PRIORITIZING CLIMBING SITES FOR RISK ASSESSMENTS: A GEOCONSERVATION APPROACH IN THE CORUMBATAÍ GEOPARK PROJECT DOMAIN

João Paulo Monticelli [1]; Rogério Pinto Ribeiro [2]; Maria da Glória da Motta Garcia [3]

Resumo – O projeto do Geoparque Corumbataí no estado de São Paulo, Brasil, inclui vários geossítios significativos que representam o geopatrimônio da Terra. Entre eles, há vários geomorfossítios que fornecem registros da evolução da paisagem, onde alguns podem ser usados para atividades recreativas ao ar livre, como escalada. Neste estudo, avaliamos os locais de escalada dentro do domínio do Geoparque no estado de São Paulo, Brasil, usando um método de geoconservação para estabelecer uma hierarquia de locais para inspeções de campo e avaliações de risco. O objetivo principal era quantificar a atratividade desses locais para o turismo de aventura e dar suporte a futuras estratégias de gerenciamento de risco. O método foi aplicado tanto a locais de escalada bem estabelecidos em São Paulo quanto àqueles dentro do domínio do Geoparque Corumbataí. O método provou ser valioso na classificação de locais, permitindo comparações, como entre o Morro do Cuscuzeiro e a Pedra do Baú. Ambos emergem como principais atrações. Além disso, os resultados permitiram classificar os locais de escalada de uma maneira que aprimorou o processo de tomada de decisão para escolher um local para estabelecimento de uma avaliação de risco. Embora esse método ainda não seja definitivo, ele mostra forte potencial para refinamento e uso como uma ferramenta para avaliar locais de escalada. Os locais de escalada estudados aqui têm o potencial para serem reconhecidos como de importância regional a nacional no Brasil, embora muitos ainda estejam em desenvolvimento ou enfrentem conflitos de uso da terra.

Abstract – The Corumbataí Geopark project in São Paulo State, Brazil, includes several significant geosites representing the Earth's geoheritage. Among them, there are several geomorphosites providing records of landscape evolution, where some could be used for outdoor recreational activities, such as climbing. In this study, we assess the climbing sites within the Geopark domain in São Paulo State, Brazil, using a geoconservation method to establish a hierarchy of sites for field inspections and risk assessments. The primary goal was to quantify the attractiveness of these sites for adventure tourism and to support future risk management strategies. The method was applied to both well-established climbing sites in São Paulo and those within the Corumbataí Geopark domain. It proved valuable in ranking sites and enabling comparisons, as Morro do Cuscuzeiro and Pedra do Baú emerged as top attractions. These sites demonstrated strong infrastructure, community support, and promotional efforts. Also, the results allowed rank climbing sites in a manner that enhanced a decision-making process to choose a site for risk assessment. While this method is not yet definitive, it shows strong potential for refinement and use as a tool for assessing climbing sites. The climbing sites studied here have the potential to be recognized as regional to national significance in Brazil, although many are still under development or face land-use conflicts.

Keywords – Geoconservation; Climbing sites; Risk assessment; Adventure tourism; Corumbataí Geopark.

[1] Geol., PhD student, University of São Paulo, Tel. (11) 98677-4772, joao.monticeli@usp.br
[2] Geol., PhD, University of São Paulo, Tel. (16) 98177-7721, rogerioprx@sc.usp.br
[3] Geol., PhD, University of São Paulo, Tel. (11) 3091-3909, mgmgarcia@usp.br

1. INTRODUCTION

The perceptions of outdoor recreational areas and their adventure activities, such as climbing sites, in São Paulo State, Brazil, reveal significant concerns from an engineering geology perspective (Figure 1d-g). Of the 148 cataloged sites (Monticelli et al., 2025), approximately 63% are located in areas classified as highly to very highly susceptible to gravitational mass movements, according to regional-scale maps (Perrotta et al., 2005). The main geological threats include rockfalls, rock slides, and toppling (Hungr et al., 2014), creating a risk scenario for adventure (geo)tourists and other exposed elements (Fell et al., 2005). Additionally, the access trails leading to these sites are often subject to similar risks, beyond the erosion processes.

Recent events in Brazil, such as the fatal rockfalls at Capitólio Canyon in Minas Gerais and Praia de Timbaú in Rio Grande do Norte, as well as flash floods in national parks, highlight the urgent need for risk assessment in adventure tourist areas (Norma ABGE 500, in press). In this sense, the geoscientist professionals would point out that at least 93 climbing sites (i.e., 63%) require field inspections to verify the previous findings and conduct preliminary risk evaluations. Since rock detachment is a common process in rock masses, it frequently leads to accidents during climbing sports (Correio Braziliense, 2021).

In accordance with 12.514 law (Brasil, 2012), implementing risk assessments is essential for mitigation, planning, prevention, monitoring, and early warning systems (Pimentel and Santos, 2018). In other words, guidelines that can be applied also for touristic areas in detailed scales; examples include reports related to beaches, waterfalls, rock cliffs, etc. (Dias et al., 2024; Moraes et al., 2023). However, unlike studies focusing on isolated sites, the costs associated with field inspections, data acquisition, and analysis make large-scale risk assessments economically unfeasible for 63% of climbing sites during an academic program (Monticelli, in press). This challenge is similar across various sectors dealing with geological-geotechnical risks, including urban areas and highway infrastructures.

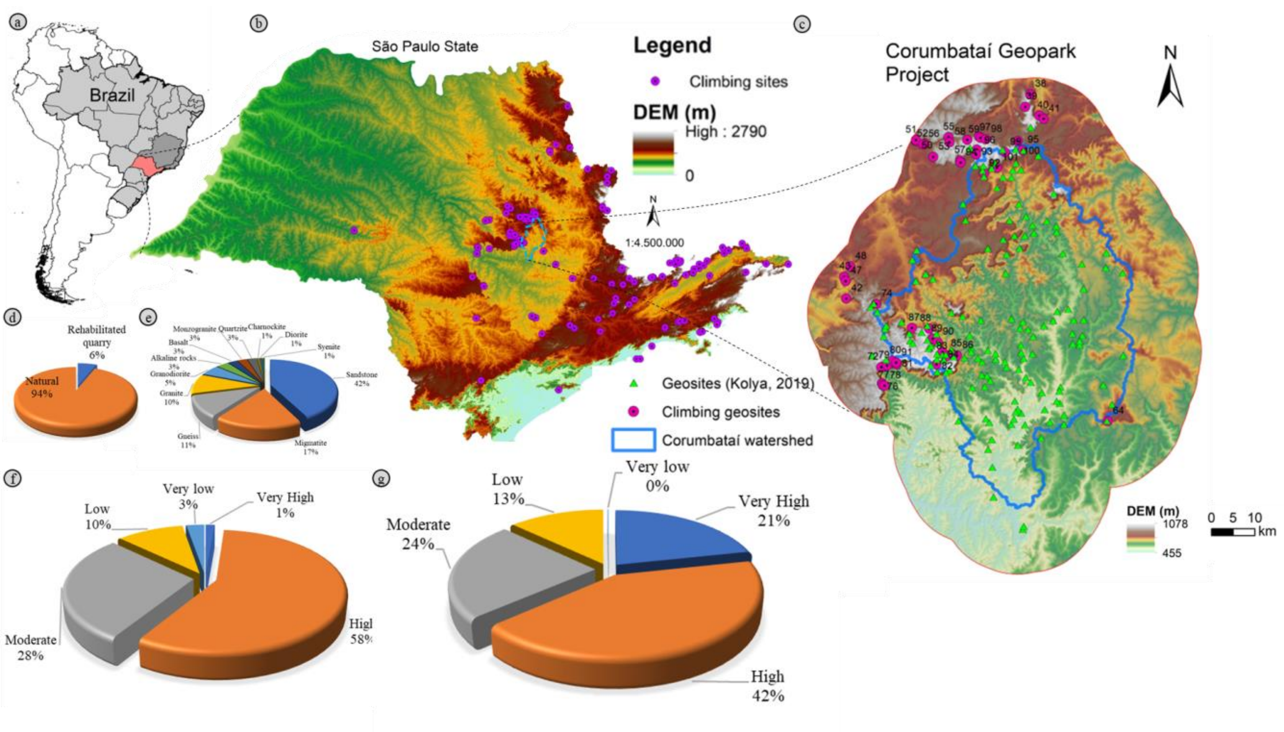

Figure 1. Some perspectives of adventure tourism based on climbing sites from São Paulo State: a-b) study location, c) kind of sites, d) lithotypes in leisure use, e) erosion, and f) rockfall susceptibilities (Monticelli et al., 2025).

Given these financial constraints, geoconservation approaches offer a viable strategy for prioritizing climbing sites, even from an engineering geology perspective. Geoconservation methods are commonly used to promote geotourism, education, and scientific activities, supporting community welfare and sustainable development (Brilha, 2016). Climbing sites, for instance, can be classified as geosites or geodiversity sites of geomorphological interest, among other categories (Santos and Brilha, 2023). In recent years, specific geoconservation methodologies for outdoor recreation areas, such as climbing, trekking, and mountaineering, have advanced significantly, particularly in European geotourism destinations (Panizza and Mennella, 2007; Bollati et al., 2015, 2016, 2024; Ruban and Ermolaev, 2020). Among them, one promising approach emerges: a simple method for quantitatively assessing climbing sites (Biancotti et al., 2001). This classification system assigns a score to attributes, such as rock characteristics, environmental features, landowners' troubles, etc., creating an indicator of a site's attractiveness and potential visitation frequency. Thus, a system that could enable the differentiation quantitatively between climbing sites, facilitating ranking and decision-making while optimizing efforts and available resources.

Herein, we tested a methodology for classifying climbing sites based on a previously cataloged inventory from the state of São Paulo (Monticelli et al., in press). The methodology developed by Biancotti et al. (2001) was applied to assess the holistic value of climbing sites for adventure tourism. The method identifies locations with high appeal to climbers and mountaineers based on their attractiveness. Some attributes and parameters were modified to fit tropical conditions and insights from the local climbing community. This assessment was conducted at selected sites from the state and within the Corumbataí Geopark Project (CGP) domain (Kolya, 2019). The findings were satisfactory, allowing the quantitative ranking of climbing sites, making possible their analysis with numerical subsidies. Consequently, further studies and risk management initiatives can be effectively conducted based on natural attractiveness for adventure tourism.

2. STUDY AREA

The CGP is located in the middle of São Paulo State (Kolya, 2019) (Figure 1a-b). The geological context comprises the Paraná Basin, a Phanerozoic volcano-sedimentary basin that extends across Brazil, Paraguay, Argentina, and Uruguay, deposited over the crystalline rocks of the Brazilian Shield.

This basin and the Brazilian Shield are shaped by tectonic forces from the Pan African-Brazilian orogenic belts, the Mesozoic Gondwana breakup, and Cenozoic neotectonic reactivation. This interplay creates a unique sequence of landscape formations in São Paulo State, classified into five geomorphological provinces. Cuesta province in the center of the state marks the transition between the peripheral depression and western plateau. Similarly, the Corumbataí watershed lies between the escarpment and depression domains (Figure 1c). The escarpment province consists of a strip of asymmetrical scalloped escarpments that follow the basin's contours and face the Atlantic Plateau, formed by crystalline rocks of the Brazilian Shield (De Abreu and Augusto Filho, 2012).

The escarpment is responsible for the contrasting landforms, which have attracted many people for activities such as hiking, ecotourism (Perinotto, 2009), and other outdoor pursuits like biking and climbing (Chinaglia, 2014). In other words, the area offers a diverse range of geological sites by means of geoforms and geomorphosites that strongly appeal to outdoor enthusiasts. Also, fossil records, paintings, and carvings can be found (Amaral et al., 2022; Garcia et al., 2018), further reinforcing the Geopark project in the middle of the state (Figure 1 b-c) (Kolya, 2019).

3. MATERIALS AND METHODS

The assessment of climbing sites was based on their attributes and parameters, including user experience, the distance to infrastructure facilities, types of climbing on the rock, climbing difficulties and styles, as well as biological and landowner issues. The classification system is calculated by multiplying each parameter, resulting in a Climbing Note (CN), as referred to herein. Generally, the CN value can be seen as an indicator of a site's attractiveness for climbers, i.e., its potential for user frequentation (Biancotti et al. 2001). Seven parameters are used for this classification: 1) crag height, 2) rock features, 3) climate features, 4) frequentation capability, 5) landscape issues, 6) development potential, and 7) fame. Table 1 presents some parameters and attributes required to calculate the CN. For more details, see Biancotti et al. (2001).

For comparative purposes with the climbing sites of the CGP, six places in the São Paulo State where their holistic aspects are recognized between the climbing community were selected to carry out a test of the geoconservation method. These places were 1) Praia da Fortaleza (Ubatuba), 2) Iperó rocks (Iperó), 3) Pedra do Santuário (Pedra Bela), 4) Pedra do Baú Complex (São Bento do Sapucaí), 5) Jardim Garcia quarry (Campinas), and 6) Marmeleiro quarry (São Roque) (Figure 6). These six sites represent two types of climbing styles, bouldering and sportive climbing, and two kinds of environments, man-made (rehabilitated quarries) and natural sites.

Also, the classification rating was conducted for all climbing sites in the CGP domain. In total, 36 climbing sites were analyzed through field campaigns and conversations with local climbers from the municipalities of São Carlos, São Paulo, and Campinas. The experience and suggestions of nonprofit climber organizations were also considered in applying the method (i.e., Geoboulder - USP, CUME - UFSCAR). As a result, some attributes were modified based on the experiences of Brazilian climbers.

These modifications aimed to differentiate climbing sites by levels of connection and affinity with the users. For instance, the parameter 'crag seclusion' was not included. Instead, greater emphasis was placed on local climate conditions, such as the preference of Brazilian climbers for south-facing walls due to reduced sun exposure during the day. While climbers in temperate countries often prefer to climb at higher altitudes in sunny conditions, this is less essential in tropical countries.

Finally, the climbing site scores were calculated and systematically organized into tables and graphs, enabling a clear and structured analysis while establishing a quantitative hierarchy to further guide field inspections for risk assessment.

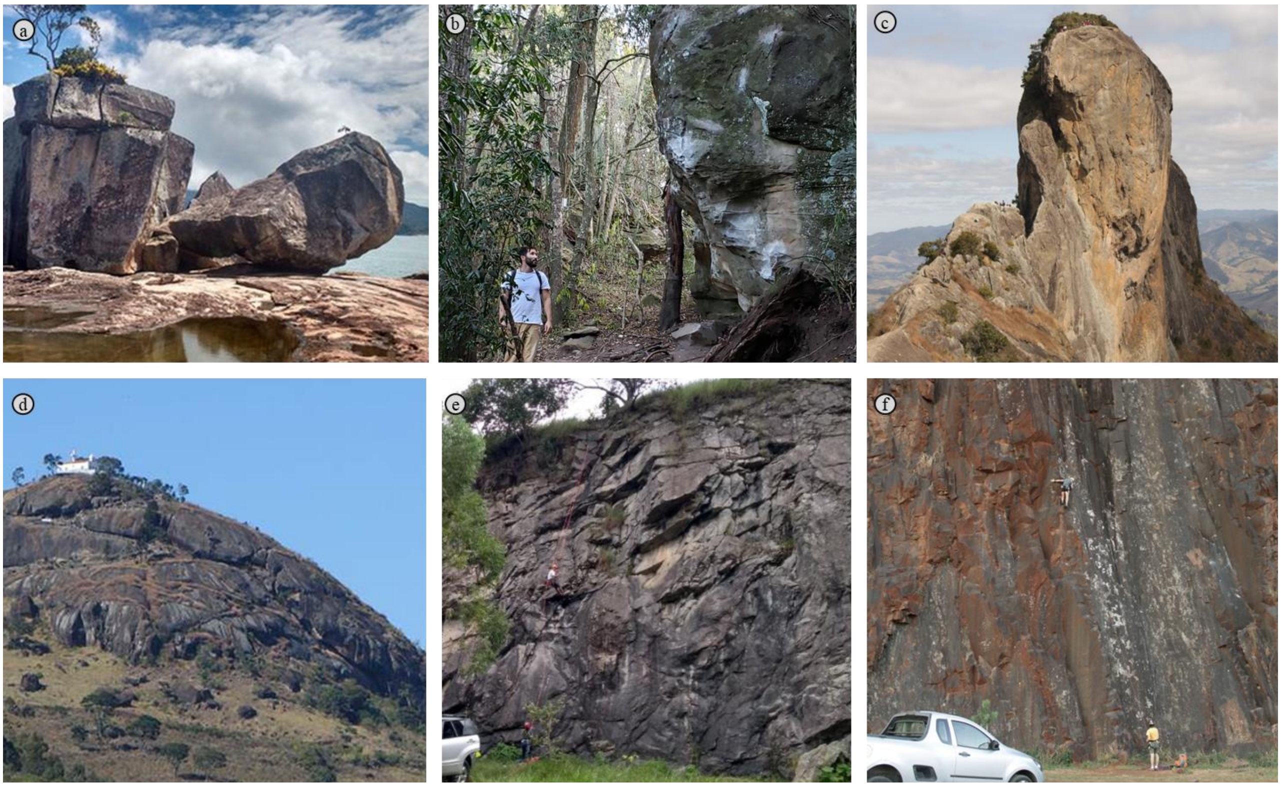

Figure 2. The selected climbing sites of São Paulo State: a) Praia da Fortaleza (Ubatuba), b) Iperó rocks (Iperó), c) Pedra do Santuário (Pedra Bela), d) Pedra do Baú Complex (São Bento do Sapucaí), e) Marmeleiro quarry (São Roque), and f) Jardim Garcia quarry (Campinas). (Author records).

Table 1 – Some parameters and values in the climbing sites classification system (Biancotti et al., 2001)

1) Crag height						
	Height (m)	< 10	10 - 20	20 - 30	30 - 50	> 50
	Rating	0.2	1	2	1.5	1

2) Rock Features		Rating
a) Rock type	Limestone	2.0
	Other sedimentary carbonatic rocks	1.7
	Siliceous eruptive rocks (granites, acid lava)	1.8
	Gneiss	1.8
	Metamorphic massive rocks (quartzite, amphibolite, marbles...)	1.3
	Metamorphic schistose rocks (phyllite)	0.6
	Sandstone	1.2
	Conglomerate	1.0
	Volcanic rocks (basalt, basic lavas)	0.8
b) Rock quality (for climbing)	Deep weathering	0.0
	Shallow weathering, it is necessary to be careful	0.2
	The rock is sometimes dubious; it is necessary to be careful	0.8
	The rock is cracked; they are not dangerous blocks	1.0
	Slabs with narrow steps, because cross of several joint systems	1.0
	Surface with weathering and case-hardening	2.0
	No cracking, smooth surface	0.3
	Surface smoothed by climbers	0.9

3) Climate features			Rating
a) Altitude for craig (m)/ wall facing	N	W/E	S
0 - 500	0.8	1	1.2
500 - 1000	1	1.2	1
1000 - 1500	1.2	1	0.8
1500 - 2000	1	0.8	0.4
> 2000	0.8	0.4	0.1

b) Dampness and rain exposition	Dry, protected	1.2
	Normal, rain exposed	1
	Very wet, water percolation in rock surface	0.8
	Possibility of climbing with rain	2
c) Wind exposition	Wall providing shelter	0.8
	Windy	0.6
	Normal	1

4. RESULTS AND DISCUSSION

4.1. Attractiveness classification testing

Among the whole inventory of São Paulo State (Monticelli et al. in press), six locations were selected to test the method of Biancotti et al. (2001) (Figure 2). These sites were chosen for their unique characteristics, specifically two that represent bouldering and four that represent sport climbing styles. Additionally, they include both natural and man-made locations. Furthermore, we have prior climbing experience at these sites and are familiar with their inherent geological values, land use conflicts, and the types of activities undertaken by climbers, i.e., the attributes and parameters.

In comparison to the other five climbing sites, Pedra do Baú in the municipality of São Bento do Sapucaí stands out with a CN value of 43.1. This value is ten to fifty times higher than those of other tested locations, indicating that it is a climbing hotspot in São Paulo State. Following Pedra do Baú, Pedra do Santuário (Pedra Bela) has a CN value of 8.2. In parallel, the climbing sites characterized by bouldering styles recorded CN values of 4.1 and 2.1, while the rehabilitated quarries had the lowest CN values, around 0.8 and 1.7 (Table 2).

Table 2 - The parameters and climbing notes for six sites of São Paulo state

	Id	I (a)	II (b)	III (c)	IV (d)	V (e)	VI (f)
Parameters (Table 1)	1	1	1	2	1.5	2	2
	2a	1.8	1.2	1.8	1.8	0.8	1.8
	2b	2	0.8	0.8	1.5	1	1
	3a	1	1.2	1	1.2	1	1
	3b	1	1	1	1	0.8	0.8
	3c	1	0.8	1	1	0.8	0.8
	4a	0.9	1	1	1	1	0.9
	4b	1	1.2	1.2	1.2	1.2	1.2
	4c	1	1.5	1.5	1	1.5	1.5
	4d	1	1	0.7	1	0.2	0.2
	5a	1	1	1	1	1	0.8
	5b	1	1.2	1	1.1	1	1
	5c	1	1	1	1	1	1
	6a	0.7	0.7	1	1.4	1	1.3
	6b	1	1	0.7	1	1	1
	6c	1	1	1.2	2	1.8	1.8
	6d	1.2	1	1.2	1.2	0.8	0.8
	7	1.5	1.5	1.5	2	1.5	1.5
Climbing note		4.1	2.1	8.2	43.1	0.8	1.7

Obs.: I(a) Praia da Fortaleza, II(b) Iperó rocks, III (c) Pedra do Santuário, IV (d) Pedra do Baú Complex, V (e) Jardim Garcia, VI (f) Marmeleiro

The calculation of the CN was crucial for assessing various parameters and attributes from the outdoor recreational areas. For instance, crag height and rock features differ among climbing sites. Bouldering styles typically have lower CN values, exemplified by the Praia da Fortaleza site, which is known for its challenging climbs compared to the Iperó site. In contrast, sport climbing, such as at Pedra do Baú, offers a range of difficulties, increasing climbing appeal. Additionally, some rock layers, like certain basalt formations, indicate low durability, particularly in quarries such as Pedreira Garcia. Also, the Iperó site, where sandstone weakens significantly on rainy days, often leads to rock grip failure (Figure 2 and Table 2).

Climate features also differentiate climbing sites. In some locations, climbers experience natural environmental conditions, meaning that if it rains or is windy, those factors become part of the climbing experience. In contrast, other sites may lack vegetation or features that enhance the sense of nature, leading to extremely low values for quarries. Moreover, the presence of water due to infiltration and weathering can further diminish the attribute values of some climbing sites. Overall, the attributes related to frequentation capability were favorable for natural sites. However, these values dropped below one for locations that also host other activities, such as kiting, aeromodelling, picnicking, and parties with barbecues. Climbers and mountaineers generally agree that many of these practices are quite disruptive and contribute significantly to littering in climbing sites. Therefore, in the calculation of the CN, attributes were selected to reflect the potential for these conflicts.

Landscape troubles also affect the CN calculation, particularly since many climbing sites located on private property experience seasonal closures. Additionally, some sites near urban areas have issues with theft. Conversely, certain climbing locations benefit from the presence of ancient human carvings, which often help preserve the area from overdevelopment. The parameters for development capability and fame are influenced by both environmental factors and the promotion of these sites through climber communities, as well as coverage in books, magazines, and websites. Some sites are well-known for their iconic routes (Tables 1 and 2).

4.2. Climbing sites hierarchization in CGP domain

A total of 36 climbing sites were used within the CGP domain to classify and assess their attractiveness. Some of these sites are located within the proposed CGP area, while others lie outside of it (Figure 1c). The majority are characterized by sportive climbing styles (Figure 3a, c-d), with a few featuring bouldering styles (Figure 3b). The primary lithotype used for these leisure activities is the sandstone from the Botucatu Formation. Most sites are situated at the transition between the peripheral depression and escarpment geomorphological provinces, where well rock exposition can be seen (Figure 3). The CN for each climbing site was them calculated, and the results were organized in Table 3.

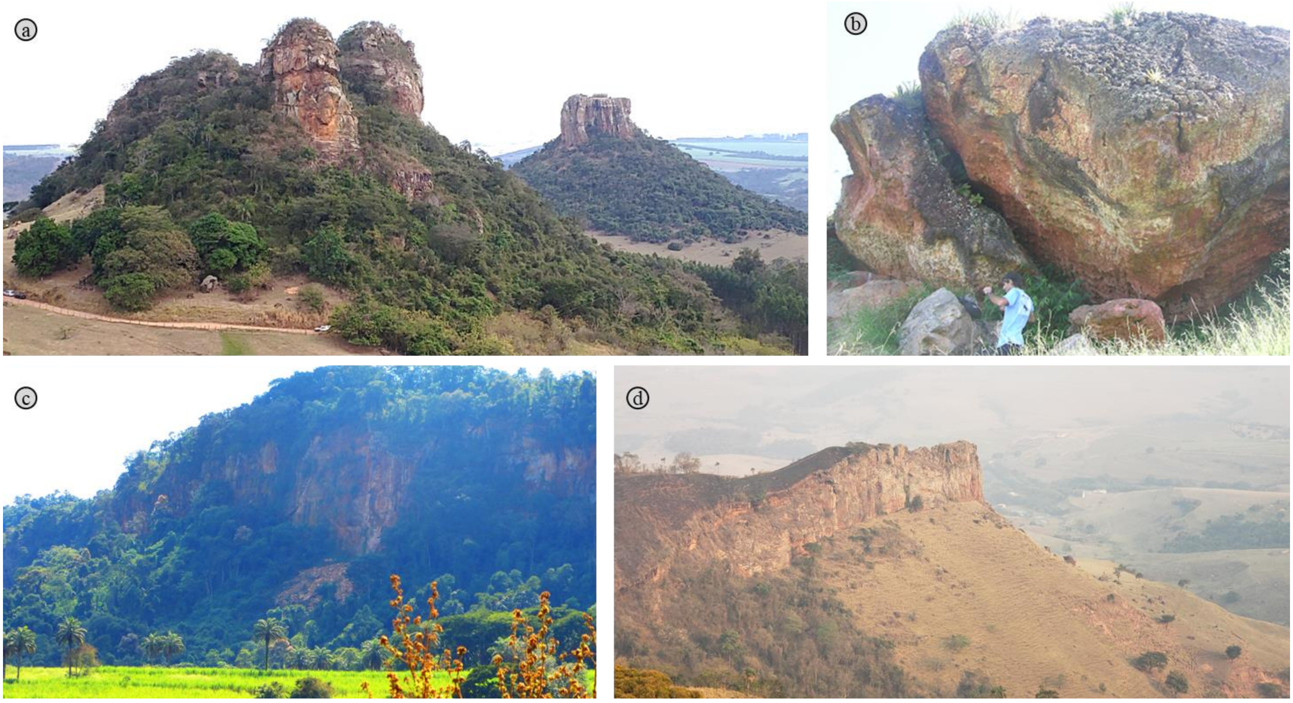

Figure 3. Some climbing sites in the CGP domain: a) Camelo and Cuscuzeiro Hills, b) boulders of Fogão, c) Desmorona-não Cliff, and d) Fogão Hills. (Authors records: a, c, d; Genga: b).

The primary climbing site identified is Cuscuzeiro Hill, which received the highest CN value, followed by Mecca, Fazenda Invernada, Falésia Colorido, and others (Figure 3a and Table 3). The Cuscuzeiro site serves as a reference point for climbing attractiveness, particularly for residents of São Carlos town and metropolitan regions of Campinas and São Paulo. It features approximately seventy crags detailed in a climbing guide, ranging from easy to quite difficult, predominantly focused on sportive climbing styles, with some reaching the top of the cliff (Chinaglia, 2014).

Access to the site is provided through the property of a benevolent owner, who has established well-constructed infrastructure, allowing it to welcome many tourists and climbers over the years. This climbing spot has been managed for more than a decade by the owner in collaboration with the University Center for Mountaineering and Touring (CUME), a non-profit association composed of community members from São Carlos and the surrounding area, including students, professors, and staff from the Federal University of São Carlos and the

University of São Paulo. These factors contribute significantly to the higher CN calculation compared to other climbing sites within the CGP domain (Table 3).

The crags at Cuscuzeiro offer a prominent view of the relationship between the peripheral depression and escarpment geomorphology (Figure 3a). Although inventoried and promoted by geoconservation methods in Kolya (2019), its significance as a climbing site was not considered in detail in the previous study, nor was it compared to other geosites within the CGP. In this study, Cuscuzeiro Hill can be classified as a climbing hotspot in the CGP, based on the approach by Biancotti et al. (2001). This makes it a prime geomorphosite for promoting geotourism through climbing (Panizza, 2001; Panizza & Menella, 2007), trekking, and mountaineering. Thus, enhancing the holistic and sustainable values of a geopark proposal (Bollati et al., 2015; Bollati et al., 2016; Bollati et al., 2018).

Table 3 - Climbing sites and notes for CGP domain

Name	CN	Name	CN
A Bolha	0.022	Falésia Pedra Vermelha	3.285
Boulders Fogão	1.283	Falesinha	0.232
Cabeça do Índio	0.970	Fazenda Invernada	4.927
Cantagalo	0.067	Grande Proa	2.022
Caverna Z	0.039	Gruta da Boca do Sapo	0.597
Caverninha de São Carlos	2.426	Gruta do Fazendão	0.006
Morro do Cuscuzeiro	12.165	Mecca 1	4.313
El paredon Fz. Itaguassu	0.041	Mecca 2	5.599
Eldorado	0.647	Mineiros do Tietê	3.359
Falésia Colorido	4.778	Morro do Fogão	0.470
Falésia da Lapinha	0.622	Paredes do Vale da Bocaina	1.003
Falésia da Pizza	4.031	Pedra do Gorila	2.874
Falésia do Colorido Setor 4	2.588	Pedra Vermelha Testemunho	3.732
Falésia do Colorido Setor Além	1.294	Pedreira Iracemápolis	2.986
Falésia Desmorona-Não	3.762	Piroquinha	0.290
Falésia do Lemão	4.147	Tanzânia	2.986
Falésia do Sol	0.130	Titanic	1.960
Falésia dos Elpas	0.065	Veio do Queijo	1.866

The Cuscuzeiro site achieved a CN value of approximately 12.1, which stands out compared to other climbing locations in the CGP (Table 3). Other sites, such as Mecca I/II, Invernada, and Falésia do Colorido, have mid-range CN values between 1 and 10. The lower CN values for some CGP climbing sites are due to several factors, including the lack of guides or sketches, a limited number of crags, and issues with landowners (Figure 3b). While some of these sites offer easy access, shade areas, and impressive views from the top, others face challenges like weak sandstone, significant weathering and infiltration (Figure 3c), long access routes, and constant sun exposure throughout the day (Figure 3d). These factors contributed to CN values ranging from 0 to 1 (Table 3). It's also important to note that certain decimal attributes in Biancotti et al.'s (2001) classification system resulted in CN values lower than one, which can be difficult to represent accurately on some graphical scales.

The total sum of CN values of climbing sites within the CGP domain reached approximately 80, which is notably high for what could be considered just one site. For comparison, the renowned Pedra do Baú climbing site has a CN value of around 40 (Figure 2b and Table 2). Notably, the Cuscuzeiro site stood out using this approach, while many other climbing sites in the CGP displayed CN values higher than selected sites from São Paulo State. This highlights the CGP domain’s potential as a prime adventure tourism and geotourism destination, supported by a structured and quantitative evaluation. However, Ruban and Ermolaev (2020) noted that geoconservation approaches like Biancotti et al. (2001) may require adjustments when applied beyond their original contexts. In fact, some modifications were necessary in this study, yet the method proved valuable not only for hierarchy climbing sites but also as a foundation for further applied studies, such as geoconservation methods and risk assessments.

Based on findings, the climbing sites were hierarchized for some sites in São Paulo State and for the whole CGP. A structured plan of field inspections and risk assessments may be drawn up to aim for sustainable use of climbing sites. Regarding the protection and safety of adventure tourism activities, two preliminary concerns were checked at the Cuscuzeiro Hill climbing site, extending it also for Camelo Hill. First, nearly both climbing sites, along with their access routes and camping areas, seem to be located in rockfall risk zones. Second, the primary safety equipment used in climbing, namely rock anchors, is known to have limited load capacity in sandstone formations (Law and Hawkshaw, 2015). The main sandstone in the area pertains to the Botucatu Formation; although typically hardened by silicification processes, it can occasionally display weakness in certain rock exposures. Both of these factors pose significant geological, geotechnical, and geotechnological risks. These issues warrant close attention, as they represent substantial safety concerns for the sustainable development of the adventure (geo)tourism industry in CGP.

5. CONCLUSIONS

In this study, we applied a geoconservation method to assess the climbing sites within the Corumbataí Geopark proposal domain in São Paulo State, Brazil. The primary goal was to establish a hierarchy of these sites to support the development of novel risk assessments. The key findings are summarized as follows:

The geoconservation method proved valuable for quantitatively evaluating the attractiveness of adventure tourism. Successfully applied to both well-established climbing sites in São Paulo State and those within the CGP domain, it effectively ranked sites and facilitated comparisons with other destinations.

In a regional analysis, Pedra do Baú emerged as a standout climbing site in São Paulo State, while Cuscuzeiro Hill distinguished itself as a major hotspot within the Corumbataí Geopark domain. For the second, the climbing score of 12.1 reflects its well-maintained infrastructure, strong community support, and the availability of promotional books and guides. Other climbing sites within the CGP also demonstrate significant potential for adventure tourism development, particularly when compared to climbing sites across the broader state.

To fully realize the potential of these sites, targeted initiatives are needed to enhance safety, improve infrastructure, and strengthen collaboration between climbers and geoscientist professionals. Increasing visibility through updated books, guides, and informational panels can attract more visitors while also addressing safety concerns, such as rockfall risk areas and the condition of the installation of climbing anchors. By adhering to sustainable climbing practices like the "leave no trace" principle, the Corumbataí Geopark proposal can align its development strategies with UNESCO's geoconservation goals. Through these collaborative efforts, the region can not only elevate the climbing note values of its sites but also create a well-rounded geotourism experience that balances recreation with environmental sustainability.

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