ichnofossils. **n** Vertical grooves in thin granulation layers (whale's tooth)

to the difficulty and/or lack of access authorization by the property owners.

Through the inventory, it was possible the characterization of geodiversity elements (geological features present in the caves) and also generate information apparatus about the caves, involving several data, such as speleometric, geological, hydrographic, biological, land use, potential for use, and general features. All the inventory forms together totalize 252 pages of detailed information about these caves. These data may support future research, since it presents a diagnosis of the potentials, occurrence of the features, and general characteristics of each cave.

As already pointed out, five items of the inventory were chosen to accomplish the evaluation of the geodiversity of PNCG caves, which are (a) underground geodiversity features, (b) vulnerability, (c) expropriation priority, (d) sensibility, and (e) potential to scientific use of each cave. These items were evaluated according to predefined numerical parameters, presenting the results in Tables 2 and 3.

To quantify and classify each cave as from the evaluation of these five inventory items, an integrated analysis of other topics in the inventory form was performed, as shown in Table 1.

The caves with most geodiversity features were the *Sumidouro do Córrego das Fendas* (13), *Sumidouro do Rio Quebra-Perna* (11), *Andorinhas* (10), *Sumidouro da Mariquinha* (9), *Fenda Santa Maria 2* (9), *Zé* (7), *Chaminé* (7), and *Fenda Santa Maria 1* (7) caves.

Concerning the vulnerability of caves to negative environmental impacts, the *Andorinhas* and the *Sumidouro do Rio Quebra-Perna* caves are at very high vulnerability level. The *Zé*, Dolina do Matador, *Dos Trezentos*, and *Poço das Andorinhas* caves are at high vulnerability level. The *Sumidouro da Mariquinha*, *Fenda Guacharos* and *Buraco do Padre* caves are at intermediary vulnerability level. The remaining caves are at low or very low vulnerability levels.

With reference to the expropriation priority, the *Andorinhas*, the *Poço das Andorinhas*, and the *Sumidouro do Rio Quebra-Perna* caves are at very high priority level. The *Chaminé*, *Gruta da Inspirada*, *Opilião*, *Dolina do Matador*, *Dos Trezentos*, and *Zé* caves indicate high priority level when analyzing the characterization data of the caves and its immediate surroundings, according to the inventory form. The *Furna Passo do Pupo 1*, *Furna Passo do Pupo 2*,

Table 2 Quantification of underground geodiversity features and vulnerability of PNCG caves

Caves	Underground geodiversity features	Vulnerability
Andorinhas Cave	5.0	4.0
Sumidouro do Rio Quebra-Perna Cave	5.5	4.0
Poço das Andorinhas Cave	0.0	2.0
Zé Cave	3.5	2.0
Chaminé Cave	3.5	0.5
Dolina do Matador Cave	1.5	2.0
Dos Trezentos Cave	3.0	2.0
Sumidouro do Córrego das Fendas Cave	6.5	0.5
Opilião Cave	1.5	0.5
Fenda Guacharos Cave	2.0	1.0
Sumidouro da Mariquinha Cave	4.5	1.0
Fenda da Freira Cave	3.0	0.5
Fenda Sem Fim Cave	1.5	0.25
Fenda Santa Maria 2 Cave	4.5	0.5
Bugio Cave	2.5	0.5
Furna Passo do Pupo 2 Cave	1.0	0.5
Furna Passo do Pupo 1 Cave	2.5	0.5
Inspirada Cave	0.5	0.5
Buraco do Padre Cave	2.5	1.0
Furna do Anfiteatro Cave	2.0	1.0
Furna Grande Cave	2.0	0.5
Gruta Macarrão Cave	2.5	0.5
Fenda Santa Maria 1 Cave	3.5	0.5
Abismo da Brisa Cave	2.0	0.25
Abismo da Bromélia Cave	0.0	0.25
Fenda dos Tonini Cave	1.5	0.25
Toca do Beco Diagonal Cave	0.5	0.25
Toca do Golpe Cave	0.0	0.25
Gruta da Ricota II Cave	1.0	0.25
Gruta da Ricota I Cave	1.0	0.25
Abismo do Ferla Cave	0.0	0.25
Fenda Pulo do Gato Cave	1.5	0.25
Gruta de Ponta Cabeça Cave	1.0	0.25

and the *Fenda Guacharos* caves are at intermediary priority level, and the remaining caves are at low or very low expropriation priority levels.

About the sensibility context, the *Fenda Santa Maria 2*, *Sumidouro do Córrego das Fendas*, *Fenda Sem Fim*, *Fenda da Freira*, *Bugio*, *Chaminé*, *Opilião*, *Andorinhas*, *Poço das Andorinhas*, *Dos Trezentos*, *Fenda Guacharos*, *Dolina do Matador*, *Zé*, *Sumidouro do Rio Quebra-Perna*, and *Sumidouro da Mariquinha* caves indicate biotic and abiotic elements that classify these caves as sensitive caves.

Even if the cave is not classified as vulnerable (especially in relation to the immediate surrounding activities) nor does there is high expropriation priority, the caves classified as sensitive should be a priority in the management plan of the *Campos Gerais* National Park and other UC management actions. The sensibility indicates which caves are most prone to negative impacts, with the consequent risk of suppression of the geodiversity and the biodiversity elements. As an example, the *Sumidouro do Córrego das Fendas* Cave are at low vulnerability and expropriation priority levels, because in its immediate surroundings, there are no activities with significant impacts. Also, it is not an expropriation priority area, because there are no conflicts in the land usage of its immediate surroundings. However, the high diversity and abundance of species pointed out by Moss et al. (2012) and the large amount of speleothems (as indicate in the inventory form) make reasonable to classify the *Sumidouro do Córrego das Fendas* as sensitive cave.

About the potential of scientific use, the *Chaminé* and *Furna do Passo do Pupo 2* caves are the best examples pointed out by the quantification, each cave having six scientific themes; *Andorinhas*, *Sumidouro do Córrego das Fendas*, and *Furna do Passo do Pupo 1* caves, each cave having five scientific themes; being followed by *Sumidouro do Rio Quebra-Perna* and *Zé* caves, each with four potential scientific themes.

It was possible to make a ranking (Table 4) based on quantification of following features: underground geodiversity features, vulnerability, expropriation priority, sensibility, and potential of scientific use. With this evaluation, it was possible to indicate which caves should be prioritized for conservation, integrating the management of the *Campos Gerais* National Park.

The evaluation of the geodiversity in five caves, located in the immediate surroundings of the PNCG, allowed to identify areas for the expansion of the protected area. This evaluation can be considered to justify the importance of the extensions of protected areas. More detailed studies are under development for the delimitation and characterization of these proposals for expansion of the UC, focusing on the protection of the caves which have high geodiversity value.

Conclusions

The *Sumidouro do Rio Quebra-Perna* Cave and the *Andorinhas* Cave had the best classification in the geodiversity evaluation; however, these caves are not under jurisprudence of *Campos Gerais* National Park but are just near its limits. In other words, these caves are not in integral protection. This shows the importance of the use of geoconservation strategies

Table 3 Quantification of expropriation priority, sensibility, and potential of scientific use of PNCG caves

Caves	Expropriation priority	Sensibility	Potential of scientific use
Andorinhas Cave	4.0	4.0	2.5
Sumidouro do Rio Quebra-Perna Cave	4.0	4.0	2.0
Poço das Andorinhas Cave	4.0	4.0	0.5
Zé Cave	2.0	4.0	2.0
Chaminé Cave	2.0	4.0	3.0
Dolina do Matador Cave	2.0	4.0	0.5
Dos Trezentos Cave	2.0	4.0	0.0
Sumidouro do Córrego das Fendas Cave	0.5	4.0	2.5
Opilião Cave	2.0	4.0	1.0
Fenda Guacharos Cave	1.0	4.0	0.5
Sumidouro da Mariquinha Cave	0.5	4.0	1.0
Fenda da Freira Cave	0.5	4.0	1.0
Fenda Sem Fim Cave	0.5	4.0	1.0
Fenda Santa Maria 2 Cave	0.5	4.0	0.5
Bugio Cave	0.5	4.0	0.5
Furna Passo do Pupo 2 Cave	1.0	0.0	3.0
Furna Passo do Pupo 1 Cave	1.0	0.0	2.5
Inspirada Cave	2.0	0.0	1.0
Buraco do Padre Cave	0.5	0.0	1.5
Furna do Anfiteatro Cave	0.25	0.0	1.5
Furna Grande Cave	0.5	0.0	1.5
Gruta Macarrão Cave	0.5	0.0	0.5
Fenda Santa Maria 1 Cave	0.5	0.0	0.5
Abismo da Brisa Cave	0.5	0.0	0.5
Abismo da Bromélia Cave	0.5	0.0	0.5
Fenda dos Tonini Cave	0.25	0.0	0.5
Toca do Beco Diagonal Cave	0.5	0.0	0.0
Toca do Golpe Cave	0.5	0.0	0.0
Gruta da Ricota II Cave	0.5	0.0	0.0
Gruta da Ricota I Cave	0.5	0.0	0.0
Abismo do Ferla Cave	0.5	0.0	0.0
Fenda Pulo do Gato Cave	0.5	0.0	0.0
Gruta de Ponta Cabeça Cave	0.5	0.0	0.0

for the identification of priority areas for conservation, creation, or expansion of protected areas. This avoids the fact that protected areas do not include caves with expressive geodiversity. Perhaps, the exclusion is the result of lack of information about caves during PNCG creation and little attention involving all the geodiversity.

The results demonstrated that the geodiversity evaluation of caves may contribute to the management actions in the *Campos Gerais* National Park and can be applied to other places that are not in protected areas. This method also can be used in proposal for expansion or creation of new protected areas and determination of speleological relevance according to the current Brazilian law. However, these strategies must consider the environmental particularities of each studied area.

The evaluation through the underground geodiversity inventory and quantification allows to establish a mathematical parameter, assigning a numerical value and, consequently, establishing a classification (ranking) of the caves. It is a management tool that enables the identification of the most expressive environments scientifically, the most threatened. Those end up demanding urgent management actions.

Nonetheless, when analyzing caves, a systemic approach should be undertaken to evaluate the caves. Even the focus being on geodiversity, the biodiversity elements should be

Table 4 PNCG cave classification (ranking) considering the underground geodiversity features, vulnerability, expropriation priority, sensibility, and potential of scientific use

Caves	Rating
Sumidouro do Rio Quebra-Perna Cave	19.5
Andorinhas Cave	19.5
Sumidouro do Córrego das Fendas Cave	14.0
Zé Cave	13.5
Chaminé Cave	13.0
Sumidouro da Mariquinha Cave	11.0
Dos Trezentos Cave	11.0
Poço das Andorinhas Cave	10.5
Fenda Santa Maria 2 Cave	10.0
Dolina do Matador Cave	10.0
Fenda da Freira Cave	9.0
Opilião Cave	9.0
Fenda Guacharos Cave	8.5
Bugio Cave	8.0
Fenda Sem Fim Cave	7.25
Furna do Passo do Pupo 1 Cave	6.5
Buraco do Padre Cave	5.5
Furna do Passo do Pupo 2 Cave	5.5
Fenda Santa Maria 1 Cave	5.0
Furna do Anfiteatro Cave	4.75
Furna Grande Cave	4.5
Gruta Macarrão Cave	4.0
Gruta da Inspirada Cave	4.0
Abismo da Brisa Cave	3.25
Fenda dos Tonini Cave	2.5
Fenda Pulo do Gato Cave	2.25
Gruta da Ricota I Cave	1.75
Gruta de Ponta Cabeça Cave	1.75
Gruta da Ricota II Cave	1.75
Abismo da Bromélia Cave	1.25
Toca do Beco Diagonal Cave	1.25
Abismo do Ferla Cave	0.75
Toca do Golpe Cave	0.75

included in the analysis, identifying and evaluating the geodiversity in the context of the provision of ecosystem services and the biodiversity influence on the geodiversity elements and vice versa. Geological and biological studies developed in these caves have shown that this geobiodiversity interaction is inseparable and goes beyond as a simple interaction; it is a mutual dependence.

Similarly, it is a fact that the continuous search for updating and improving the inventory information and the non-subjectivity data and parameters to quantify and qualify should be a priority for geoconservation strategies. In these terms, we must always critically assess studies with this focus.

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