International Journal of Geoheritage and Parks 12 (2024) 485–500

Contents lists available at ScienceDirect

International Journal of Geoheritage and Parks

journal homepage: http://www.keaipublishing.com/en/journals/international-journal-of-geoheritage-and-parks/

Research Paper

Inventory and assessment of geological sites at Alto Ribeira Touristic State Park (São Paulo, Brazil): A contribution to its management

Priscila L.A. Santos *, José Brilha

Institute of Earth Sciences, Pole of the University of Minho, Campus of Gualtar, 4710-057 Braga, Portugal

ARTICLE INFO

Article history:
Received 20 October 2023
Received in revised form 11 July 2024
Accepted 11 July 2024

Available online 15 July 2024

Keywords:
geoconservation
geosites
geodiversity sites
System for Registration and Quantification of Geosites and Geodiversity Sites (GEOSSIT)
Alto Ribeira Touristic State Park

ABSTRACT

Over the past decade, various methodologies have been developed to systematize, discuss, and propose measures for protecting and sustainably managing geological heritage. The Alto Ribeira Touristic State Park is a crucial component of the most significant network of protected areas in the State of São Paulo, Brazil. It has international recognition for its speleological heritage, which underpins its status as a popular tourist destination. This intensive touristic use necessitates solid management plans that ensure sustainable tourism while preserving the karst features. Therefore, this work refined the inventory of geological sites and provided a quantitative assessment of their degradation risk and potential for use. Three geosites and twenty four geodiversity sites were identified and assessed. The quantitative evaluation of these geological sites was conducted using the System for Registration and Quantification of Geosites and Geodiversity Sites (GEOSSIT), which was developed by the Geological Survey of Brazil. The application of this tool, designed for use in a vast and diverse country like Brazil, revealed the need for adaptations when applied to a smaller area such as Alto Ribeira Touristic State Park. This work helped establish management priorities for these sites and determine the most suitable uses for each geological site, providing valuable information for park managers. Such studies demonstrate that proper management of protected and conserved areas should always include geodiversity and geoconservation in their action plans.

1. Introduction

Geoconservation encompasses a range of techniques and initiatives designed to preserve and safeguard geological heritage. This includes activities that promote awareness and the recording of data and specimens from sites at risk of degradation or loss (Prosser, 2013; Worton, 2008). Geoconservation is rooted in fundamental principles that guide a comprehensive approach to nature conservation and the planning and management of geological sites. These principles emphasize the acknowledgment of the diverse values associated with geodiversity and geological heritage, such as cultural, aesthetic, ecological, scientific, educa-

* Corresponding author.
E-mail addresses: priscila.lopes.santos@usp.br (P.L.A. Santos), jbrilha@dct.uminho.pt (J. Brilha).

https://doi.org/10.1016/j.ijgeop.2024.07.003

tional, and touristic values (Crofts et al., 2022; Crofts et al., 2020; Gordon, Crofts, Díaz-Martínez, & Woo, 2017). They necessitate a systematic approach to all aspects of identifying and managing geological sites, recognizing the sensitivity of the environment to natural changes, and integrating the management of natural processes while understanding the interdependence between geodiversity and biodiversity, all within the ecological capacity of the environment (Crofts et al., 2022; Crofts et al., 2020; Gordon et al., 2017).

Over the past decade, various methodologies have been developed to systematize, discuss, and propose measures for protecting and sustainably managing geological heritage. These methodologies encompass inventorying, evaluating, designating, conserving, promoting, disseminating, and monitoring geological sites (Brilha, 2005, 2016).

The inventory of geological sites involves identifying, selecting, and systematically characterizing the elements of geodiversity that require protection. Quantitative assessments reduce the subjectivity inherent in the evaluation process and aid in establishing management priorities (Brilha, 2016).

Various methods for numerically evaluating geological sites have been developed, but no universally accepted approaches exist. The geoscientific community has proposed different methods based on analyses, tests, and combinations of previous methods, leading to a diverse range of approaches (Cendrero, 1996a, 1996b; Coratza & Giusti, 2005; Pralong & Reynard, 2005; Pereira, Pereira, & Alves, 2007; Reynard, Fontana, Kozlik, & Scapozza, 2007; Bruschi & Cendrero, 2009; Migoń, 2009; Reynard, Coratza, & Regolini-Bissig, 2009; Knapik et al., 2009; Pereira & Pereira, 2010; Bruschi, Cendrero, & Albertos, 2011; Medina, 2012; Fassoulas, Mouriki, Dimitriou-Nikolakis, & Iliopoulos, 2012; Pereira & Pereira, 2012; Bollati, Smiraglia, & Pelfini, 2013 cited by Brilha, 2016; Kubalíková & Kirchner, 2016; Serviço Geológico do Brasil, 2022; Woo & Kim, 2018; Dollma, 2019; Pontes et al., 2019; Simón-Porcar, Martínez-Graña, Simón, González-Delgado, & Legoinha, 2020; Telbisz et al., 2020; Maksoud, Kholoud, Baghdadi, & Ruban, 2021; Naimi & Cherif, 2021; Menin & Bacci, 2023).

In general, these methods rely on assigning scores to different criteria for assessing the scientific, educational, and/or touristic values, as well as considering usage and management aspects and establishing priorities for the protection of geological sites.

The Alto Ribeira Touristic State Park (acronym in Portuguese PETAR) is a vital component of the most important network of protected areas of the State of São Paulo, Brazil: the Paranapiacaba Ecological Continuum (Fundação Florestal, 2010). This continuum represents one of the best-preserved areas of the Atlantic Forest in Southeast Brazil and is part of Mata Atlântica Biosphere Reserve. The Alto Ribeira region has earned international recognition for its speleological heritage, which serves as a foundation for its status as a tourist destination. Various authors, such as Lobo (2008), Ferreira (2014) and Ferreira, Lobo and de Perinotto (2018), highlight that in recent decades, ecotourism, especially cave tourism, has emerged as the primary source of income for local communities in the municipalities of Apiaí and Iporanga. Given the geological importance of the region and its potential for geotourism development, several researches have been undertaken to enhance our understanding of the geological heritage and facilitate its dissemination (Karmann & Ferrari, 2002; Theodorovicz, 2014; Ferreira, 2014; Ferreira et al., 2018; Garcia et al., 2018; Santos, 2019; Santos & Garcia, 2021; Santos & Garcia, 2022; Santos & Garcia, 2023; Santos & Garcia, 2023b; Menin, Tognetta, & Bacci, 2022; Menin & Bacci, 2022, 2023; Santos & Brilha, 2023).

This endeavor seeks to initiate a geoconservation strategy applied to PETAR and its surrounding areas, encompassing the refinement of the inventory of geological sites and a quantitative assessment of their degradation risk and potential for use. These efforts aim to inform future steps and foster a sustainable tourism use of these sites.

2. Material and methods

2.1. Study area

2.1.1. Background information

PETAR is located in the southwest of the State of São Paulo, within the Vale do Ribeira political-administrative region (Fig. 1). The park extends over portions of the municipalities of Apiaí (10,048 ha) and Iporanga (25,829 ha) while bordering the municipalities of Guapiara (to the north and northwest) and Itaóca (to the southeast), encompassing a total area of 35,772.5 ha.

PETAR is an Integral Protected Area designated under the national park management category, in accordance with Brazil's National System of Protected Areas (acronym in Portuguese SNUC). While the park was formally established in 1958, its effective implementation began in 1985 after land surveys carried out in the region, coordinated by the State Environmental Council (acronym in Portuguese COMSEMA). This work resulted in the implementation of the current administrative nuclei (Santana, Ouro Grosso, Caboclos and Casa de Pedra). In 2007, the park became administrated by the Foundation for Conservation and Forest Production of the State of São Paulo–Forest Foundation (FF), which operates under the Secretary of Environment (SMA).

PETAR is part of one of the most important protected areas networks in the State of São Paulo, the Paranapiacaba Ecological Continuum covering about 120,000 ha of forests distributed by Carlos Botelho State Park, Intervales State Park, the Xitué Ecological Station State Park, and PETAR (Fig. 2). These parks are core areas of the Mata Atlântica Biosphere Reserve (Fundação Florestal, 2010).

The PETAR region holds a prominent place among Brazil's speleological areas, with approximately 652 caves officially registered in the National Cave Register of Brazil (acronym in Portuguese CNC) (Sociedade Brasileira de Espeleologia, 2023). Legal protection and the regulated public use of geodiversity, particularly the speleological heritage and biodiversity within PETAR, are guaranteed by the Management Plan (Fundação Florestal, 2010) and the Speleological Management Plan (Fundação, F. & Brasil, 2010).

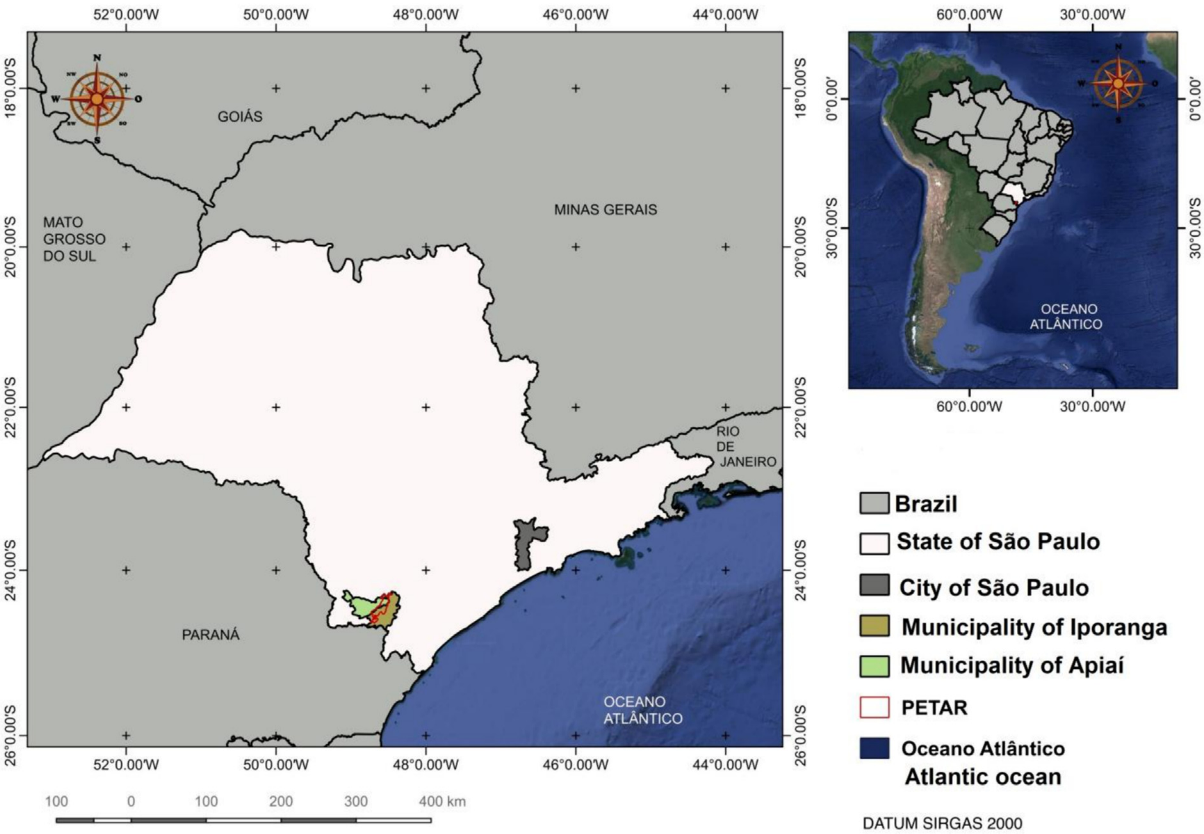

Fig. 1. Map showing PETAR's location in the State of São Paulo and in South America.

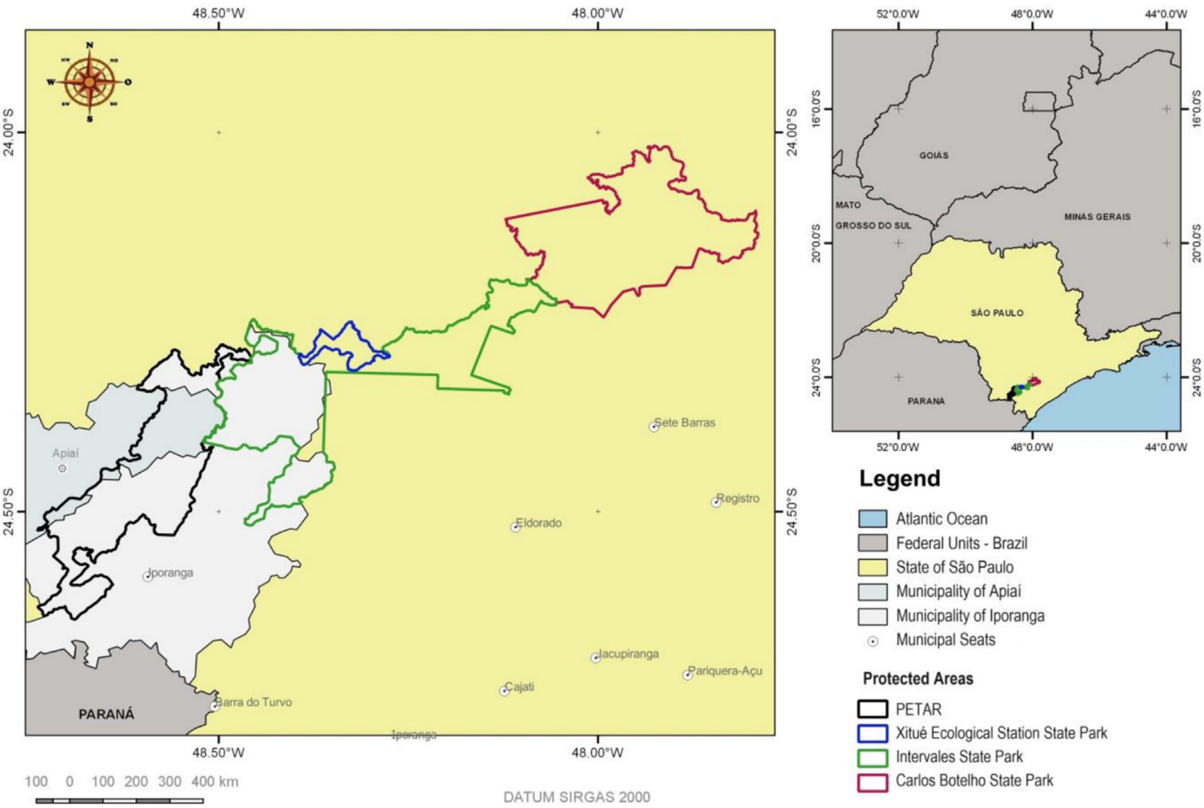

Fig. 2. Map of protected areas networks in the State of São Paulo: Paranapiacaba Ecological Continuum.

This cave heritage, along with other elements of geodiversity such as karst morphology, hydrological features, and rich biodiversity, is the primary attractions for tourists visiting the Alto Ribeira region (Santos, 2019). Numerous authors, such as Lobo (2008), Ferreira (2014), Ferreira et al. (2018) and Menin and Bacci (2022), highlight that in recent decades, ecotourism, especially cave tourism, has been the primary source of income for local communities in the municipalities of Apiaí and Iporanga.

Visitation activities at PETAR began in the late 1950s at the Caboclos nucleus, followed by the Santana Cave in the 1970s. Subsequently, during the 1980s, with the creation of Santana and Ouro Grosso nuclei and the development of some infrastructure, the Santana Cave began to receive regular visitors. The 1990s witnessed a significant surge in park visitation. However, between 2008 and 2009, PETAR had to suspend its activities due to the absence of both park and speleological management plans for the caves open to visitors (Lobo, 2011).

In 2021, the São Paulo State Government initiated a process to grant public use of the park's visitation areas to private enterprises. This initiative has faced criticism from local traditional communities and groups of scientists. Among the primary concerns raised are the lack of transparency in the proposals regarding the local economy and the preservation of the natural environment. Furthermore, there have been objections about the absence of meaningful discussions with local communities and the scientific community regarding the entire process.

2.1.2. Geological and geomorphological settings

The rocks that make up the State of São Paulo are part of the Mantiqueira Province (Almeida et al., 1977;Almeida et al., 1981, which records the geological history during the Neoproterozoic (900–520 Ma). These rocks are the remains of Archean, Paleoproterozoic and Mesoproterozoic tectonic units (Bizzi et al., 2003). The study area corresponds to the central sector of this province, known as Ribeira Orogen (Heilbron et al., 2004) or Ribeira Fold Belt (Hasui, Carneiro, & Coimbra, 1975). This Orogen is an ENE-trending transcurrent shear belt in southeastern South America associated with the Neoproterozoic and early Cambrian formation of Western Gondwana (Campanha et al., 2023; Faleiros et al., 2022).

PETAR is included in the Apiaí Terrane (or Domain) of the Ribeira Fold Belt. It is limited to the south by the Lacinha–Cubatão crustal-scale shear zone and covered by Phanerozoic rocks of the Paraná Basin to the north (Campanha et al., 2023; Faleiros et al., 2022; Faleiros et al., 2011). This terrain comprises low to medium-grade metasedimentary rocks, collectively known as the Açungui Supergroup (Campanha, 1991; Campanha & Sadowski, 1999). These rocks are underlain by gneissic–migmatitic rocks with varying intercalations of metasediments and charnockitic cores. Additionally, these rocks are intruded by several granitoid bodies of diverse characteristics (Campanha, 2002) (Fig. 3). In PETAR area there are metasedimentary rocks of low metamorphic grade, most of which deposited from Mesoproterozoic to early Neoproterozoic on a carbonate platform, constituting the Lajeado Group. This group was later metamorphized from upper Neoproterozoic to Cambrian (Campanha et al., 2023; Campanha, Faleiros, & Nutman, 2016; Santos et al., 2022). Part of PETAR area also encompasses fine metasediments of the Iporanga Formation (Campanha et al., 2008) and Votuverava Group (Campanha et al., 2015; Faleiros et al., 2011). These rocks alternate between siliciclastic (pelitic, psammitic) and carbonate formations, intruded in its upper part by the Apiaí Gabbro (Campanha, 2002; Campanha et al., 2016). Carbonate rocks display distinct compositions of CaO and MgO and variations in siliciclastic composition, giving rise to several regional karstic systems (Sallun & Sallun Filho, 2009), which collectively form the Speleological Province of Vale do Ribeira (Karmann & Sánchez, 1979). Mesozoic basic dikes with NW strikes, as the one that controls the Betari river valley, and restricted Cenozoic alluvial deposits, make up the region geological context (Campanha, 1991).

This Speleological Province encompasses the carbonate formations of the Lajeado Group (Campanha et al., 2016). These rocks create a polygonal karst landscape with karstic cones, canyons, deep fluvial valleys, underground drainage systems connected with cave systems, and a rich variety of speleothems (Karmann, 1994). This extensive cave systems preserves an important fossil record of Pleistocene-Holocene South America megafauna (Ghilardi, Fernandes, & Bichuette, 2011). In general, the fossil record is associated with Quaternary sediments, which accumulated in the vertical conduits or stagnate in stretches along the vertical passages (Karmann & Ferrari, 2002; Campanha, 2002; Ghilardi et al., 2011). According to Ghilardi et al. (2011), the fossils of Quaternary fauna in the Alto Ribeira karst region depict different moments related to climate changes during the Quaternary.

From a geomorphological point of view, the PETAR region falls within the Morphoclimatic Domain of Mountainous Regions, characterized by humid tropical regions and extensive forested terrain, often refereed as “sea of hills” (Ab'Saber, 1970; Ab’Saber, 1973). The park is located on the southwestern flank of the Paranapiacaba mountain, featuring mountainous relief with topographic variations of up to 700 m (Karmann & Ferrari, 2002; Campanha, 2002).

2.2. Methods

The inventory of geological sites in PETAR and neighbouring areas was done taking into account the main aspects related to the regional geological history. The inventory method was founded on the procedures outlined by Brilha (2016) and graphically presented in Fig. 4.

2.2.1. Identification of geological sites

The review of geoconservation actions developed in the study area aimed to pinpoint potential geological sites previously described by the geoscientific community. As a result, 45 potential sites were initially identified, comprising 30 sites from the report *Alto Vale do Ribeira Geopark: Proposal,* which was completed by the Geological Survey of Brazil (acronym in Portuguese SBG-CPRM) (Theodorovicz, 2014), 9 sites from the “Inventory of the Geological Heritage of the State of São Paulo” (Garcia et al., 2018), and 6 sites from various bibliographic sources, such as master's dissertations and doctoral theses, as well as consultations

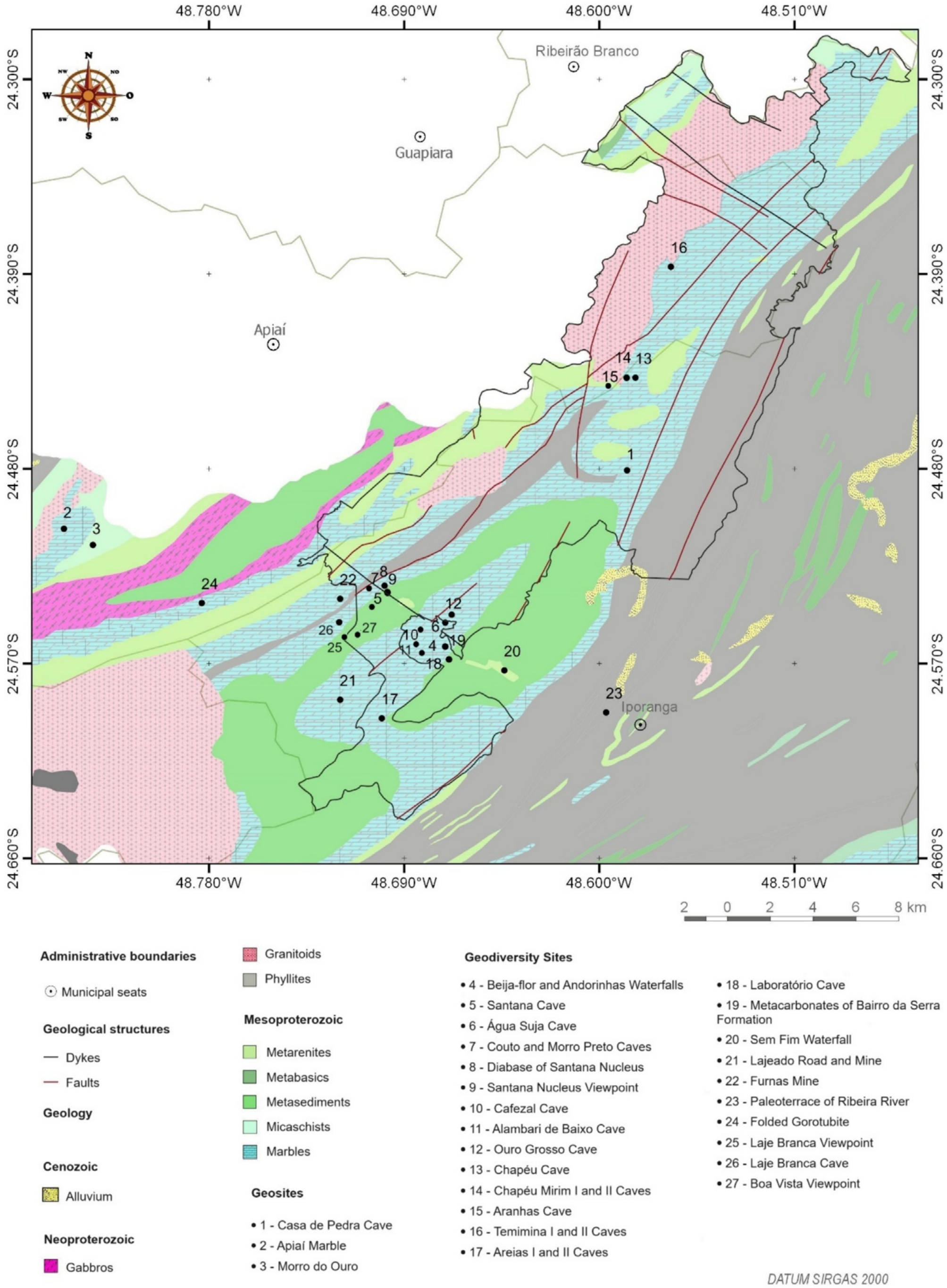

Fig. 3. Geological map of PETAR (scale 1: 125,000) with the location of geological sites (adapted from CBH-SP, 2013, based on Campanha, 2002).

with experts. Subsequent fieldwork led to the exclusion of 18 of these sites for various reasons, including inaccessibility, restricted visitation, or their distance from the research area. Consequently, the inventory of geological sites at PETAR now encompasses 27 geological sites, as described and thoroughly characterized by Santos (2019) (Figs. 3, 5 and 6).

2.2.2. Quantitative assessment of geological sites using the GEOSSIT database

The quantitative assessment of geological sites was done using the System of Registration and Quantification of Geosites and Geodiversity Sites (GEOSSIT) database, an online software designed for inventorying and both qualitative and quantitative

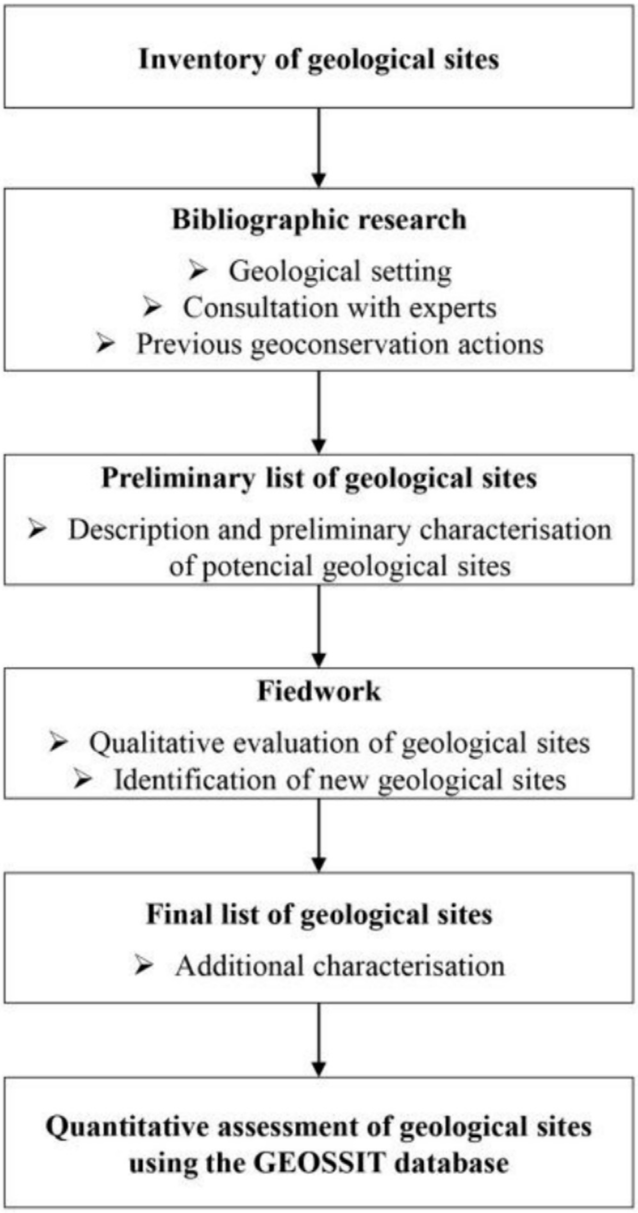

Fig. 4. Stages for the development of the inventory of geological sites in PETAR and neighbouring areas (adapted from Brilha, 2016).

assessment of geological sites across Brazil. This software was developed by SBG-CPRM, based on the methodology of Brilha (2016) and García-Cortés et al. (2009), with adaptations of some criteria tailored to the Brazilian setting (Fig. 5).

The criteria selected for the quantitative evaluation of geological sites were grouped into three categories: A. scientific value (SV), B. degradation risk (DR), C. potential educational use (PEU) and potential touristic use (PTU). The SV calculation incorporates the following criteria and respective weights: A1–representativeness (30%), A2–type locality (20%), A3–scientific knowledge (5%), A4–integrity (15%), A5–geological diversity (5%), A6–rarity (15%) and A7–use limitations (10%). The criteria for the calculation of DR were described as follows: B1–deterioration of geological elements (35%), B2–proximity to areas/activities with potential to cause degradation (20%), B3–statutory protection (20%), B4–accessibility (15%) and B5–population density (10%). The results obtained for DR classify geological sites into three levels: low ($DR \leq 200$), medium ($200 < DR \leq 300$), and high ($300 < DR \leq 400$). The PEU and PTU of the geological sites were evaluated using criteria C1 to C15 (Table 1).

According to Brilha (2016), geosites are "in situ occurrences of geodiversity elements with high scientific value (national or international)." In addition to the scientific value, they may possess educational, aesthetic, and cultural values. Geodiversity

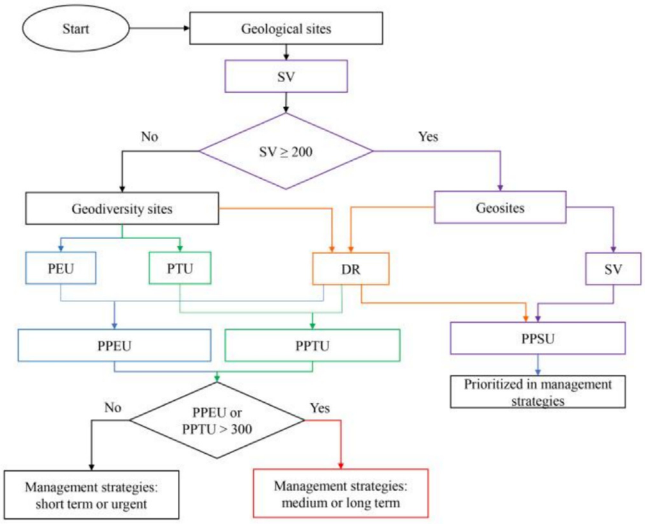

Fig. 5. Quantitative assessment process using the System of Registration and Quantification of Geosites and Geodiversity Sites (GEOSSIT) software.
Note: SV: scientific value; PEU: potential educational use; PTU: potential touristic use; DR: degradation risk; PPEU: priority protection of potential educational use; PPTU: priority protection of potential touristic use; PPSU: priority protection of scientific use.

sites, on the other hand, are occurrences of geodiversity elements that, while not exceptionally scientifically valuable, hold importance for touristic, educational purposes, or cultural identity. These geodiversity sites can have significance at the local, national, or international level.

Based on the concepts of Brilha (2016) and in line with the GEOSSIT algorithm, a geosite was considered to have national relevance when its scientific value falls within the range between 200 and 299. When the scientific value reaches or exceeds 300, it was regarded as having international relevance. Similarly, a geodiversity site was considered of national relevance when its potential for tourism and educational uses equals or exceeds than 200. For values below 200, geodiversity sites were considered to have regional or local relevance.

According to García-Cortés et al. (2009), the protection priority (PP) of a geological site is an indicator used to prioritize conservation actions. In the GEOSSIT algorithm, PP was calculated for each type of value. Hence, PP for scientific use equals SV plus RD; PP for the educational use equals the educational value (EV) plus RD; and PP for touristic use equals the touristic value (TV) plus RD. The PP for each geological site can be categorized into four levels: long-term ($PP \leq 400$); medium-term ($400 < PP \leq 700$); short-term ($700 < PP \leq 900$); and urgent ($900 < PP \leq 1000$). These levels assist in assessing the urgency and priority for protection and conservation efforts.

3. Results

The scores assigned to each criterion used for the SV, DR, PEU and PTU assessments are provided in tables available as appendices (Tables A1 and A2 in Appendix).

For SV assessment, the results range from 65 to 280 out of a maximum of 400 points (Table A1 in Appendix). DR scores vary between 30 and 300 points (Table A2 in Appendix).

Tables A4 and A5 detail the values assigned to the criteria used to calculate PEU and PTU, respectively. The PEU assessment took into account criteria C1 to C12 (Table A3 in Appendix), and the resulting values were expressed by the educational value (EV). Regarding PTU, criteria C11 and C12 were excluded from the calculation of touristic value (TV). The significance of EV and TV can be considered at local, regional or national levels (Figs. 7 and 8). Finally, the categorization of all inventoried geological sites is presented in Table 2.

Tables 3, 4, and 5 display the PP scores calculated for each type of use (scientific, educational, and touristic). In the context of geodiversity sites, it is worth noting that, except for two sites (Metacarbonates of Bairro da Serra Formation and Furnas Mine), the priority for protection in relation to educational use consistently surpassed that of touristic use.

The final ranking for the Protection Priority of all 27 geological sites was determined using the following criteria (Table 6):

i. The first three positions were assigned to the three geosites based on their scientific value. This prioritization is in accordance with the principles detailed Brilha (2016), and it signifies the need to prioritize their management.
ii. For the geodiversity sites, the highest PP value was considered, whether it was obtained for educational or touristic uses.

Fig. 6. Some aspects of geological sites at PETAR.
a. Entrance portico of Morro Preto Cave viewed from the inside. b. Exit portico of Couto Cave, next to Couto River sinkhole. c. Apiaí Marble, main outcrop near Apiaí railroad. d. Morro do Ouro, ruins of the gold processing industry. E. Beija-flor and andorinhas waterfalls, general view of Beija-flor waterfall. f. Metacarbonates of Bairro da Serra Formation, general view of the outcrop and detail of the carbonate rock. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4. Discussion

The analysis of the SV assessment revealed that three geological sites, namely Casa de Pedra Cave, Morro do Ouro, and Apiaí Marble, achieved the highest SV scores, all reaching the maximum score of 4 in criteria A1 (representativeness) and A6 (rarity). Since their SV exceeds 200, these sites were the only ones in the inventory considered as geosites of national significance, as indicated in Table 2. Additionally, among the 27 geological sites, 21 sites obtained PTU and PEU scores higher than 200, thereby designating them as geodiversity sites of national significance. The three sites with scores below 200 points were categorized as geodiversity sites of regional/local significance (Table 2).

In the context of the SV assessment, one can conclude that the representativeness criterion had the most significant impact on the final score. Concerning the rarity criterion, it is important to note that when more than 6 identical occurrences of a particular feature exist in the study area, this criterion received a score of zero, signifying that the feature is not considered rare. However, this approach may undervalue some sites that are anticipated to have high PP. For example, Santana Cave is characterized by a

Table 1
Criteria and their weights assigned for the quantitative assessment of PEU and PTU in the GEOSSIT database.

Potential Educational and Touristic Uses			
Criteria		Weight	
		PEU	PTU
C1	Vulnerability	10%	10%
C2	Accessibility	10%	10%
C3	Use limitations	5%	5%
C4	Safety	10%	10%
C5	Logistics	5%	5%
C6	Population density	5%	5%
C7	Association with other values	5%	5%
C8	Scientific knowledge	5%	15%
C9	Uniqueness	5%	10%
C10	Observation conditions	10%	5%
C11	Didactic potential	20%	–
C12	Geological diversity	10%	–
C13	Potential for dissemination	–	10%
C14	Economic status	–	5%
C15	Proximity to recreational areas	–	5%
Total		100%	100%

high diversity of speleothems, making it a notable example of these geological elements. Consequently, it received a high score in representativeness criterion. Nonetheless, because there are many other caves in the study area with similar speleothems, these elements are not deemed rare, and as a result, the rarity criterion was evaluated with zero points. This leads to Santana Cave not receiving a high PP, which contradicts its status as one of the most visited sites at PETAR, necessitating a high management priority.

It is also worth to underline that the criteria of population density and economic level do not significantly impact the assessment of sites within small areas, such as PETAR. In this case, the indicators for both criteria are uniform across the entire area, which do not differentiate between geological sites.

The analysis of the quantitative assessment results for the geological sites revealed that the same site can received different evaluations in different inventories. For instance, the geodiversity sites Couto and Morro Preto Caves, Santana Cave, Água Suja Cave and Areias I and II Caves were considered geosites in previous inventories (Theodorovicz, 2014; Garcia et al., 2018). However, the assessment made by GEOSSIT has assigned a lower SV to these sites in this instance. These differences in evaluation can be attributed to specific aims and scale of the study area, in addition to differences in how each researcher defines a geosite. Once again, these disparities underscore the difficulty of comparing numerical values of geological sites calculated using different methods.

Concerning the DR results (as indicated in Table A2 in Appendix), they generally align with what was expected based on the data collected during fieldwork. The Apiaí Marble geosite holds the top position in the ranking, followed by the geodiversity sites Paleoterrace of Ribeira River, Metacarbonates of Bairro da Serra Formation and Folded Gorotubito. These four geological sites were categorized as having medium DR because they are located in areas without legal protection and access control. Most geological sites were scored zero on the proximity to areas/activities with the potential to cause degradation criterion since they are located within the park, where activities are strictly regulated.

Regarding the calculation of PEU and PTU, the assessment of EV and TV was exclusively conducted for the geodiversity sites, as indicated in Tables A3 and A4 in Appendix. According to Brilha (2016), geosites should always be prioritized in a geoconservation strategy due to the scientific value they represent. Therefore, EV and TV were not used for the three geosites in the inventory (Casa de Pedra Cave, Morro do Ouro, and Apiaí Marble). The determination of national or regional/local relevance based on VE and VT, as per the GEOSSIT, will not be discussed in detail for the purposes of this work since it does not directly align with the article's objectives.

The scientific PP was calculated solely for the three geosites (Table 3) since geodiversity sites, by definition, possess low or no scientific value. All three geosites exhibited a medium-term protection priority. For the geodiversity sites, the educational and touristic PP were calculated (Tables 4 and 5). The top four positions in the ranking are held by Paleoterrace of Rio Ribeira, Diabásio do Núcleo Santana, Santana Cave and Metacarbonates of Bairro da Serra Formation (Lajeado Group), all categorized with medium-term PP.

The sorting of geological sites in PETAR and its surroundings (Table 6) was categorized into two groups: geosites and geodiversity sites. The top three positions of the final ranking are hold by the geosites of Apiaí Marble, Casa de Pedra Cave, and Morro do Ouro, which were ranked based on their scientific PP. Subsequently, the geodiversity sites were ranked using the results of the educational PP and touristic PP. To determine their ranking, the highest value between these two categories, as presented in Tables 4 and 5, was taken into consideration. This approach ensures that geodiversity sites were ranked based on their greater educational or touristic significance.

Fig. 7. Some aspects of geodiversity sites of national significance at PETAR.
a. Structure of the Santana Nucleus viewpoint. b. View from the Santana lookout point, where you can see features of the karst relief (cone morphology). c. Portico at the main entrance of Água Suja Cave. d. Set of speleothems (stalactites, stalagmites and columns) of Água Suja Cave. e. Interior view of the main hall of Chapéu Cave. f. Travertine lakes inside the main hall of Chapéu Cave.

5. Conclusion

The Alto Ribeira Touristic State Park (PETAR) is renowned nationally for its speleological heritage, with approximately 652 caves that attract both experts and general public. This makes PETAR one of the most visited protected areas in São Paulo State. The effective management of this geoheritage is of utmost importance, given the significant number of caves that require oversight and the park's limited resources. The inventory and quantitative assessment of the 27 geological sites identified in PETAR and its surroundings have provided valuable insights into establishing management priorities. This information is essential for park managers, aiding them in effectively managing this extensive geological heritage. The quantitative assessment was done using GEOSSIT, an online application developed by the Geological Survey of Brazil (Serviço Geológico do Brasil, 2022. While GEOSSIT was created as a nationwide geoheritage database, it has revealed certain challenges when applied to a relatively small area like PETAR. This highlights the need for specific adaptations in GEOSSIT to make it a more efficient and relevant tool for geoconservation at both the national and local scales in Brazil. This will enhance the effectiveness of managing and preserving the geological and speleological treasures found in PETAR and similar areas.

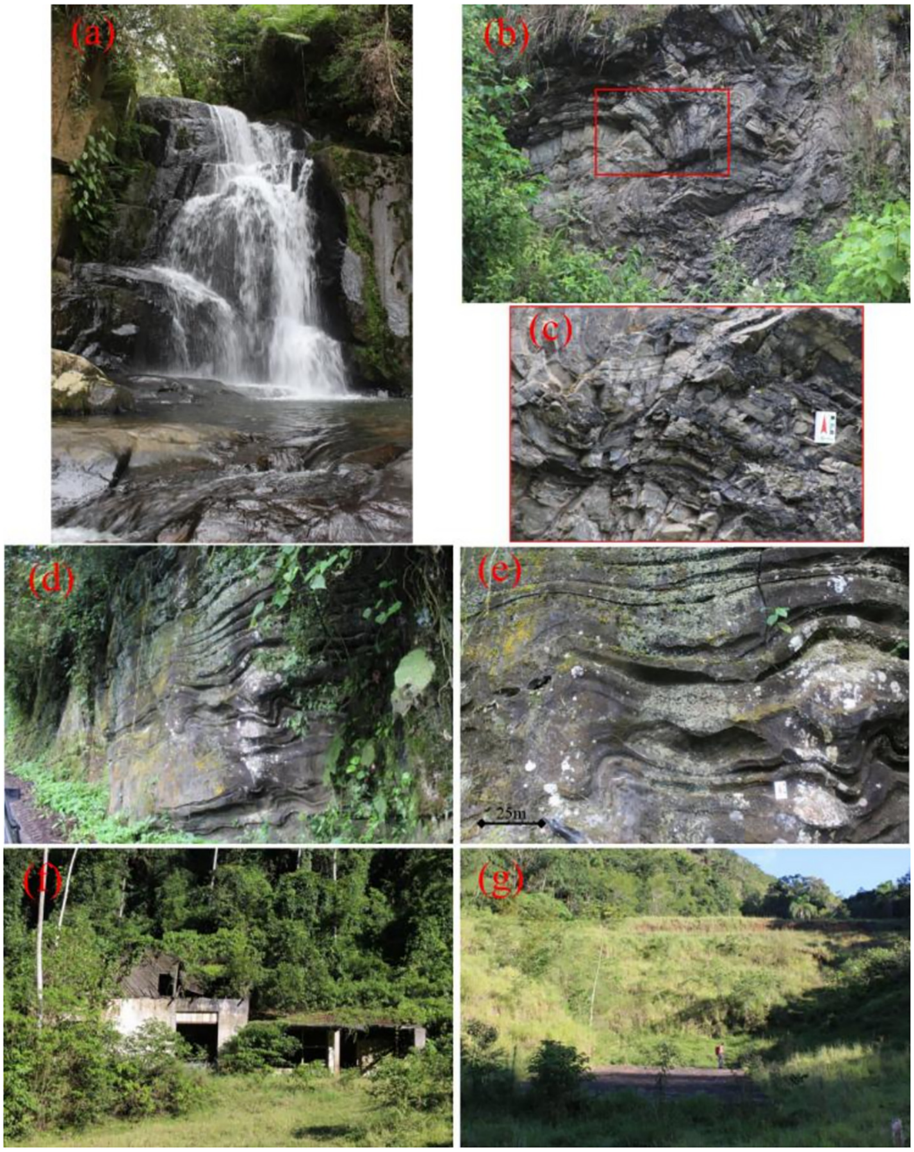

Fig. 8. Some aspects of geodiversity sites with national, local and regional significance at PETAR.
a. Sem Fim Waterfall. b General view of the outcrop Folded Gorotubite. c. Detail of the outcrop at Folded Gorotubite. d. Lajeado road and mine. e. Calcite marble from the Mina de Furnas Formation on the Lajeado road.f. Ruins of the old mine at Furnas Mine. g. Furnas mine yard.

Funding

This work was funded by Sciences Without Borders Program (Process No: 233271/2014-7) of Brazilian National Council for Scientific and Technological Development (CNPq, Portuguese: Ciências sem Fronteiras / Conselho Nacional de Desenvolvimento Científico e Tecnológico), and co-funded by projects UIDB/04683/2020 and UIDP/04683/2020 of Foundation for Science and Technology (FCT, Portuguese: Fundação para a Ciência e a Tecnologia).

Ethical statement

Not applicable, because this article does not contain any studies with human or animal subjects.

Table 2
Categorization of geological sites according to the results obtained with GEOSSIT.

Geological sites	Categorization
Casa de Pedra Cave Apiaí Marble Morro do Ouro	Geosite of national significance
Diabase of Santana Nucleus Santana Nucleus Viewpoint Beija-flor and Andorinhas Waterfalls Santana Cave Água Suja Cave Couto and Morro Preto Caves Cafezal Cave Laje Branca Viewpoint Laje Branca Cave Alambari de Baixo Cave Ouro Grosso Cave Chapéu Cave Chapéu Mirim I and II Caves Aranhas Cave Areias I and II Caves Lajeado Road and Mine Sem Fim Waterfall Laboratório Cave Paleoterrace of Ribeira River Boa Vista Viewpoint Folded Gorotubite	Geodiversity sites of national significance
Temimina I and II Caves Metacarbonates of Bairro da Serra Formation Furnas Mine	Geodiversity sites of local/regional significance

Table 3
Priority protection considering the scientific use.

Geosites	SV	DR	SV + DR	PP for scientific use	Ranking
Apiaí Marble	250	300	550	Medium-term	1st
Casa de Pedra Cave	280	100	380		2nd
Morro do Ouro	275	75	350		3rd

Table 4
Priority protection considering an educational use.

Geodiversity sites	EV	DR	EV + DR	PP for educational use	Ranking
Paleoterrace of Ribeira River	245	295	540	Medium-term	1st
Diabase of Santana Nucleus	270	195	465		2nd
Santana Cave	280	150	430		3rd
Metacarbonates of Bairro da Serra Formation	180	245	425		4th
Laboratório Cave	250	175	425		
Folded Gorotubite	200	205	405		5th
Alambari de Baixo Cave	285	115	400		6th
Santana Nucleus Viewpoint	305	90	395		7th
Cafezal Cave	205	175	380		8th
Areias I and II Caves	260	120	380		
Lajeado Road and Mine	225	150	375		9th
Couto and Morro Preto Caves	285	80	365		10th
Laje Branca Cave	250	100	350		11th
Água Suja Cave	275	65	340		12th
Boa Vista Viewpoint	270	65	335		13th
Sem Fim Waterfall	245	85	330		14th
Furnas Mine	160	170	330		
Ouro Grosso Cave	270	45	315		15th
Chapéu Cave	265	45	310		16th
Chapéu Mirim I and II Caves	265	45	310		
Aranhas Cave	265	45	310		
Beija-flor and Andorinhas Waterfalls	275	30	305		17th
Laje Branca Viewpoint	220	80	300	Long-term	18th
Temimina I and II Caves	195	100	295		19th

Table 5
Priority protection considering a touristic use.

Geodiversity sites	TV	DR	TV + DR	PP for touristic use	Ranking
Paleoterrace of Ribeira River	215	295	510	Medium-term	1st
Diabase of Santana Nucleus	255	195	450		2nd
Metacarbonates of Bairro da Serra Formation	190	245	435		3rd
Santana Cave	250	150	400		4th
Cafezal Cave	205	175	380		5th
Laboratório Cave	195	175	370		6th
Folded Gorotubite	165	205	370		
Santana Nucleus Viewpoint	270	90	360		7th
Alambari de Baixo Cave	240	115	355		8th
Areias I and II Caves	225	120	345		9th
Furnas Mine	170	170	340		10th
Couto and Morro Preto Caves	235	80	315		11th
Lajeado Road and Mine	165	150	315		
Sem Fim Waterfall	215	85	300	Long-term	12th
Laje Branca Viewpoint	215	80	295		13th
Boa Vista Viewpoint	230	65	295		
Água Suja Cave	225	65	290		14th
Laje Branca Cave	185	100	285		15th
Temimina I and II Caves	185	100	285		
Beija-flor and Andorinhas Waterfalls	245	30	275		16th
Ouro Grosso Cave	230	45	275		
Chapéu Cave	225	45	270		17th
Chapéu Mirim I and II Caves	225	45	270		
Aranhas Cave	225	45	270		

Table 6
Final ranking regarding the protection priority of all PETAR's geological sites.

Geological sites	Protection priority	Ranking
Apiaí Marble	550	1st
Casa de Pedra Cave	380	2nd
Morro do Ouro	350	3rd
Paleoterrace of Ribeira River	540	4th
Diabase of Santana Nucleus	465	5th
Metacarbonates of Bairro da Serra Formation	435	6th
Santana Cave	430	7th
Laboratório Cave	425	8th
Folded Gorotubite	405	9th
Alambari de Baixo Cave	400	10th
Santana Nucleus Viewpoint	395	11th
Cafezal Cave	380	12th
Areias I and II Caves	380	
Lajeado Road and Mine	375	13th
Couto and Morro Preto Caves	365	14th
Laje Branca Cave	350	15th
Água Suja Cave	340	16th
Furnas Mine	340	
Boa Vista Viewpoint	335	17th
Sem Fim Waterfall	330	18th
Ouro Grosso Cave	315	19th
Chapéu Cave	310	20th
Chapéu Mirim I and II Caves	310	
Aranhas Cave	310	
Beija-flor and Andorinhas Waterfalls	305	21st
Laje Branca Viewpoint	300	22nd
Temimina I and II Caves	295	23rd

CRediT authorship contribution statement

Priscila L.A. Santos: Writing – review & editing, Writing – original draft, Data Curation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **José Brilha:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors thank the Alto Ribeira Touristic State Park and Forestry Foundation of the State of São Paulo for assistance and support during fieldwork.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijgeop.2024.07.003.

References

Ab'Saber, A. N. (1970). Províncias geológicas e domínios morfoclimáticos no Brasil [Geological Provinces and Morphoclimatic Domains in Brazil]. *Geomorfologia*, *20*, 1–26.
Ab'Saber, A. N. (1973). Participação das Depressões Periféricas e Superfícies Aplainadas na Compartimentação do Planalto Brasileiro [Participation of peripheral depressions and flattened surfaces in the compartmentalisation of the Brazilian plateau]. *Geomorfologia*, *28*, 1–38.
Almeida, F. F., Hasui, Y., de Brito, N. B., & Fuck, R. A. (1977). Províncias estruturais brasileiras [Brazilian structural provinces]. *Simpósio de Geologia do Nordeste*, *8*, 363–391.
Almeida, F. F. M., Hasui, Y., de Brito Neves, B. B., & Fuck, R. A. (1981). Brazilian structural provinces: An introduction. *Earth-Science Reviews*, *17*, 1–29.
Bizzi, L. A., Schobbenhaus, C., Vidotti, R. M., & Gonçalves, J. M. (2003). *Geologia, Tectônica e Recursos Minerais do Brasil: Texto, mapas e SIG [Geology, tectonics, and mineral resources of Brazil: Text, maps].* Brasilia: Serviço Geológico do Brasi–CPRM.
Bollati, I., Smiraglia, C., & Pelfini, M. (2013). Assessment and selection of geomorphosites and trails in the Miage Glacier area (Western Italian Alps). *Environmental Management*, *51*(4), 951–967. https://doi.org/10.1007/s00267-012-9995-2.
Brilha, J. (2005). *Património geológico e geoconservação: a conservação da natureza na sua vertente geológica [Geological heritage and geoconservation: The conservation of nature from a geological perspective].* Braga: Palimage.
Brilha, J. (2016). Inventory and quantitative assessment of geosites and geodiversity sites: A review. *Geoheritage*, *8*(2), 119–134. https://doi.org/10.1007/s12371-014-0139-3.
Bruschi, V. M., & Cendrero, A. (2009). Direct and parametric methods for the assessment of geosites and geomorphosites. In E. Reynard, P. Coratza, & G. Regolini-Bissig (Eds.), *Geomorphosites* (pp. 73–88). München: Verlag Dr. Friedrich Pfeil.
Bruschi, V. M., Cendrero, A., & Albertos, J. A. C. (2011). A statistical approach to the validation and optimisation of geoheritage assessment procedures. *Geoheritage*, *3*(3), 131–149. https://doi.org/10.1007/s12371-011-0038-9.
Campanha, G. A. C. (1991). *Tectônica proterozóica no alto e médio Vale do Ribeira, estados de São Paulo e Paraná [Proterozoic tectonics in the upper and middle Ribeira Valley, states of São Paulo and Paraná]. (Doctoral dissertation).* Universidade de São Paulo, São Paulo, Brazil. https://doi.org/10.11606/T.44.1992.tde-13032013-115922.
Campanha, G. A. C., Basei, M. S., Tassinari, C. C. G., Nutman, A. P., & Faleiros, F. M. (2008). Constraining the age of the Iporanga Formation with SHRIMP U-Pb zircon: Implications for possible Ediacaran glaciation in the Ribeira Belt, SE Brazil. *Gondwana Research*, *13*(1), 117–125. https://doi.org/10.1016/j.gr.2007.05.010.
Campanha, G. A. C., Faleiros, F. M., Basei, M. A. S., Tassinari, C. C. G., Nutman, A. P., & Vasconcelos, P. M. (2015). Geochemistry and age of mafic rocks from the Votuverava Group, southern Ribeira Belt, Brazil: Evidence for 1490Ma oceanic back-arc magmatism. *Precambrian Research*, *266*, 530–550. https://doi.org/10.1016/j.precamres.2015.05.026.
Campanha, G. A. C., Faleiros, F. M., Cabrita, D. I. G., Ribeiro, B. V., & Cawood, P. A. (2023). The southern Ribeira Belt in Western Gondwana: A record of a long-lived continental margin and terrane collage. *Journal of South American Earth Sciences*, *127*, Article 104404. https://doi.org/10.1016/j.jsames.2023.104404.
Campanha, G. A. C. (2002). *O papel do sistema de zonas de cisalhamento transcorrentes na configuração da porção meridional da Faixa Ribeira [The role of strike-slip shear zone system in the configuration of the southern portion of the Ribeira Belt] (Teaching thesis).* Universidade de São Paulo, São Paulo, Brazil. https://doi.org/10.11606/T.44.2009.tde-16122009-094247.
Campanha, G. A. C., Basei, M. S., Faleiros, F. M., & Nutman, A. P. (2016). The mesoproterozoic to early neoproterozoic passive margin Lajeado Group and Apiaí Gabbro, Southeastern Brazil. *Geoscience Frontiers*, *7*(4), 683–694. https://doi.org/10.1016/j.gsf.2015.08.004.
Campanha, G. A. C., & Sadowski, G. R. (1999). Tectonics of the southern portion of the Ribeira Belt (Apiaí domain). *Precambrian Research*, *98*(1–2), 31–51. https://doi.org/10.1016/S0301-9268(99)00027-3.
Cendrero, A. (1996a). El patrimonio geológico. Ideas para su protección, conservación y utilización [Geological heritage: Bases for its assessment, protection, conservation and use]. In Ministry of Public Works, Transport and Environment of Spain (Ed.), *El patrimonio geológico. Bases para su valoración, protección, conservación y utilización [Geological heritage: Ideas for its protection, conservation and use. In: Geological heritage. Bases for its assessment, protection, conservation and use] (pp. 17–27).* Madrid: Ministry of Public Works, Transport and Environment of Spain.
Cendrero, A. (1996b). Propuestas sobre criterios para la clasificación y catalogación del patrimonio geológico [Geological heritage: Bases for its assessment, protection, conservation and use]. In Ministry of Public Works, Transport and Environment of Spain (Ed.), *El patrimonio geológico. Bases para su valoración, protección, conservación y utilización [Geological heritage. Bases for its assessment, protection, conservation and use] (pp. 29–38).* Madrid: Ministry of Public Works, Transport and Environment of Spain.
Coratza, P., & Giusti, C. (2005). Methodological proposal for the assessment of the scientific quality of geomorphosites. *Alpine and Mediterranean Quaternary*, *18*(1), 305–311.
Crofts, R., Gordon, J. E., Brilha, J., Gray, M., Gunn, J., Larwood, J., ... Worboys, G. L. (2020). *Guidelines for geoconservation in protected and conserved areas (English Verision). Best Practice Protected Area Guidelines Series No. 31.* Gland: IUCN. https://doi.org/10.2305/IUCN.CH.2020.PAG.31.en.
Crofts, R., Gordon, J. E., Brilha, J., Gray, M., Gunn, J., Larwood, J., ... Worboys, G. L. (2022). *Diretrizes Para a geoconservação em áreas protegidas [Guidelines for geopreservation in protected and conserved areas] (Portuguese Version). Best Practice Protected Area Guidelines Series No. 31.* Gland: IUCN. https://doi.org/10.2305/IUCN.CH.2020.PAG.31.pt.
Dollma, M. (2019). Geotourism potential of Thethi National Park (Albania). *International Journal of Geoheritage and Parks*, *7*(2), 85–90. https://doi.org/10.1016/j.ijgeop.2019.05.002.
Faleiros, F. M., Ferrari, V. C., Costa, V. S., & da Cruz Campanha, G. A. (2011). Geoquímica e petrogênese de metabasitos do grupo Votuverava (Terreno Apiaí, Cinturão Ribeira Meridional): evidências de uma bacia retroarco calimiana [Geochemistry and petrogenesis of metabasites from the votuverava group (Apiaí Terrane, Southern Ribeira Belt): Evidence of a calymmian back-arc basin]. *Geologia USP-Série Científica*, *11*(2), 135–155. https://doi.org/10.5327/Z1519-874X2011000200008.

Faleiros, F. M., Ribeiro, B. V., Campanha, G. A. D. C., Cawood, P. A., Cabrita DI, G., Yogi, M. A. G., ... Forero-Ortega, A. J. (2022). Strain partitioning along terrane bounding and intraterrane shear zones: Constraints from a long-lived transpressional system in West Gondwana (Ribeira Belt, Brazil). *Lithosphere*, *6*(Special Issue), 2103213. https://doi.org/10.2113/2022/2103213.

Fassoulas, C., Mouriki, D., Dimitriou-Nikolakis, P., & Iliopoulos, G. (2012). Quantitative assessment of geotopes as an effective tool for geoheritage management. *Geoheritage*, *4*(3), 177–193. https://doi.org/10.1007/s12371-011-0046-9.

Ferreira, A. R. R. (2014). *Patrimônio geológico no Parque Estadual Turístico do Alto Ribeira-SP: inventariação e quantificação de geossítios [Geological heritage in the Parque Estadual Turístico do Alto Ribeira-SP: Inventory and quantification of geosites] (Unpublished mater's thesis)*. Universidade Estadual Paulista, São Paulo, Brazil.

Ferreira, A. R. R., Lobo, H. A. S., & de Perinotto, J. A. J. (2018). Inventory and quantification of geosites in the State Tourist Park of Alto Ribeira (PETAR, São Paulo State, Brazil). *Geoheritage*, *11*(3), 783–792. https://doi.org/10.1007/s12371-018-0331-y.

Fundação, F., & Brasil, E. (2010). *Plano de manejo espeleológico do Parque Estadual Turístico do Alto Ribeira [Speleological management plan of the Alto Ribeira Touristic State Park]*. São Paulo: Fundação Florestal.

Fundação Florestal (2010). *Plano de manejo do Parque Estadual Turístico do Alto Ribeira [Management plan of the Parque Estadual Turístico do Alto Ribeira]*. São Paulo: Author.

Garcia, M. G. M., Brilha, J., de Lima, F. F., Vargas, J. C., Pérez-Aguilar, A., Alves, A., ... Shimada, H. (2018). The inventory of geological heritage of the State of São Paulo, Brazil: Methodological basis, results and perspectives. *Geoheritage*, *10*, 239–258. https://doi.org/10.1007/s12371-016-0215-y.

García-Cortés, A., Carcavilla, L., Díaz-Martínez, E., & Vegas, J. (2009). *Documento metodológico para la elaboración del inventario español de lugares de interés geológico (IELIG) [Methodological document for the development of the Spanish inventory of geological sites of interest (IELIG)]*. Madrid: Geological and Mining Institute of Spain.

Ghilardi, A. M., Fernandes, M. A., & Bichuette, M. E. (2011). Megafauna from the late Pleistocene-Holocene deposits of the upper Ribeira karst area, Southeast Brazil. *Quaternary International*, *245*(2), 369–378. https://doi.org/10.1016/j.quaint.2011.04.018.

Gordon, J. E., Crofts, R., Díaz-Martínez, E., & Woo, K. S. (2017). Enhancing the role of geoconservation in protected area management and nature conservation. *Geoheritage*, *10*(2), 191–203. https://doi.org/10.1007/s12371-017-0240-5.

Hasui, Y., Carneiro, C. D. R., & Coimbra, A. M. (1975). The Ribeira folded belt. *Revista Brasileira de Geociencias*, *5*, 257–266.

Heilbron, M., Pedrosa-Soares, A. C., da Campos Neto, M. C., Silva, L. C., Trouw, R. A. T., & Janasi, V. A. (2004). Província mantiqueira [Mantiqueira Province]. In V. M. Neto, A. Bartorelli, C. D. R. Carneiro, & B. B. B. Neves (Eds.), *Geologia do continente sul-americano: evolução da Obra de Fernando Flávio marques de Almeida. [Geology of the south American continent: Evolution of the work of Fernando Flávio marques de Almeida]*. São Paulo: Beca Produções Culturais Limitada.

Karmann, I. (1994). *Evolução e dinâmica atual do sistema cárstico do alto Vale do rio Ribeira de Iguape, sudeste do estado de São Paulo [Evolution and current dynamics of the karst system in the upper Ribeira de Iguape River valley, southeastern São Paulo State] (Doctoral dissertation)*. Universidade de São Paulo, Brazil.

Karmann I, Ferrari J. A. (2002) Carste e cavernas do Parque Estadual Turístico do Alto Ribeira (PETAR), SP [Karst and caves of the Alto Ribeira Tourist State Park (PETAR), São Paulo]. Retrieved from https://www.researchgate.net/publication/237685818_Carste_e_cavernas_do_Parque_Estadual_Turistico_do_Alto_Ribeira_PETAR_SP.

Karmann, I., & Sánchez, L. E. (1979). Distribuição das rochas carbonáticas e províncias espeleológicas do Brasil [Distribution of carbonate rocks and speleological provinces in Brazil]. *ESPELEO-TEMA*, *13*, 105–167.

Knapik, R., Jała, Z., Sobczyk, A., Migoń, P., Alek-sandrowski, P., Szuszkiewicz, A., ... Krakowski, K. (2009). Inwentaryzac-ja i waloryzacja geostanowisk Karkonoskiego Parku Narodowego i jego otuliny oraz wyko-nanie mapy geologicznej tego obszaru [Inventory and valorization of geosites in the Karkonosze National Park and its buffer zone, and the creation of a geological map of this area]. *Jelenia Góra*, 5–8. https://doi.org/10.13140/RG.2.2.16097.51043.

Kubalíková, L., & Kirchner, K. (2016). Geosite and geomorphosite assessment as a tool for geoconservation and geotourism purposes: A case study from Vizovická Vrchovina Highland (eastern part of the Czech Republic). *Geoheritage*, *8*(1), 5–14. https://doi.org/10.1007/s12371-015-0143-2.

Lobo, H. A. S. (2008). Ecoturismo e percepção de impactos socioambientais sob a ótica dos turistas no Parque Estadual Turístico do alto Ribeira–PETAR [Ecotourism and perception of socio-environmental impacts from the tourists' perspective in the tourist State Park of alto Ribeira–PETAR]. *Pesquisas em Turismo e Paisagens Cársticas*, *1*(1), 67–75.

Lobo, H. A. S. (2011). *Estudo da dinâmica atmosférica subterrânea na determinação da capacidade de carga turística na caverna de Santana (PETAR, Iporanga, SP) [Study of underground atmospheric dynamics in determining the tourist carrying capacity in Santana Cave (PETAR, Iporanga, SP)] (Doctoral dissertation)*. Universidade Estadual Paulista, São Paulo, Brazil.

Maksoud, A., Kholoud, M., Baghdadi, M. I., & Ruban, D. A. (2021). Caves as geoheritage resource in remote desert areas: A preliminary evaluation of Djara Cave in the Western Desert of Egypt. *Geologos*, *27*(2), 105–113. https://doi.org/10.2478/logos-2021-0011.

Medina, W. M. (2012). *Propuesta metodológica Para el inventario del patrimonio geológico de Argentina [Methodological proposal for the inventory of Argentina's geological heritage] (unpublished master's dissertation)*. Universidade do Minho, Braga, Portugal.

Menin, D. S., & Bacci, D. L. C. (2022). Avaliação de inventários e mecanismos de qualificação de cavernas pela perspectiva do uso educativo e da divulgação científica [Assessment of cave inventories and qualification mechanisms from the perspective of educational use and scientific dissemination]. *Geologia USP. Série Científica*, *22*(3), 3–17. https://doi.org/10.11606/issn.2316-9095.v22-184311.

Menin, D. S., & Bacci, D. L. C. (2023). Qualification of caves for educational use and scientific dissemination: A methodological proposal. *Geoheritage*, *15*, 29. https://doi.org/10.1007/s12371-023-00789-x.

Menin, D. S. D., Tognetta, L. R. P., & Bacci, D. L. C. (2022). As cavernas Como tema interdisciplinar no ensino fundamental [Caves as an interdisciplinary theme in elementary educations]. *Revista Brasileira de Educação Ambiental*, *17*(3), 72–91.

Migoń, P. (2009). Geomorphosites and the world heritage list of UNESCO. In E. Reynard, P. Coratza, & G. Regolini-Bissig (Eds.), *Geomorphosites*. München: Verlag Dr. Friedrich Pfeil.

Naimi, M. N., & Cherif, A. (2021). Inventory and assessment of significant scientific Algerian geoheritage: Case of remarkable geosites from Orania (Western Algeria). *International Journal of Geoheritage and Parks*, *9*(1), 13–29. https://doi.org/10.1016/j.ijgeop.2020.09.001.

Pereira, P., & Pereira, D. (2010). Methodological guidelines for geomorphosite assessment. *Géomorphologie: Relief, Processus, Environnement*, *2*, 215–222. https://doi.org/10.4000/geomorphologie.7942.

Pereira, P., & Pereira, D. I. (2012, September). *Assessment of geosites tourism value in geoparks: The example of Arouca Geopark (Portugal)*. Paper presented at the 11th European Geoparks Conference, Arouca, Portugal 231–232.

Pereira, P., Pereira, D., & Alves, M. I. (2007). Geomorphosite assessment in Montesinho Natural Park (Portugal). *Geographica Helvetica*, *62*(3), 159–168. https://doi.org/10.5194/gh-62-159-2007.

Pontes, H. S., Massuqueto, L. L., Fernandes, L. A., Foltran, A. C., de Melo, M. S., & Moreira, J. C. (2019). Caves geodiversity evaluation as an instrument to the management of the Campos Gerais National Park, Southern Brazil. *Geoheritage*, *11*(2), 641–651. https://doi.org/10.1007/s12371-018-0317-9.

Pralong, J. -P., & Reynard, E. (2005). A proposal for a classification of geomorphological sites depending on their tourist value. *Alpine And Mediterranean Quaternary*, *18*(1), 313–319. https://doi.org/10.1016/j.pgeola.2012.06.001.

Prosser, C. D. (2013). Our rich and varied geoconservation portfolio: The foundation for the future. *Proceedings of the Geologists' Association*, *124*, 568–580.

Reynard, E., Coratza, P., & Regolini-Bissig, G. (2009). *Geomorphosites*. München: Verlag Dr. Friedrich Pfeil.

Reynard, E., Fontana, G., Kozlik, L., & Scapozza, C. (2007). A method for assessing "scientific" and "additional values" of geomorphosites. *Geographica Helvetica*, *62*(3), 148–158. https://doi.org/10.5194/gh-62-148-2007.

Sallun, A. E. M., & Sallun Filho, W. (2009). Geologia em planos de manejo: subsídios para zoneamento ambiental do Parque Estadual Intervales (PEI), Estado de São Paulo [Geology in management plans: Subsidies for environmental zoning of the Intervales State Park (PEI), São Paulo, Brazil]. *Geociências*, *28*(1), 91–107.

Santos, L. R., Fadel Cury, L., Rosenblume, J., Trindade Mendes, M., Fedalto, G., Lopes, A. P., ... Basei, M. (2022). Tracing the continental margins of the southern Ribeira Belt, Brazil: Provenance and connections of post-Rodinia fragments. *Precambrian Research*, *378*, Article 106756. https://doi.org/10.1016/j.precamres.2022.106756.

Santos, P. L. A. (2019). *Patrimônio geológico na área do Parque Estadual Turístico do Alto Ribeira (PETAR), Vale do Ribeira, SP Brasil: a capacidade de carga na definição de estratégias de gestão para o uso público de sítios geológicos [Geological heritage of the Touristic State Park of Alto Ribeira (PETAR), São Paulo, Brazil: Definition of management strategies to promote the public use of geological sites based on the carrying capacity evaluation] (Doctoral dissertation)*. Universidade do Minho, Braga, Portugal.

Santos, P. L. A., & Brilha, J. (2023). A review on rourism carrying capacity assessment and a proposal for its application on geological sites. *Geoheritage*, *15*(2), 47. https://doi.org/10.1007/s12371-023-00810-3.

Santos, P.L.A., & Garcia, M. G. M. (2021, November). *Gestão de geossítios para uso educativo e turístico com base em geoindicadores: Aplicação ao Inventário do Patrimônio Geológico do Estado de São Paulo [Management of geosites for educational and tourist use based on geoindicators: Application to the Geological Heritage Inventory of the State of São Paulo]. Paper presented at the 3rd Meeting of Postdoctoral Researchers at IGc/USP, Institute of Geosciences, University of São Paulo, São Paulo, Brazil.*

Santos, P.L.A., & Garcia, M.G.M. (2022, November). *Avaliação da Prioridade de Gestão e Identificação de Geossítios Prioritários: Aplicação ao Inventário do Patrimônio Geológico do Estado de São Paulo* [Evaluation of management priority and identification of priority geosites: Application to the geological heritage inventory of the State of São Paulo]. Paper presented at the 4th Meeting of Postdoctoral Researchers at IGc/USP, Institute of Geosciences, University of São Paulo, São Paulo, Brazil.

Santos, P. L. A., & Garcia, M. G. M. (2023, December). *Identificação Preliminar de Indicadores Físicos para Avaliação do Estado de Coservação de Geossítios: Aplicação ao Inventário do Patrimônio Geológico do Estado de São Paulo [Preliminary identification of physical indicators for assessing the conservation state of geosites: Application to the geological heritage inventory of the State of São Paulo]. Paper presented at the5th Meeting of Postdoctoral Researchers at IGc/USP, Institute of Geosciences, University of São Paulo, São Paulo, Brazil.*

Santos, P. L. A., & Garcia, M. G. M. (2023b). Identification of priority geosites for public use management: Application to the geological heritage inventory of São Paulo state. *Geologia USP. Série Científica*, *23*(2), 27–40. https://doi.org/10.11606/issn.2316-9095.v23-204971.

Serviço Geológico do Brasil (SBG-CPRM) (2022). Sistema de Cadastro e Quantificação de Geossítios e Sítios da Geodiversidade (GEOSSIT) [System for Registration and Quantification of Geosites and Geodiversity Sites (GEOSSIT)]. Retrieved from https://www.sgb.gov.br/.

Simón-Porcar, G., Martínez-Graña, A., Simón, J. L., González-Delgado, J.Á., & Legoinha, P. (2020). Ordovician ichnofossils and popular architecture in Monsagro (Salamanca, Spain): Ethnopaleontology in the service of rural development. *Geoheritage*, *12*(3), 76. https://doi.org/10.1007/s12371-020-00506-y.

Sociedade Brasileira de Espeleologia (SBE) (2023). Cadastro Nacional de Cavernas do Brasil [National register of caves of Brazil]. Retrieved from https://www.sgb.gov.br/.

Telbisz, T., Gruber, P., Mari, L., Kőszegi, M., Bottlik, Z., & Standovár, T. (2020). Geological heritage, geotourism and local development in Aggtelek National Park (NE Hungary). *Geoheritage*, *12*(1), 5. https://doi.org/10.1007/s12371-020-00438-7.

Theodorovicz, A. (2014). *Geoparque Alto Vale do Ribeira: proposta. Preservação do patrimônio geológico. Visibilidade e desenvolvimento através do geoturismo [Alto Vale do Ribeira Geopark: Proposal. Preservation of geological heritage. Visibility and development through geotourism].* Brasília: Geological Survey of Brazil.

Woo, K. S., & Kim, L. (2018). Geoheritage evaluation of caves in Korea: A case study of limestone caves. In E. Reynard, & J. Brilha (Eds.), *Geoheritage: Assessment, protection, and management* (pp. 373–386). Amsterdam: Elsevier. https://doi.org/10.1016/B978-0-12-809531-7.00021-6.

Worton, G. J. (2008). A historical perspective on local communities and geological conservation. *Geological Society Special Publications*, *300*, 137–146. https://doi.org/10.1144/SP300.11.