

Original Research

Segmentation and Classification of the Trail of the Site of Geological Interest 'Portal do Palmiro', Caminhos dos Cânions do Sul UNESCO Global Geopark (Brazil)

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Article History

Received:
9 May 2026
Revised:
20 June 2026
Accepted:
25 June 2026
Published online:
25 June 2026
Published in Issue:
30 June 2026

Abstract:

The Portal do Palmiro trail leads to the Paleotoca "Toca do Tatu" in Timbé do Sul, Brazil, within the Caminhos dos Cânions do Sul UNESCO Global Geopark (CCSUGGp). As visitation increases, providing information about the trail's characteristics, environmental conditions, and challenges becomes essential. This study aimed to classify and describe the trail according to the standards of ABNT NBR 15505-2/2019. Thus, the trail was segmented into homogeneous sections according to changes in its configuration and physical characteristics, following the criteria established by the standard. The trail was evaluated using four criteria rated from 1 to 5. Results indicated Environmental Severity Level 2 (moderately severe), Route Orientation 2 (signposted), Technical Difficulty 3 (uneven or stepped surfaces), and Physical Demand 3 (considerable). Although some sections present medium to steep inclines, 63.5% of the route has slopes below 10%, indicating low overall difficulty. The proposed classification contributes to standardizing trail assessment criteria and improving visitor safety and activity planning along the route.

Keywords: Geoheritage, Geoconservation, Environmental Sustainability, Geotourism, Sustainable Development.

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Cite this article: Miranda, L., Silva, J. G. S. d., Souza, G. d. S., Back, Á. J., Valdati, J., & Campos, J. B. (2026). Segmentation and Classification of the Trail of the Site of Geological Interest 'Portal do Palmiro', Caminhos dos Cânions do Sul UNESCO Global Geopark (Brazil). *Geoconservation Research*, 9(1), 164–181. <https://doi.org/10.57647/gcr.2026.0901.10>

1. Introduction

Brazil is distinguished by its diverse attractions and significant geodiversity, which serves as a foundation for geotourism and the establishment of UNESCO Global Geoparks (UGGp) (Schobbenhaus and Silva 2012; Bento *et al.* 2020). Specifically, since 2022, southern Brazil has gained international recognition through the designation of the Caminhos dos Cânions do Sul UNESCO Global Geopark (CCSUGGp) (Silva *et al.* 2025a).

The CCSUGGp has documented a total of 30 Sites of Geological Interest¹ (geosites; SGI) in its application dossier submitted to UNESCO, the majority of which are accessible to the public. These designated SGI showcase significant examples of geological (Franzen *et al.* 2023), geomorphological (Gomes *et al.* 2022), paleontological (Valdati *et al.* 2024a), archaeological (Campos *et al.*

¹This term is used in reference to the guidelines of the International Union of Geological Sciences (IUGS 2023).

2020; Campos and Miziesck 2022), and cultural (Santos et al. 2024). Collectively, these attributes enhance the region's potential for tourism development.

Beyond the canyons and waterfalls, the region is notable for its distinctive paleontological heritage, referred to as burrows, paleoburrows (*paleotocas*) or biotunnels. Burrows are trace fossils created by the indigenous megafauna of South America during the Pliocene and Quaternary epochs, and they are located within sandstone formations (Bergqvist and Maciel 1994; Buchmann et al. 2003; Valdati et al. 2024a). These geological features hold significant international importance and have thus far been identified exclusively in this part of the world.

The CCSUGGp showcases several well-preserved structures and a broad variety of ichnofossils (Valdati et al. 2024a; Valdati et al. 2024b). Nevertheless, only three of these sites are accessible to the public, situated in the municipalities of Morro Grande, Timbé do Sul, and Jacinto Machado in the state of Santa Catarina.

Starting in 2017, the establishment of a UGGp project in southern Brazil, along with its later acknowledgment by UNESCO, significantly elevated the profile of these attractions, solidifying their status as alternative destinations for exploring natural environments. The establishment and solidification of UGGps in Brazil have bolstered tourist destinations and regions (Silva et al. 2024). The UGGp play a crucial role in enhancing regional tourist itineraries, focusing on the economic and socio-environmental advancement of geoheritage. This strategy combines both natural and cultural heritage, particularly via geotourism (Eder and Patzak 2004).

In this sense, Rivero et al. (2019) highlight that the promotion of new tourist destinations, focused on the sustainability of local communities, constitutes one of the main priorities of the contemporary tourism industry, as opposed to traditional mass tourism. The authors emphasize that the creation of any tourist destination must be based on the premise of sustainability, articulating the conservation of tourism resources with local economic development.

In this framework, geotourism is recognized as a burgeoning form of sustainable tourism on a global scale (Dowling 2013; Ólafsdóttir and Tverijonaite 2018; Chylińska and Kołodziejczyk 2025). This trend is fueled by the growing number of destinations that highlight their geoheritage as attractions for tourists, applicable in both natural (Pralong 2006) and urban settings (Del Lama et al. 2014), or even itineraries that integrate both in situ and ex situ geosites (Guglielmi et al. 2026).

Geotourism is articulated in this context according to the framework established by the Global Geoparks Network (GGN) and the Center for Sustainable Destinations of the National Geographic Society. They characterize geotourism as "tourism that sustains and enhances the identity of a territory, taking into account its geology, environment, culture, aesthetic values, heritage, and the well-being of its residents" (Arouca Declaration 2011).

In pursuit of this objective, there has been a notable increase in the number of visitors to the SGI that comprise

the CCSUGGp, particularly to the biogenic structures (Silva et al. 2025b). This rise in foot traffic along the trails leading to the burrows highlight the potential of this tourism sector, which merges attractions like burrows with the increasing interest in sustainable tourism experiences.

The growing interest in recreation and tourism within natural environments has underscored the need for effective visitor management strategies capable of reconciling public use with the preservation of natural heritage and geodiversity (Dowling and Newsome 2017; Leung et al. 2018; Anougmar et al. 2024). Visitor management encompasses the strategic planning, implementation, and monitoring of actions designed to enhance safety and improve the visitor experience through appropriate infrastructure, effective interpretation, and clear signage (Eagles 2002; Manning 2011; ICMBio 2011). As noted by Tomczyk et al. (2017), even trails subject to minimal visitor traffic remain susceptible to degradation.

In protected areas and sites of recognized geological significance, such as UGGp, these strategies are particularly relevant, as they enable a balance between public access and the safeguarding of fragile natural features (Hose 2012; Gordon 2018). Given that tourism, visitation, and recreational activities have become the third most significant threat to World Heritage sites (IUCN 2017; Mandić 2019).

In this context, trail classification constitutes an essential visitor management tool, providing standardized information on trail characteristics, difficulty levels, physical exertion, and the navigational and adaptive skills required (Lukoseviciute et al. 2021; Sunkar et al. 2022; Mantuano and Bruno 2025).

In light of this, and with the intention of reducing the impact of visitor traffic and mitigating risks associated with one of the accessible structures, we aimed to map, characterize, and classify the Portal do Palmiro trail an access route to the Toca do Tatu Burrow located in Timbé do Sul. This effort was guided by theoretical and methodological frameworks in accordance with the normative standards set forth by the Brazilian Association of Technical Standards (ABNT), regulated by the Brazilian Standard (NBR) 15505-2/2019.

2. Study area

The CCSUGGp currently encompasses seven municipalities, four of which are situated in the state of Santa Catarina and three in the state of Rio Grande do Sul (Figure 1). The combined area of these municipalities totals 2,830 km². Together, they are home to a population of 79,040 individuals (IBGE 2022). This study focuses on the Portal do Palmiro trail, which serves as an access route to the Burrow Toca do Tatu, located in Timbé do Sul.

It is essential to emphasize that historical human habitation of this area can be linked to its indigenous populations, particularly the *Guarani Mbyá*, referred to as the sambaquian peoples, who lived along the coastline (Campos et al. 2023), and the Laklãnō-Xokleng, who

inhabited the inland regions. Research indicates that human presence in this region extends back around 10,000 years (Campos and Mizieski 2022).

Archaeological sites today offer valuable perspectives on historical documentation, with a particularly significant legacy found at the SGI 'Portal do Palmiro' (burrow 'Toca do Tatu'). This location is distinguished by rock engravings carved into sandstone walls, which are derived from the Botucatu formation (Figure 2) (Cezaro et al. 2016).

The geographic area that includes the seven municipalities forming the CCSUGGp stretches from the coastal region of Torres/RS, traversing canyons and cliffs to arrive at the Serra Geral plateau. As a result, the CCSUGGp showcases a diverse array of landscapes and a wide variety of geological and geomorphological features, which include an extensive array of unique structures, lithologies, topographic forms, and geomorphological processes (Rapanos and Valdati 2024).

The geomorphological landscape of Southern Santa Catarina is characterized by a significant variety of relief forms, shaped by the interplay of ancient geological processes and ongoing external forces, including water and wind. This region comprises three primary geomorphological units: the Southern Brazilian Plateau, the Peripheral Depression, and the Coastal Plain (GAPLAN 1986). Each of these units possesses distinct features that have a direct impact on land utilization, human settlement, and overall environmental dynamics.

The Southern Brazilian Plateau, situated more inland, consists of crystalline formations and volcanic rocks from the Paraná Basin, with elevations between 800 and 1,200 m. This region features a more rugged landscape characterized by deep valleys and steep escarpments, shaped by significant river erosion over time (Godoy et al. 2011; Franzen et al. 2023; Ricetti et al. 2025).

The Peripheral Depression serves as a transitional zone between the plateau and the coastal area, distinguished by its rolling terrain and reduced elevation. This region is predominantly composed of clay-rich and fertile soils, which have facilitated agricultural development, particularly in the cultivation of rice and tobacco (Ricetti et al. 2025).

The Coastal Plain represents one of the most active regions in the geomorphological landscape of southern Santa Catarina (Gomes et al. 2022). Composed of recent sediment deposits, this area features sandbanks, dunes, lagoons, and mangrove ecosystems. Its closeness to the ocean, coupled with the ongoing influence of tides and winds, facilitates the movement of coastal landforms (Ricetti et al. 2025). This region supports vital ecosystems and houses a considerable portion of the population, necessitating a careful equilibrium between environmental preservation and the advancement of tourism.

The geomorphology of the CCSUGGp is striking, characterized by towering canyons and cliffs that delineate the plateau's boundary, primarily consisting of rocks from the Serra Geral Group (Gomes et al. 2022). Alongside the canyons, the geopark's topography fea-

tures plateaus and plains. The canyons serve as ecological pathways and support various plant and animal species that thrive in particular microclimates. Furthermore, the topography significantly impacts tourism, agriculture, and environmental preservation, making it vital for the sustainable development of the area designated by UNESCO as a Global Geopark.

3. Methodology

The selection of the Palmiro portal trail was based on the fact that it is the sole trail among the three accessible to the public that features a visitor management system, as it is situated on private land. Additionally, this trail is accompanied by a permanent guide who, along with his family, has been engaged in this endeavor for several decades, establishing a small family-run business. This enterprise not only provides the trail and paleotoca experience but also offers lodging rentals on their property. Consequently, this arrangement ensures that the trail receives more effective maintenance.

Three field surveys were conducted as follows:

1. The initial visit took place on April 6, 2024, to obtain permission from the site owner. During this visit, reconnaissance activities were performed, including data collection through notes, mapping, and photographic documentation.
2. The second visit occurred on May 15, 2024, with the purpose of verifying and validating the previously collected data.
3. The third visit, held on June 29, 2024, involved accompanying a group of visitors experiencing the trail and the burrows for the first time. This visit aimed to assess visitor numbers and behaviors, measure travel time, and capture images of both the pathway and the interior of the structures. All surveys were conducted with the guidance of a facilitator.

The trail was charted utilizing a GPS (Global Positioning System) in trail mode, which automatically documented the route and captured coordinates every five seconds. Additionally, points of interest were manually noted as they emerged along the trail. These identified points were assigned numbers in sequential order and later processed and analyzed with GIS (Geographic Information System) software, specifically ArcGIS 10.3, to create thematic maps.

On that day, a digital camera was employed to document the pathway. The trail's width was assessed using a tape measure, which was positioned perpendicular to the trail's direction, with measurements taken from the endpoints. This assessment focused solely on the bed area, specifically the section devoid of vegetation.

The information regarding precipitation, air temperature, humidity, and wind speed utilized for the analyses in this research was acquired via a formal request to the Agricultural Research and Rural Extension Company of Santa Catarina (Epagri), the entity overseeing meteo-

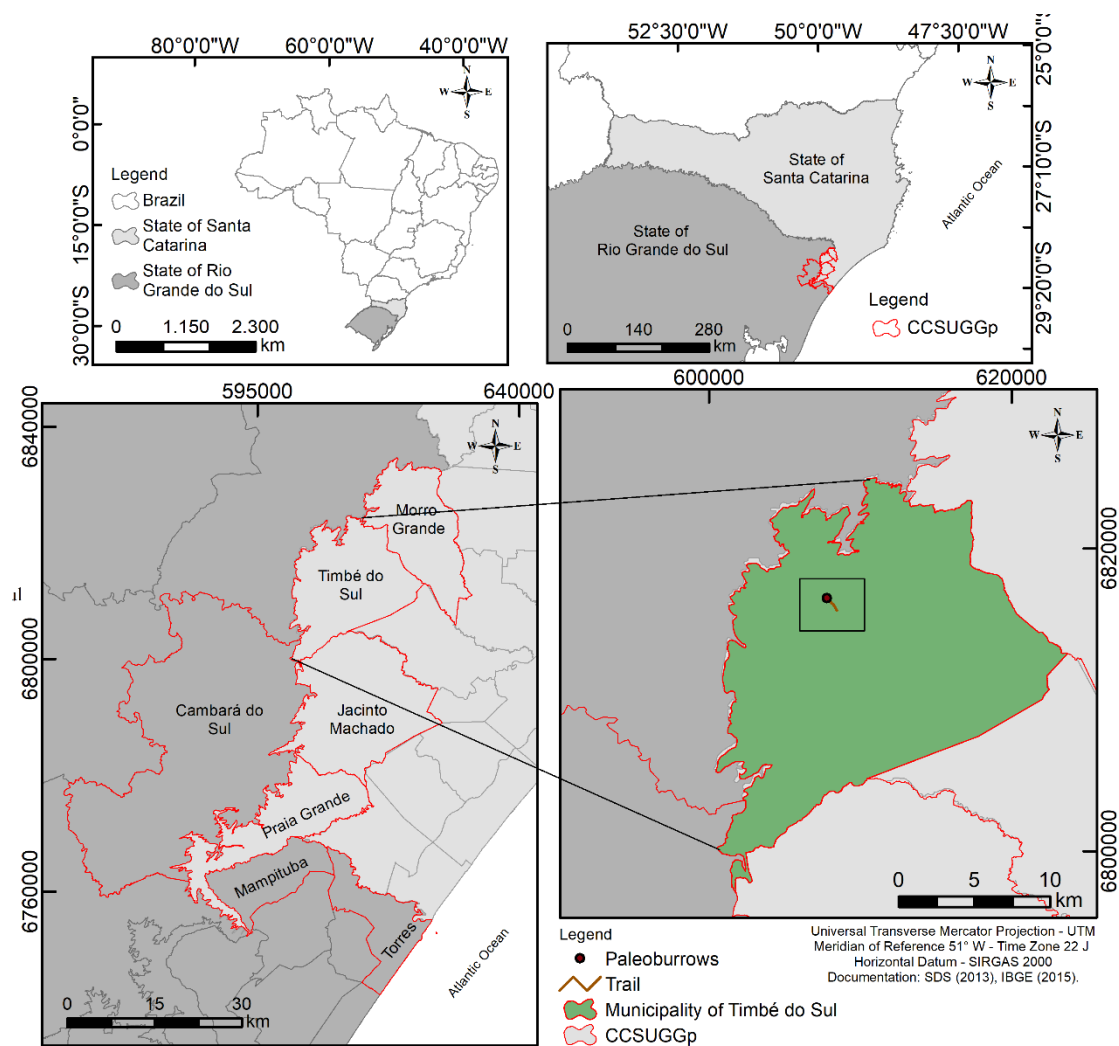


Figure 1. CCSUGP and study area location. Source: Authors 2024.

rological monitoring stations within the State of Santa Catarina. The data were supplied by the organization.

The classification approach presented in this article is grounded in NBR 15505-2/2019 - "Adventure Tourism - Hiking - Part 2: Classification of Routes." This technical standard delineates the criteria for categorizing hiking routes that do not involve overnight stays, based on their specific characteristics and levels of difficulty. The "Degree of Difficulty" takes into account both the distance and the variations in terrains, including ascents and descents. The assessment is based on an adult who is not an athlete and is carrying minimal luggage. This methodology encompasses four primary aspects (Table 1).

It is essential to recognize that the categorization of a route can change based on differing conditions experienced in each season. In this study, fieldwork was conducted during autumn. The guidelines stipulate that the process of route classification should be segmented into distinct sections, each assessed independently according to the four criteria outlined previously. Each criterion is to be rated on a scale from 1 to 5, as illustrated in Table 2.

In assessing the environmental severity, it is essential to evaluate each segment of the route based on a set of twenty factors. This approach enables their classification, as illustrated in Table 3.

For the orientation criterion, it is essential to assess each segment based on its travel accessibility, with values assigned according to the classifications outlined in Table 4.

The technical assessment of the route takes into account the challenges and obstacles encountered in traversing each segment, as detailed in Table 5.

The degree of physical effort aims to categorize the physical exertion necessary to navigate the route, factoring in both the distance and the terrain's variability (including ascents and descents), based on the perspective of an average practitioner, as outlined in Table 6.

To assess the level of physical exertion required, the criterion takes into account the distance of the segments and the terrain's topography, including the impact of elevation changes, such as ascents and descents. The time taken to traverse flat areas can be calculated using

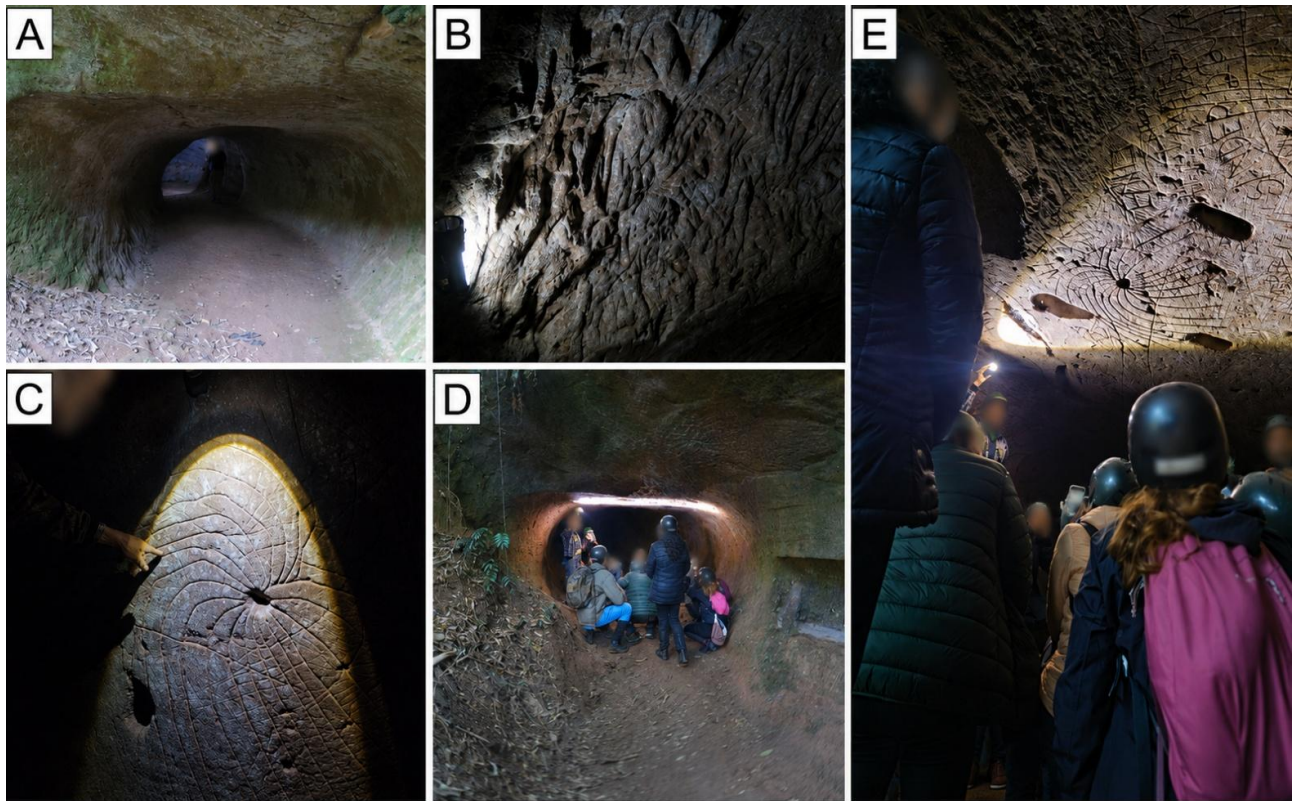


Figure 2. A) Entrance to the Site of Geological Interest - Burrows 'Toca do Tatu'. B) Claw marks of megafauna animals, C) Rock recordings made in sandstone by indigenous populations. D, E) Visitors at the entrance of the burrow observing the engravings and marks. Source: Authors 2024.

Table 1. Criteria for classifying trails.

Criteria	Features
Severity level of the environment	The hazards and challenges posed by the natural environment, including factors such as temperature, precipitation, the potential for falls, and the accessibility of rescue, among others, that may be faced during the journey.
Directions for the pathway	The level of challenge associated with navigation, which includes factors such as the availability of signage, clearly defined paths, and identifiable landmarks, among other elements, necessary for successfully traversing the route.
Technical level of the route	The characteristics encountered along the route concerning the surface and the travel conditions, including various surface types, areas with obstacles, and segments featuring loose stones, among other factors.
Level of physical exertion	The level of physical exertion needed to navigate the route, factoring in its length and variations in terrain, such as inclines and declines, based on the capabilities of an average participant.

Source: [ABNT NBR 15505-2/2019](#).

Table 2. Classification according to the severity level of the environment.

Level	Features	Number of factors
1	Little severe	Until 3
2	Moderately severe	4 or 5
3	Severe	6 or 8
4	Quite severe	9 or 12
5	Very severe	At least 13

Source: [ABNT NBR 15505-2/2019](#).

the following formula:

$$T_h = \frac{D_p}{V_h},$$

where T_h is horizontal displacement time [h]; D_p is the distance covered along the segment [km]; and V_h is the average horizontal speed [km/h].

The speed to be taken into account is related to the characteristics of the terrain in question, with 4 km/h designated for roads and tracks with easy surfaces; 3 km/h

Table 3. Factors for the severity level of the environment.

Features	Features of the factor
a	Exposure to spontaneous detachment of stones during the route;
b	Exposure to rockfall resulting from the actions of the group or other individuals along the route;
c	Potential to descend into an abyss or tumble down a steep incline;
d	There are sections along the route where hand usage is required to advance;
e	Indication of sections along the route that are consistently slippery, rocky, or prone to flooding.
f	Exposure to areas that are slippery or inundated as a result of rainfall along the route;
g	Traversing rivers or other moving water bodies without the support of a bridge;
h	There is a high probability of continuous or heavy rainfall during this time;
i	High probability that the temperature will drop below 0 °C at night;
j	There is a high probability that the temperature will drop below 5 °C and the relative humidity will exceed 90 %;
k	High probability of exposure to strong or cold winds;
l	There is a high probability that the relative humidity will be below 30%;
m	High probability of exposure to heat at temperatures above 32 °C;
n	Prolonged periods of exposure to intense sunlight;
o	The duration required to finish the activity must be at least one hour of walking without encountering a populated area, a distress communication device (such as a telephone, cell phone, or radio signal), or an accessible road with vehicle traffic;
p	The duration required to finish the activity is three hours or more, provided that it does not involve passing through a populated area, accessing a distress telephone (or mobile phone or radio signal), or traveling along an open road with vehicle traffic;
q	The gap between the duration required to finish the route and the hours of natural daylight left at the end of the day (considering the specific time of year) is under 3 hours;
r	A reduction in visibility caused by atmospheric conditions that can significantly complicate navigation or the ability to find individuals along any segment of the route;
s	A path winding through thick foliage or rugged ground that could pose challenges in navigation or in spotting individuals at various points along the way;
t	Regions or areas lacking access to potable water.

Source: [ABNT NBR 15505-2/2019](#).

for trails, smooth paths, and meadows with moderate surfaces; and 2 km/h for rocky paths and riverbeds with difficult surfaces ([ABNT, 2019](#)).

The formula for calculating time on uneven surfaces is:

$$T = \frac{D}{V},$$

where T is the duration of travel when ascending or descending [h]; D is unevenness [m]; and V is the speed of vertical displacement when moving uphill or downhill [m/h].

The elevation changes were measured using GPS throughout the trail. For ascents and descents, it is recommended to use speeds of 200 m/h and 300 m/h, respectively. The effort index is calculated as the total time spent on both horizontal and vertical segments ([ABNT,](#)

2019).

$$IE_{ABNT} = Major\ T + \frac{minor\ T}{2},$$

where IE_{ABNT} is the Effort Index for walking on tourist routes [h]; Major T is the largest sum of travel times [h]; and minor T is the shortest sum of travel times [h].

The standard suggests the development of a preliminary indicative table that adheres to the four specified criteria. This table should be positioned at the start of the route to inform visitors about the technical and physical demands associated with the walk, following the model illustrated in the accompanying figure.

Furthermore, the authors of this study developed a reference table to assist in the field data collection regarding the attributes of the trails and the project ([Table 7](#)).

Table 4. Classification according to the route directions for the pathway.

Level	Features	Walking Route Orientation Conditions
1	Well-defined paths and intersections	Clearly marked main paths feature distinct junctions that provide both explicit and implicit guidance. Following the path does not require any effort to determine the route.
2	Path or sign indicating continuity	A distinct path is marked on the ground, along with signs indicating the route's continuity. While it is important to pay attention to the connections and intersections with other routes, there is no requirement for an exact understanding of the geographical features.
3	Requires the identification of geographical features and cardinal points	Selecting the appropriate route, whether it involves trails or paths defined by natural landmarks such as rivers, valleys, coastlines, ridges, and rocky shores, relies on the ability to identify these geographical features and understand the cardinal directions.
4	Requires off-course navigation skills	The landscape is uncharted, and there are no clear reference points in sight. Navigating the path relies on comprehending the terrain and determining the direction to take.
5	Requires navigation to use alternative and previously unknown routes	The itinerary relies on a thorough comprehension of the terrain and effective route planning, along with the navigation skills necessary to successfully traverse the path. Unexpected obstacles may arise along the route, necessitating alternative solutions to navigate around them.

Source: [ABNT NBR 15505-2/2019](#).**Table 5.** Classification according to the technical degree of the course.

Level	Classification	Technical conditions of the route
1	Route on flat surfaces	Roadways and pathways designed for vehicles, irrespective of their incline. Tiered trails featuring a smooth and even surface. Shorelines composed of sand or gravel that provide a stable and level ground.
2	Route through paths without obstacles	Routes traversing different types of firm terrain characterized by a smooth surface, with clearly marked trails and no steep gradients or obstacles requiring significant physical effort to navigate. Pathways across level landscapes, such as fields and meadows, that maintain a gentle slope.
3	Pathway through terraced trails or rugged landscapes	Paths that traverse trails featuring obstacles or irregular steps of varying sizes, heights, and slopes. Routes that deviate from established trails and navigate through uneven landscapes. Areas that involve crossing rocky terrains or regions with prominent rock formations (such as stone slabs). Segments characterized by loose stones, unstable quarries, highly exposed roots, sandbanks, or significant erosion.
4	Obstacle course	Routes featuring barriers that may necessitate jumping or the use of hands, classified up to I Sup. (UIAA grade for climbing or vertical ascent).
5	A path that necessitates the use of vertical techniques	Sections necessitating climbing techniques ranging from grade II to III Sup. (as per the UIAA grading system for climbing or vertical progression) demand the utilization of specialized equipment and methods. The presence of these sections must be noted in the "Specific Conditions" section, as illustrated in figure 3.

Source: [ABNT NBR 15505-2/2019](#).

Table 6. Classification according to the degree of physical effort.

Level	Classification	Estimated travel time (h) for walking activity
1	Little effort	Up to 1 h
2	Moderate effort	More than 1 h and up to 3 h
3	Significant effort	More than 3 h and up to 6 h
4	Intense effort	More than 6h and up to 10h
5	Extraordinary effort	More than 10h

Note: It is important to note that the time measurement is represented by the effort index associated with walking on tourist paths, and it may not accurately indicate the actual chronological duration of the activity.

Source: [ABNT NBR 15505-2/2019](#).

ROUTE CLASSIFICATION ADVENTURE TOURISM - WALKING				
Route:				Symbols and specific conditions
Activity:				
Average travel time:				
Path:				
				Specific Conditions
Severity Level	Route Orientation	Terrain Conditions	Degree of Physical Effort	
				Route classified according to ABNT NBR 15505-2/2019

Figure 3. Indicative sign model for route classification. Source: [ABNT NBR 15505-2/2019](#).

4. Results

4.1 Trail segmentation and characterization

To delineate the trail, an initial survey and data gathering were conducted on-site, along the designated route. The Portal do Palmiro trail, which leads to the Toca do Tatu Paleotoca, traverses the slope of the Serra Geral and measures 1,809 m in the outward direction. The return journey extends for 643 m back to the intersection point, which coincides with the original departure path, resulting in a cumulative distance of 2,452 m for the entire route.

The route experiences an elevation variation of 85 m, as recorded by the GPS devices, when comparing the trail's starting point to the burrows. The highest elevation along the route reaches 97 m, while the lowest point corresponds to the trail's starting location. Thus, the trail was segmented based on its configuration and physical characteristics.

Figure 4 illustrates the path, as recorded by GPS, alongside the perceived difficulty levels. It identifies

"separation points" at various locations, including the bifurcation to the right at the trail division, stream crossings, areas with smooth and slippery terrain, sections featuring stones (rocks) and exposed tree roots, as well as steep inclines and declines that involve stairs and the use of a rope, culminating at the bifurcation point marked by a black flag. Additionally, the entrance to the burrows is indicated by a red dot.

4.2 Classification of the Portal do Palmiro Trail

Each track section was analyzed separately. Five out of the twenty factors were identified based on their cumulative frequency of occurrence, which include: i) the presence of consistently slippery, rocky, or inundated areas along the route, ii) a significant likelihood of heavy or persistent rainfall during the specified period, iii) relative humidity levels surpassing 90%, iv) a high chance of encountering strong or cold winds, and v) the necessity to traverse rivers or other water bodies with currents at a ford (in the absence of a bridge).

Regarding the factor of "high probability of intense

Table 7. Data collection field form.

Characteristics of the Enterprise			
Location			
City:	State:	Country:	
Owner			
Public:	Private:	Consortium:	
Infrastructure			
Parking:	Lodging:	Toilets:	Showers:
Snack bar:	Internet:	Information boards:	Social media:
Telephone:	Folders:	Meeting point:	Resting place:
Equipment			
Radio Communicator:	Leg warmers	First aid kit	Rescue stretcher:
Personnel available			
Guides / Lead Conductors	Rescuers	Secretary:	Housekeeping Staff:
Features of the Trail			
Length:	Width:	Horizontal Sections:	Steep stretches:
Irregular and slippery surface:		Crossing of water bodies	Eroded soil:
Staircase:	Exposed roots:	Rope access:	Loose stones:

Source: Authors, 2024.

or continuous rains for the period”, the designation “h” does not specify a clear minimum or maximum precipitation threshold to be utilized based on the environmental severity level.

Consequently, a minimum daily precipitation of over 5.50 mm has been established as a guideline for the Portal do Palmiro trail location. The data were collected from the Timbé do Sul rainfall station (2849019), situated in the urban area of the city, which is the sole station in proximity to the study area. This station is managed by EPAGRI and is under the jurisdiction of the National Water and Sanitation Agency (ANA).

The 5.50 mm rainfall threshold is particularly important because of the location on a mountain slope; historically, this region experiences higher precipitation levels, leading to a range of environmental issues (Back 2022; Souza et al. 2022). The uplift of warm, moist air facilitates the development of cumuliform clouds, which in turn results in greater volumes of local rainfall. This threshold reflects concerns for visitor safety as the track traverses several water bodies.

A summary of the monthly and annual rainfall data is presented in Table 8.

Considering the factor of a “high likelihood of temperatures dropping below 5 °C”, as indicated by data from the Timbé do Sul meteorological station, the values presented in Table 9 are as follows.

During the observed period, the minimum daily temperature remained below 5.7 °C. Consequently, it was not regarded as a cumulative factor, as it failed to satisfy

the criteria outlined in letter “i”, which indicates a high likelihood of nighttime temperatures dropping below 0 °C, and letter “j”, which indicates a high likelihood of temperatures falling below 5 °C. Regarding the factor of “relative humidity”, data from the Timbé do Sul weather station is presented in Table 10.

During the 354 days studied, there were 117 days where the relative humidity surpassed 90%, accounting for 33.05% of the total days examined, and approaching 99.9% of the maximum daily levels recorded for the year. In the context of the twenty factors evaluated, relative humidity greater than 90% was included in the route classification under item “j”.

The “wind speed” factor pertains to the relationship between wind velocity and the conditions experienced either at sea or on land. Wind speed is measured according to a scale that ranges from 0 (indicating calm) to 12 (representing hurricane conditions), which corresponds to a specific height above ground or sea level, known as the Beaufort Scale (Hasse 2015).

Data collected from the Criciúma meteorological station reveals the values presented in Table 11, which were recorded during the year 2023.

The designation “k” was assigned to categorize the route, indicating a “high likelihood of exposure to strong or cold winds”, as per the Beaufort Scale. During the observed period of twelve days, which accounts for 3.34% of the total monitored days, wind speeds fluctuated between 50 and 61 km/h. This range is classified as a force index (grade) 7, characterized as “Strong Wind”,

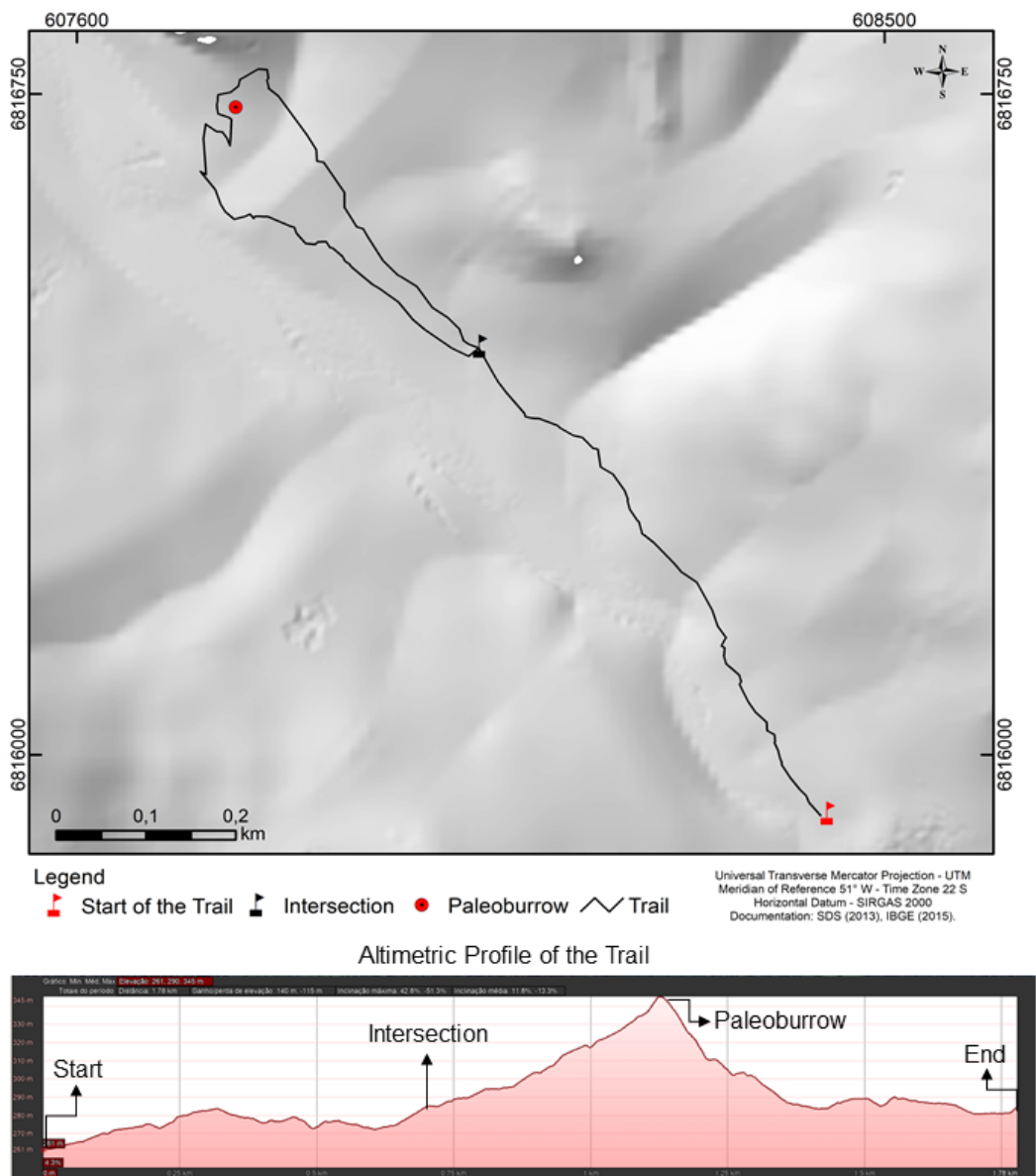


Figure 4. Segments of the Portal do Palmiro Trail. Source: Authors, 2024.

Table 8. Precipitation of the period (2013/2023).

Date	Monthly Maximum (mm)	Monthly Minimum (mm)	Monthly Average (mm)	Annual Total (mm)
2013	469,8	34,9	162,9	1.954,3
2014	348,3	49,5	190,1	2.281,0
2015	443,9	52,5	254,9	3.059,4
2016	279,9	14,6	142,9	1.714,8
2017	261,9	5,5	160,3	1.924,2
2018	278,2	79,0	167,3	2.007,6
2019	293,5	23,0	155,6	1.867,6
2020	334,5	27,0	157,3	1.887,9
2021	356,2	23,2	159,6	1.915,3
2022	298,2	63,8	176,9	2.123,6
2023	322,5	92,3	203,0	1.624,4

Source: The authors, based at the National Water and Sanitation Agency, 2024.

Table 9. Air temperature (2023).

Instant air temperature	(°C)
Annual Daily Minimum	5.8
Annual Daily Average	17.3
Annual Daily Maximum	24.8

Source: The authors, based in EPAGRI-SC, 2024.

Table 10. Relative Air Humidity (2023).

Instant relative air humidity	(%)
Annual Daily Minimum	59,0
Annual Daily Average	87,3
Annual Daily Maximum	99,9

Source: The authors, based in EPAGRI-SC, 2024.

Table 11. Wind velocity - 2023.

Velocity categories (km/h)	Days	% of days
< 1	0	0,00
1-5	0	0,00
6-11	4	1,11
12-19	65	18,11
20-28	152	42,34
29-38	91	25,35
39-49	28	7,80
50-61	12	3,34
62-74	6	1,67
75-88	0	0,00
89-102	1	0,28
103-117	0	0,00
> 118	0	0,00

Source: The authors, based in EPAGRI-SC, 2024

which results in effects such as "large trees swaying" and "challenges in walking against the wind".

In evaluating the criterion of "Degree of severity of the environment", a classification of two (2), denoted as "Moderately Severe", was assigned based on the presence of five factors out of a total of twenty (20). These factors include:

"e" - Encountering stretches of the route that are consistently slippery, rocky, or flooded;

"g" - Navigating rivers or other water bodies with currents at fords (without bridges);

"h" - A significant likelihood of experiencing intense or continuous rainfall during the specified period;

"j" - Relative humidity levels surpassing 90%;

"k" - A high probability of being subjected to strong or cold winds.

The environment of the trail can be challenging (Figure 5), characterized by a rocky and slippery terrain, the presence of water bodies, and fallen tree trunks along

the trail. These factors complicate movement and pose a risk of falls for visitors navigating the route.

Orientation along a route is influenced by its level of difficulty and the available information throughout the trail. This includes the existence of signs, notable landmarks, clearly marked paths, junctions, and forks that provide guidance on the route's continuity, as well as other informational resources that aid in comprehending how to successfully navigate the path (ABNT 2019).

The evaluation of the route was conducted based on the orientation conditions, which indicated that there is a distinct path visible on the ground or markers indicating the route's continuation. However, caution is necessary regarding the continuity and intersections with other paths, although a detailed understanding of geographical features is not essential. This route is categorized as a "path or signpost indicating continuity [...]" and is assigned a Grade 2 classification, as outlined in Table 3.

There are informational signs along the trail (Figure 6). While these signs function as markers, they do not indicate the path to be taken or the distance to the primary attraction. Their primary purpose is to convey information regarding the site itself.

The "Technical grade of the route" pertains to the various characteristics of the path concerning the terrain and the conditions for traversing it. This includes factors such as the type of ground, the presence of obstacles, and areas with loose stones, among others. The assessment of the route took into account "irregular obstacles or steps of varying sizes, heights, and inclinations, as well as crossings over rocky areas, stretches of loose stones, unstable quarries, and prominently exposed roots". It has been categorized as "Route over stepped trails or uneven terrain" and assigned a Grade 3 classification according to Table 7.

The route includes some hazards (Figure 7) such as uneven steps characterized by differing heights and angles along the pathway, as well as sections featuring loose stones and visible roots.

Table 12 shows the data on the sections of the route according to the difficulty of movement.

The time recorded for flat surfaces with an inclination of less than ten percent (10%) was 0.52 hours. For surfaces with an inclination (hill) exceeding ten percent (10%), the time recorded was 2.4 hours, while for surfaces with a slope greater than ten percent (10%), the time was 1.6 hours (Table 13). The Effort Index is calculated by summing the times of the horizontal and vertical sections, utilizing the following formula:

$$IE_{ABNT} = \text{major } T + \frac{\text{minor } T}{2} \text{ Then: } IE_{ABNT} = 4 + \frac{0,52}{2} \text{ It has: } IE_{ABNT} = 4.2 \text{ hours.}$$

There are also challenges to movement along the trail (Figure 8), which include segments with inclines and/or declines, stairs, rocky areas, and ropes.

The analysis of the Portal do Palmito trail reveals that 63.5% of the trail, equating to 1,556 m with an incline of less than 10%, is categorized as low difficulty. In contrast, 22.75% of the trail, which measures 557.95 m and features an incline ranging from 10% to 20%, is



Figure 5. Severity of the environment - dangers and difficulties on the trail. A) Stony and slippery ground, B) crossing water bodies, C) tree trunks in the trail bed. Source: Authors, 2024.



Figure 6. Signposts along the trail. A) Sign at the start of the trail, B) portal identifying the trail, C) historical information plaques about the burrows. Source: Authors 2024.

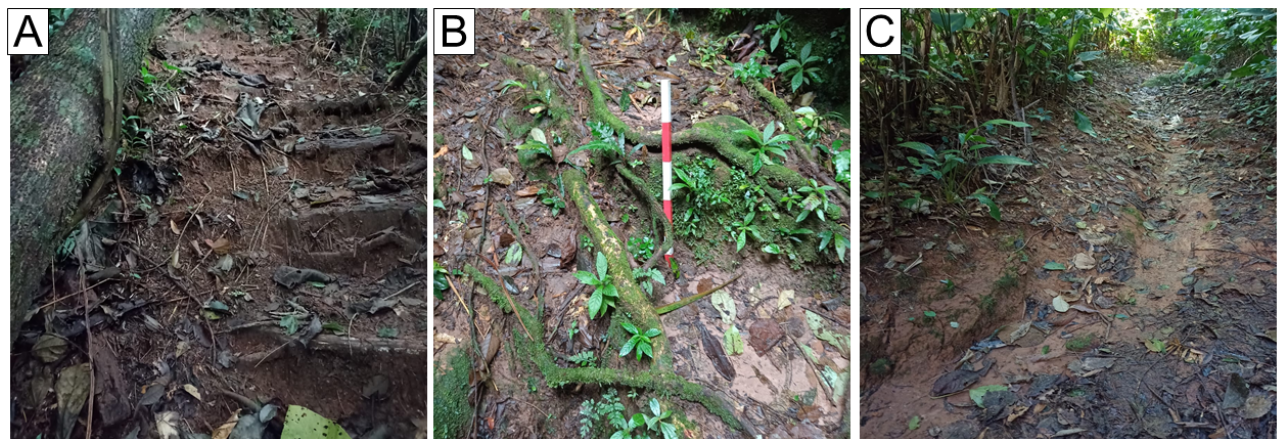


Figure 7. Pathway traversing stepped trails or rugged landscapes. A) Uneven steps featuring diverse elevations and inclines, B) areas characterized by loose rocks and visible roots, C) a steep and slick segment. Source: Author, 2024.

Table 12. Trail route according to each section.

Slope	< 10% (Inclines/declines)	> 10% (Inclines)	> 10% (Declines)
Route (m)	1.566,92	475,69	475,64

Source: Authors 2024.

Table 13. Physical effort index of the trail.

Inclination	< 10% (inclines and declines)	> 10% (inclines)	> 10% (declines)
Route (km)	1,56	0,47	0,47
Results (km/h)	0,52	2,4	1,6
IE_{ABNT}	4,2 hours		

Source: Authors, 2024

**Figure 8.** Challenges in mobility include: A) Inclines and/or declines, B) use of a rope for assistance during ascents, C) areas featuring rocks of different dimensions. Source: Authors, 2024.

classified as medium difficulty. Finally, the remaining 13.75%, with an incline exceeding 20% and a length of 337.56 m, is deemed to be of great difficulty.

An important observation is that the measurement of time, expressed by the effort index for walking on tourist routes, in this case 4.2 hours, does not necessarily reflect the chronological duration of an activity, as it includes stops for rest and contemplation.

The "Degree of physical effort" assesses the anticipated travel time (h) for walking activities, specifically for durations exceeding 3 hours but not surpassing 6 hours, necessary to finish the route. This evaluation considers both the distance and the terrain's irregularities, including ascents and descents. A typical participant in this context has been categorized as experiencing a "Significant effort", designated as Degree 3, in accordance with Table 5, which outlines the classification based on the Degree of physical effort.

The classification of the route with an informative table at the start of the path (Figure 9) outlines the technical and physical requirements necessary for the hike. This table adheres to the standards set forth by ABNT 15505-2/2019. Alongside the field research carried out in collaboration with CCSUGP, it is suggested that an identification and classification plaque be installed at the research site (Figure 10).

The signage located on-site will fulfill both an orienting and interpretive role, providing visitors with accurate information throughout the trail, while simultaneously enhancing the understanding and preservation of the geological heritage.

5. Discussion

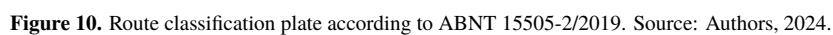
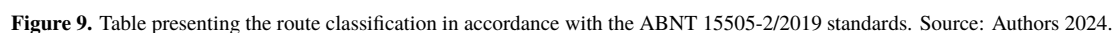
The categorization of routes serves as a vital tool in enhancing the availability of tourist products that promote safe walking activities. It establishes clear criteria and provides participants with essential information in a systematic, standardized, and comparative format. Beyond offering information to participants, this classification aids in the improved planning and design of tourism enterprises and facilitates the analysis of incident studies, among other benefits (ABNT 15505-2/2019).

Trail classification extends beyond its informative role, functioning as an important tool for geoconservation. By providing standardized information on route characteristics, difficulty level, and visitation conditions, it reduces uncertainty for visitors, supports informed decision-making, and facilitates the advance planning of recreational activities.

In highly fragile geosites, such as burrows, this information supports the management of public use and helps minimize unnecessary incursions into sensitive environments, thereby strengthening preventive geoconservation strategies.

Furthermore, the information sign contributes to communicating the characteristics of the trail in a clear and standardized manner, allowing visitors to assess in advance whether the route is compatible with their physical condition and technical experience. This information can discourage inappropriate use and support safer visitation.

From a management perspective, the proposed classification extends beyond visitor guidance by providing a practical tool for planning public use. Consequently,



the methodology can be replicated in other trails located in protected areas, contributing to more efficient visitor management and the conservation of fragile geological environments.

The trail under consideration is classified as "moderately severe" (Grade 2) according to the Environmental severity level, indicating the presence of challenges such as slippery areas, river crossings, and high humidity. Nevertheless, 63.5% of the trail features a gradient of less than 10%, categorizing it as low difficulty. This accessibility allows individuals with moderate physical fitness to navigate the route. As noted by [Sunkar et al. \(2022\)](#), the level of difficulty is a crucial factor that can influence visitor numbers at the location. The initial segment of the trail is characterized as easy and free of obstacles.

The evaluation of the trail's orientation was classified as "Path or signage indicating continuity" (Grade 2), highlighting the necessity for enhancements in the signage and informational resources available along the trail. While there are some informational signs, they do not adequately ensure complete independence for visitors.

The Technical grade of the route has been designated as "Route through stepped trails or uneven terrain" (Grade 3), owing to the existence of challenges including loose rocks, visible roots, and irregular steps. Similarly, the Physical effort was assessed as "significant effort" (Grade 3), signifying that the hike demands a moderate to high level of energy, varying by different sections of the trail.

The results support existing literature that underscores the necessity for well-defined criteria to categorize trails in natural environments ([ABNT 2019](#)). Comparable research in UGGp highlights the importance of comprehensive classifications to enhance visitor safety and facilitate effective environmental management ([Mazzali et al. 2021](#); [Marsiglia 2022](#); [Sunkar et al. 2022](#); [Pimentel et al. 2023](#)).

Thus, trail classification provides important guidance for visitors. Although the classification itself does not directly reduce impacts on the burrows, it provides essential information that supports management actions aimed at minimizing such impacts. By offering advance information on the trail's difficulty level, route conditions, and physical characteristics, it enables visitors to assess their physical and technical capabilities before undertaking the hike, thereby reducing the likelihood of accidents, off-trail travel, and behaviors that could compromise the integrity of the geological heritage.

While various methodologies for trail classification have been proposed in Brazil ([Andrade and Rocha 2008](#); [Silva et al. 2016](#); [Guimarães et al. 2022](#)), the prevailing standard is outlined in ABNT NBR 15505-2/2008, which was subsequently updated to ABNT NBR 15505-2/2019.

Despite the existence of this formal standard, there is a notable scarcity of technical and scientific studies that have adopted it as a classification framework ([Magri et al. 2018](#); [Vila Verde et al. 2020](#); [Silva and Sezerino 2021](#)). Within the CCSUGGp, only two trails have been

classified in accordance with this standard ([Mazzali et al. 2021](#); [Pimentel et al. 2023](#)).

While the criteria employed are acknowledged for their strength, it is important to note certain limitations. Specifically, the classification is influenced by local climate and geomorphological data, which can fluctuate due to extreme events or unexpected seasonal changes. Research by [Mazzali et al. \(2021\)](#) and [Pimentel et al. \(2023\)](#) on the SIG Rio do Boi trail and the SIG Cânion Malacara trail underscores the necessity of assessing the atmospheric and geomorphological features of the area, incorporating hydrological analysis to mitigate risks to tourists posed by potential extreme events, such as sudden floods and landslides.

An additional aspect to emphasize in the methodology is that the data regarding physical effort was derived from estimates, which can differ based on the characteristics of the visitors. To address this issue, it is advisable to conduct preliminary research on the visitor profiles associated with the trail under examination, specifically by calculating the social tourist support capacity of the trail in advance ([Kayat and Radzi 2012](#)).

It is recommended that comparative analyses be conducted with other CCSUGGp trails to uncover shared patterns and challenges across these trails. This would facilitate the establishment of a classification standard, thereby assisting tourists in navigating the CCSUGGp communication platforms and the national parks that feature these attractions.

The significance of enhancing the infrastructure of informational signage is highlighted, as these signs can convey information to visitors in a more direct and accessible manner, as noted by [Lima et al. \(2016\)](#). Interpretive panels serve to educate visitors and provide explanations of specific aspects of the area, foster visitor engagement, and promote awareness of appropriate conduct. These panels hold value even when visitors spend only a brief moment in front of them ([Lima et al. 2016](#)).

Finally, trail classification can also be integrated into geosite monitoring programs, as the parameters used for classification require periodic reassessment. Trails in natural environments are dynamic and tend to change over time.

Variations in route conditions, vegetation cover, drainage patterns, or visitor safety may alter the original classification, thereby providing indirect indicators of changes in the site's environmental conditions. Consequently, periodic trail reclassification can serve as a complementary tool for monitoring geosite conservation and supporting the continuous improvement of management strategies.

6. Concluding Remarks

The introduction of UGGps in Brazil has led to a significant rise in the emergence of new tourist destinations and regions, accompanied by a marked increase in visitor numbers. This growth has been particularly pronounced since 2022, following the recognition of additional territories. However, the identification and development

of these new attractions, along with their swift promotion and improved accessibility, pose a potential risk of causing irreversible adverse effects on these destinations if not managed through meticulous planning and professional oversight.

This study sought to characterize and classify the Portal do Palmiro trail, which serves as an access route to Paleotoca Toca do Tatu within CCSUGGp. The key findings are as follows:

1. The primary contribution of this study was to categorize the Portal do Palmiro trail based on its level of difficulty, taking into account the various features present along the path.
2. The establishment of a preliminary table at the start of the route that outlines the technical and physical requirements of the walk, while prioritizing the safety of the visitors.
3. The sections evaluated based on the established criteria were categorized as follows: Environmental Severity - Level 2 (moderately severe); Route orientation - Level 2 (presence of paths or signage indicating the route); Terrain conditions - Level 3 (characterized by stepped trails or uneven surfaces); and Physical effort intensity - Level 3 (requiring considerable physical exertion).
4. While certain parts of the route feature inclines ranging from 10% to 20%, classified as medium difficulty, and other sections exceed 20%, categorizing them as high difficulty, the predominant portion of the trail (63.5%) or 1,556 meters of the total 2,452 meters, exhibits an incline of less than 10%, thus deemed to be of low difficulty.
5. The Effort index for traversing tourist paths, which indicated a duration of 4.2 hours, does not strictly represent the actual time spent on the activity, as it accounts for breaks taken for rest and reflection.

The findings of this study hold considerable importance for advancing sustainable tourism within the CCSUGGp. The comprehensive categorization of the trail facilitates the delivery of objective and standardized information to visitors regarding the difficulty level, thereby enhancing safety and enriching the tourist experience. These trails serve not merely as routes through nature but also offer a wealth of information that can be gleaned from their accurate interpretation.

The results demonstrate that the application of ABNT NBR 15505/2 is an effective tool for the technical classification of trails in natural areas, enabling the standardization of information essential for visitor management and planning. The development of the informational sign further enhances this contribution by translating technical findings into accessible language for visitors, thereby strengthening communication between managers and trail users and supporting safer and more informed visitation.

In addition to fostering a safer and more informed visitor experience, this approach contributes to public use management, strengthens geoconservation strategies, and provides a replicable methodological framework for the classification of trails in geosites and other protected areas.

The methodology presented in this study has the potential for enhancement as additional data is incorporated into the equations. Nevertheless, the adaptations implemented in this work can serve as a framework for classifying other trails within the CCSUGGp and comparable UGGps, thereby aiding in the establishment of methodologies aligned with ABNT NBR 15505-2/2019.

Given that this is a Brazilian standard, its implementation in other areas of the country is achievable, necessitating only that the data be modified by the researchers or the relevant public authorities. Ultimately, the proposed methodology aims to promote the implementation of standardized trail classification systems within UGGp and other protected regions, thereby enhancing public use policies, fostering sustainable visitor management, and aiding in the preservation of geological heritage.

Conflicts of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Declaration of Funding

This study was financed in part by the 'Coordenação de Aperfeiçoamento de Pessoal de Nível Superior' - Brazil (CAPES) - Finance Code 001. This study was financed in part by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the postdoctoral fellowship awarded to the second author (150258/2025-9) and the Research Productivity Scholarship awarded to the last author (312543/2022-0).

Author Contributions

Luciano Miranda: Writing - review & editing, Writing - original draft, Methodology, Investigation, Data curation, Conceptualization. **José Gustavo Santos da Silva:** Writing - review & editing, Writing - original draft, Methodology, Investigation, Data curation. **Gabriel da Silva Souza:** Writing - review & editing, Visualization, Validation. **Álvaro José Back:** Project administration, Data curation, Conceptualization. **Jairo Valdatti:** Writing - review & editing, Validation, Supervision. **Juliano Bitencourt Campos:** Writing - original draft, Supervision, Project administration.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the author(s) used Ahrefs Free AI Paragraph Rewriter (<https://ahrefs.com/writing-tools/paragraph-rewriter>) to enhance the document's readability in English, considering that English is not the authors' native language. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

During the preparation of this work, the author(s) used ChatGPT/OpenAI 5.3 (Free) to collate and format references, support analysis and scholarly language. After using this tool/service, the author(s) reviewed and edited the content as needed, and take(s) full responsibility for the content of the publication.

Acknowledgments

We extend our heartfelt gratitude to the community and visitors who participated. A special acknowledgment goes to Mrs. Marta Baumarte and Mr. Valdivino Alano (Portal do Palmiro).

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