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INVESTIGATION OF THE PHYSICAL CARRYING CAPACITY OF SELECTED CAVES IN THE BUDA MOUNTAINS AND SZEKLERLAND FROM THE PERSPECTIVE OF TOURISM SUSTAINABILITY

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ABSTRACT

The desire to escape everyday life, the allure of nature's beauty, and the exploration of underground worlds that are accessible, often within developed areas, are increasingly driving tourist demand for caves. Visiting caves, whether from a tourist or professional perspective, is the discovery of a natural wonder, an exhilarating and unforgettable adventure for most tourists. From an ecotourism standpoint, beyond ensuring a fulfilling tourist experience, safeguarding the integrity of the cave system as a whole is paramount, as sustainability and preservation are both crucial. To this end, this study aimed to investigate the physical carrying capacity of caves in four locations with significant tourist potential at various geographical locations. Through on-site research, the recommended maximum number of visiting groups was determined for each cave, considering the size of the usable area for tourism activities and the social comfort distance of visitors. This is vital to prevent overcrowding in narrow sections during tours and may aid in the preservation of the cave and its formations. The research results obtained in this manner were compared with current visitor data. This comparison revealed what the optimal number of visitors is during existing tourist activities, how tourism impacts cave preservation, and whether it contributes to degradation, necessitating a reduction in visitor numbers.

Keywords: cave tourism, ecotourism, physical carrying capacity, sustainable development, quantitative analysis

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A BUDAI HEGYVIDÉKI ÉS SZÉKELYFÖLDI BARLANGOK FIZIKAI TEHERBÍRÓ KÉPESSÉGÉNEK VIZSGÁLATA A TURIZMUS FENNTARTHATÓSÁGA SZEMPONTJÁBÓL

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ABSZTRAKT

A mindennapi élet elől való menekülés vágya, a természet szépségének varázsa és a föld alatti világok felfedezése, amelyek gyakran a fejlett területeken belül is elérhetőek, egyre inkább a barlangok iránti turisztikai keresletet mozgatják. A barlanglátogatás, akár turista, akár szakmai szempontból, a legtöbb turista számára egy természeti csoda felfedezését jelenti, amely izgalmas és felejthetetlen kalandot jelent. Az ökoturizmus szempontjából a teljes értékű turisztikai élmény biztosításán túl a barlangrendszer integritásának megőrzése a legfontosabb, mivel a fenntarthatóság és a megőrzés egyaránt kulcsfontosságú. E tekintetben a tanulmány célja a barlangok fizikai teherbíró képességének vizsgálata volt négy, különböző földrajzi elhelyezkedésű, jelentős turisztikai potenciállal rendelkező helyszínen. Terepi kutatással minden barlang esetében meghatároztuk a látogatócsoportok ajánlott maximális létszámát, figyelembe véve a turisztikai tevékenységekhez használható terület nagyságát és a látogatók közötti megfelelő fizikai távolságot. Ez elengedhetetlen ahhoz, hogy a túrák során a szűk szakaszokon ne legyen túlzsúfoltság, és segítheti a barlang és képződményeinek megőrzését. Az így kapott kutatási eredményeket összevetettük a jelenlegi látogatói adatokkal. Ez az összehasonlítás rámutatott arra, hogy a jelenlegi turisztikai tevékenységek során mi az optimális látogatószám, hogyan hat a turizmus a barlang megőrzésére, és hozzájárul-e a degradációhoz, ami a látogatószám csökkentését teszi szükségessé.

Kulcsszavak: barlangturizmus, ökoturizmus, fizikai teherbíró képesség, fenntartható fejlődés, kvantitatív elemzés

Köszönetnyilvánítás: Köszönetünket fejezzük ki a Magyar Duna-Ipoly Nemzeti Park Igazgatóságnak a különböző barlangokhoz szükséges belépési és mérési engedélyek megadásáért, valamint a Gyilkostó Adventure Egyesületnek. Külön köszönet Szabó Tivadar barlangkutatónak, aki önzetlenül hozzájárult terepmunkánkhoz.

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1. Introduction

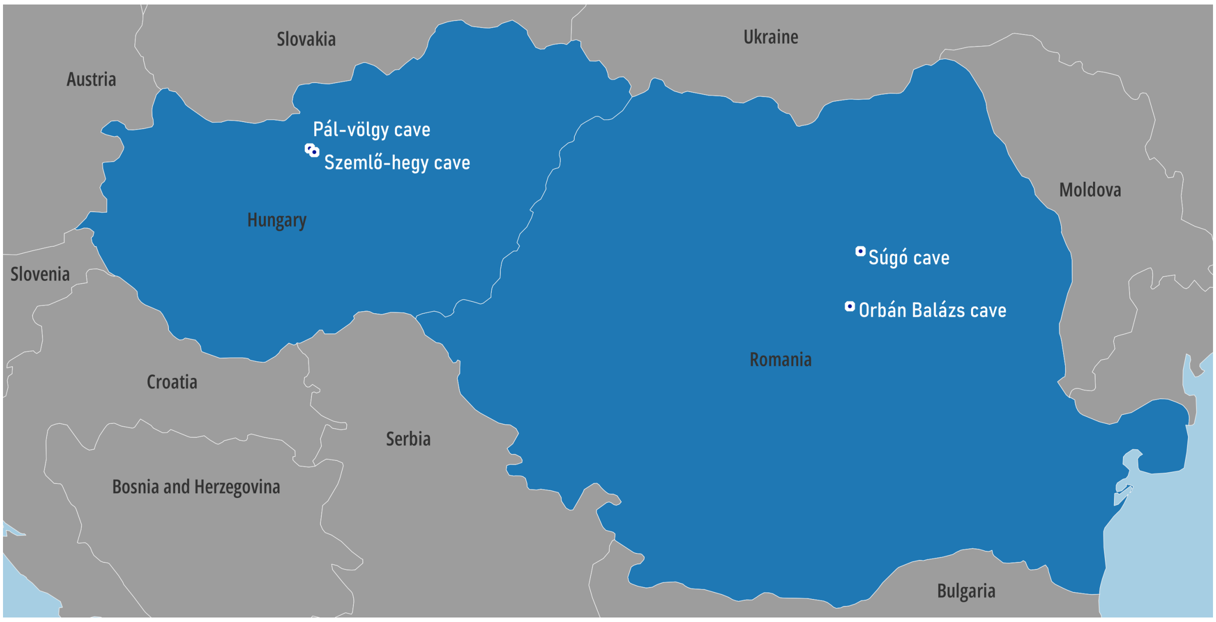
Geotourism plays a critical role in achieving sustainable tourism development. This approach prioritizes experiences centered around geological features, including caves, while fostering environmental and cultural understanding, appreciation, and conservation efforts (Dowling, 2013).

Geotourism can significantly enhance local economies by creating jobs within the tourism sector and promoting economic growth, particularly in remote regions. Furthermore, it cultivates public awareness and appreciation of the significance of geological features, motivating geoconservation initiatives to safeguard them from degradation. Through guided tours and designated geo-trails, geotourism fosters education among tourists regarding Earth's geological history. It also incentivizes local communities to preserve their cultural heritage by offering opportunities for participation in tourism operations (Bujdosó et al., 2015; Jayakumar, 2015). However, the sustainable development and management of geotourism remains paramount to minimize environmental impact and ensure the long-term preservation of geosites (Šambronská et al., 2023).

Caves, as subterranean marvels, hold immense appeal for ecotourists (Knežević & Grbac-Žiković, 2011). Their inherent mystique, shaped by geological processes over millennia, beckons explorers seeking a distinctive experience (Main, 2014; Antić et al., 2022). Caves harbor geological formations that captivate the imagination. Among these structures, stalactites stand out. Their delicate beauty and intricate patterns evoke wonder. However, stalactites are just one facet; other formations, such as stalagmites and flowstones, contribute to the overall enchantment. These formations, shaped by water, minerals, and time, create a unique underground landscape. Visitors are drawn to these natural sculptures, marveling at their delicate balance between fragility and endurance (Telbisz et al., 2023).

Caves are not mere geological curiosities, however; they also serve as repositories of history. Archaeological excavations reveal artifacts, ancient tools, and evidence of human habitation. These findings provide a temporal dimension, connecting contemporary visitors to past civilizations. Tourists, led by knowledgeable guides, can explore these subterranean time capsules, unraveling stories etched in stone. The juxtaposition of natural wonders and human history creates a layered narrative, enriching the ecotourism encounter (Zieliński et al., 2022).

Figure 1: Geographical location of the caves included in the research in the Carpathian Basin



Source: own editing

Beyond geological wonders, caves harbor a distinct ecosystem – the cave fauna. These specialized organisms have adapted to the darkness, scarcity of resources, and unique microclimates within caves. From blind fish to translucent spiders, these creatures exemplify evolution's ingenuity. Ecotourists, guided by experts, explore this hidden world, witnessing life forms that defy conventional expectations. The presence of cave fauna adds depth to the ecotourism experience, emphasizing the interconnectedness of life across diverse habitats.

The Szemlő-hegy and Pál-völgy caves located in Hungary stand out as exceptional choices for this study due to their well-established popularity and the extensive research conducted within them (Czuppon et al., 2021; Piroska et al., 2016; Mari & Fehér, 1999). In the Szeklerland area of the Eastern Carpathians in Romania, the two best-known caves with the greatest attraction and tourist potential are the Súgó and the Balázs Orbán caves (Dénes, 2002). All these caves have long been recognized as significant sites for speleology and cave science, attracting numerous researchers who have dedicated their efforts to unraveling the mysteries they hold, which is the main reason for selecting them for our comparative study (Figure 1).

The caves of the Buda Hills are fascinating natural formations located in the heart of Budapest (Leél-Őssy, 2015). Among the most well-known are the Szemlő-hegy and Pál-völgy caves, where concerts and other cultural events are often held (Szakály, 2016).

When comparing the caves of the Buda Hills to those in Szeklerland (a region in Romania), it is important to note their differing environments and geological characteristics. While the Buda Hills caves are more easily accessible due to their proximity to the city and are more developed for tourism, the caves in Szeklerland are generally situated in more remote and wild environments, often presenting greater challenges for visitors. In a previous study, we examined Szeklerland's caves with the greatest tourism potential (Molnár & Magyari, 2023), selecting the first two – the Súgó cave and the Orbán Balázs cave – as the focus of our current research.

Despite the approximately 500 km that separates the Buda Hills and Szeklerland caves (Figure 1), their preservation and carefully managed tourism utilization are crucial for the long-term sustainability of both local communities and the natural environment. Therefore, the aim of this study is to examine and compare the physical carrying capacity of these four caves from a tourism perspective, contributing to scientifically informed decision-making for further ecotourism utilization.

2. Literature review

Geoconservation involves safeguarding geodiversity elements with significant heritage value. As more visitors explore national parks and protected areas, the need for effective management strategies becomes paramount (Furtado Oliviera et al., 2022; Lobo, 2015).

Several methods exist for evaluating the tourism carrying capacity of geological sites, encompassing three important approaches. Quantitative models use mathematical equations to estimate optimal visitor load. Parameters include site characteristics, infrastructure, and environmental factors. Visitor surveys are important for informing carrying capacity assessments by collecting data on visitor behaviors, preferences, and impacts (Teblisz et al., 2020). These insights guide management decisions. Considering geoindicators can be locally significant, as specific indicators are tailored to each site type to help determine carrying capacity. These may include geological fragility, habitat sensitivity, and cultural significance.

The objective of a recent study (Ajuharie et al., 2023) has been to assess various methods of carrying capacity and analyze their trends in the context of tourism management. Through comprehensive research, several key findings have emerged. One widely used method is the normative approach, which establishes limits based on predefined norms or standards. This method provides a structured framework for determining carrying capacity, ensuring that tourism activities remain within sustainable bounds. Another prominent approach is Cifuentes' method (1992), which takes into account both environmental factors and experiential changes. By considering these dynamic elements, this method offers a more holistic perspective on carrying capacity assessment.

In another relevant study (Santos & Brilha, 2023) the authors proposed a method for calculating recommended visitor numbers in geological sites, aiming to balance tourism with conservation efforts. The methodology involves the use of geoindicators, site-specific factors such as rock stability and cultural value, to guide the assessment of carrying capacity. These geoindicators serve as metrics to determine the thresholds for each site, setting limits that account for environmental and cultural sensitivities. Dynamic adjustments are integral to this method, recognizing that the total carrying capacity of a geological site is not static. Instead, it must adapt to changing conditions. This flexibility allows for ongoing monitoring and adjustments to visitor numbers as necessary, ensuring that the site's sustainability is maintained over time (Buonincontri et al., 2021).

Caves harbor intricate ecosystems which are exceptionally sensitive to human intervention (Constantin et al., 2021). Many tourists are unaware of the significance of caves and are unfamiliar with the fundamental geological processes that occur within them and with the general geological history of caves. This lack of knowledge often leads to insufficient attention to cave conservation (Hose et al., 2011). Excessive visitor presence can stress cave-dwelling organisms and irreversibly alter natural processes. Therefore, limiting simultaneous visits is crucial. The challenge lies in striking a balance between accessibility and preservation (Cerkvenik 2016; Chiarini et al., 2022). Additionally, cave infrastructure development and maintenance incur significant costs, yet providing visitors with a positive experience – exploring underground wonders, admiring geological formations, and discovering cave fauna – is equally vital. Sustainable management necessitates understanding the cave's limits while minimizing environmental impact. As ecotourists flock to caves, we confront a paradox: our fascination threatens the very environments we admire. Foot traffic, lighting, and inadvertent disturbances impact cave ecosystems. To ensure the longevity of these treasures, we must adopt a proactive stance (Cigna, 1993). A comprehensive analysis of tourism's effects – both positive and negative – is essential. By quantifying impacts, we can devise targeted conservation strategies. These may include visitor education, controlled access, and habitat restoration. Ultimately, our goal is to promote sustainable tourism practices that safeguard caves for generations to come (Béki et al., 2016).

Crowding within caves increases accident risks, especially in narrow passages or steep sections (Ghanbari et al., 2021). Carrying capacity refers to the maximum number of visitors a site can sustainably accommodate while minimizing adverse impacts. Properly assessing physical carrying capacity also ensures visitor safety. Determining physical carrying capacity is integral to sustainable tourism as it prevents overcrowding, maintains ecological balance, and safeguards cave ecosystems. By quantifying visitor limits, tourism providers can organize and supervise cave tours effectively, reducing accident and emergency risks (Lobo, 2011). Moreover, it ensures that future generations can appreciate and learn from these unique natural formations.

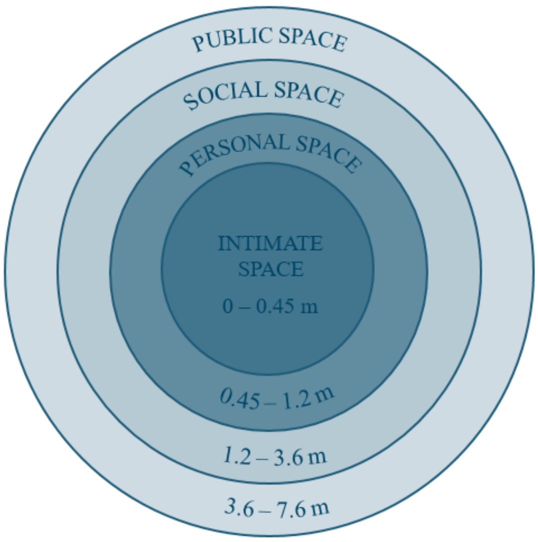
Cheablam and Rattanarat (2021) examined both physical and ecological carrying capacity in the context of cave tourism. Their study focused on two key points: physical capacity and ecological capacity. Physical capacity considerations include infrastructure, safety measures, and managing visitor flow within caves for a smooth and safe tourist experience. Ecological capacity is concerned with the impacts of tourism on cave ecosystems, aiming to mitigate any adverse effects. The calculation of carrying capacity should consider a qualitative assessment of the cave's tourist resources, which is closely linked to the availability of trained tourist guides (Igor & Gregor, 2010).

3. Research methodology

To determine the useful area, a Leica DISTOTM X310 laser distance meter was employed. During the assessment of the base area of the four cave tourist sections, various results were obtained due to the distinct characteristics of the caves. These differences include size, dimensions, popularity, geographical location, and structural composition.

Data collection was a straightforward process: using the distance meter, longitudinal and transverse measurements were recorded in each chamber or any location where visitor groups spent time. Longitudinal measurements captured the length of the chamber, while multiple smaller transverse measurements (taken every 3 or 4 meters, depending on the cave's features) were used to determine the average width of the chamber. The product of these two values – the longitudinal and average width – represents the size of the specific chamber or stop, expressed in square meters as the useful area for tourists. After calculating the base area of each individual room and stop, their totals were summed to determine the overall area of the cave's tourist section.

Figure 2: Spaces surrounding a person



Source: own editing after Forgács (1998)

After determining the base areas of the caves, the next step was the establishment of the maximum group size of visitors. To achieve this aim, it was necessary to understand the dynamics of human spatial behavior – specifically, how much space an individual typically requires within a given group to feel at ease and undisturbed. Various psychological studies (Forgács, 1998) have shown that spatial behavior is personality-dependent, varying from person to person and significantly influenced by an individual's emotional history and family background.

In general terms, an individual has four different levels or zones of personal space surrounding them. Moving outward, these zones include the intimate zone, personal zone, social zone, and public zone (Edward, 1995). These zones can be visualized in terms of distances, as illustrated in Figure 2. In the context of cave tourism, an individual's comfort zone falls within the personal distance zone, which can be further divided into two segments: close (45–75 cm) and distant (75–120 cm) from the individual. The distance at which two people can still touch each other while not perceiving each other's features as distorted and not sensing the minimal amount of heat emitted by each other's bodies falls within the close segment of personal space, approximately 45 to 75 centimeters from the individual.

Taking the above into account, to determine the maximum group size, we need to calculate the area of a circular personal space. For this calculation, an average value of 60 cm will serve as the radius of the circle. Thus, the required area for one person can be calculated by determining the area of the circle, resulting 1.13 m^2. We will denote this value as RA (required area for one person). The ratio between the base area and the area required for one person yields the maximum group size, denoted as GS. To calculate this, we use the following formula, which incorporates the total accessible area of the cave room (A) and the area required for one person (RA). In caves, the total accessible area refers to the space visitors are permitted to enter. This can encompass entire chambers in undeveloped caves or designated paths and chambers in developed caves. The required space per person can vary depending on the situation. For example, more space may be needed for children who are more active or for people who use wheelchairs. In these cases, the above mentioned 60cm should be adjusted accordingly.

$$GS = A/RA$$

Afterward, the following values were determined:

- the number of people which can be present simultaneously in the entire cave (NTA) taking into account the daily opening hours (OH)
- the number of people who can visit the cave in a single day (NVD). The latter was determined by performing the following formula:

$$NVD = \frac{A}{RA} * OH = GS * OH$$

The above formulas provide a statistical foundation for evaluating the physical carrying capacity of caves, both individually and for comparative purposes. Although these formulas are not designed to simulate all real-life situations, particularly those involving diverse visitor demographics (children, people with disabilities, wheelchair users), they can be adjusted to account for such factors.

After considering the obtained results, the number of daily visitors is compared with current statistical data, which reflects the ongoing visitation at a specific location. Interpreting and studying these differences reveals whether the positive trend favors appropriate management or if negative trends are detrimental to the cave and its formations. Consequently, reducing the daily visitor count becomes necessary for long-term preservation and sustainability.

4. Results

Due to the varying characteristics of the caves included in this study, the results significantly differ from one another. Budapest's caves exhibit intermediate values compared to the caves in Szeklerland. However, differences exist between these two locations in terms of size and cave morphology. The narrow passages and small chambers of the Súgó cave resulted in the lowest visitor count. Conversely, the Orbán Balázs cave, lacking proper tourist infrastructure, yielded a notably higher visitor count, as it remains accessible without closure.

To provide precise results, each cave's data are presented in detail. The interpretation of data included in these tables is provided below, using the following abbreviations in their headers:

A – area of a cave room
RA –required area for one person
GS – group size
OH – daily opening hours (every group starts a visit in an exact hour)
NVD – number of visitors in one day
RD – actual visitors' data from existing records
NTA – total carrying capacity of a cave (total number of persons who can stand in the cave at the same time)
NTAD – one day total carrying capacity

4.1. Szemlő-hegy cave

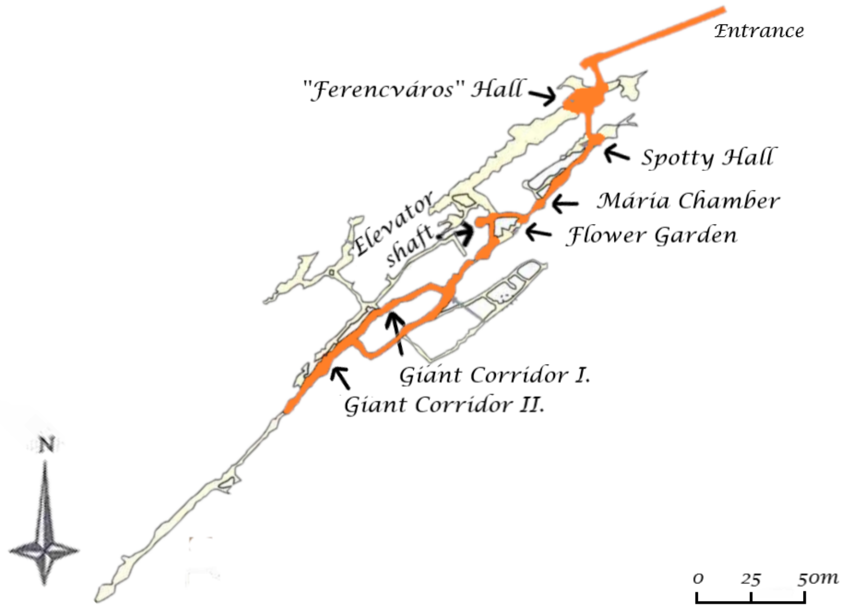
The Szemlő-hegy cave, forming part of the Duna-Ipoly National Park, is a well-known cavern within the Buda Mountains, shaped by thermal waters. It attracts numerous tourists throughout the year. The cave's total length spans 2,230 meters, of which approximately 300 meters has been accessible to visitors via the established tourist route since 1986 (Figure 3).

Figure 3: Szemlő-hegy cave. Detail of the Giant Corridor

Source: personal archive

During cave visits, groups pause at several locations. The specific stopping points vary based on the dimensions of the passages and the characteristics of the chambers. Figure 4 illustrates these stops, where groups linger and explore elongated sections that may encompass two smaller chambers.

Figure 4: Tourist section of the Szemlő-hegy cave



Source: https://szemlo-hegyi-barlang.hu with own editing

Table 1: Physical carrying capacity of the Szemlő-hegy cave

Room name	***A* (m²)**	***RA* (m²/pers.)**	***GS* (pers.)**	***OH* (h)**	***NVD* (pers.)**	***RD* (pers.)**
"Ferencváros"Hall	97.80	1.13	86	7	602	245
Spotty Hall	17.28		**15**		**105**	
Mária Chamber	44.84		39		273	
Elevator shaft	24.5		21		147	
Flower Garden	24.5		21		147	
Giant Corridor I.	43.73		38		266	
Giant Corridor II.	62.4		55		385	
	A	**RA**	**NTA**	**OH**	**NTAD**	**RD**
The tourist sections' total values	540.24	1.13	478	7	3346	245

Source: own editing

The cave's physical capacity is relatively limited due to its narrow passages, preventing large groups from occupying the space simultaneously. Consequently, only small groups, with a maximum of **35 individuals**, are permitted to visit. Access is available between **10:00 AM and 5:00 PM** daily. This translates to a potential daily capacity of **245 visitors**. Research conducted within the cave informs the recommended visitation limits, considering both the site's preservation and human well-being.

As illustrated in Table 1, the narrowest chamber within the cave is Spotty Hall. Here, visitors can be accommodated up to a maximum of 15 individuals, serving as the upper limit for group size. Based on this constraint, during the 7-hour daily visiting window, a total of 105 persons could explore the cave if tours commence every hour. However, the current allowance of 245 visitors per day may lead to overcrowding in certain areas. This congestion could compromise both the cave's integrity and safety, as tour guides might lose visual contact with segments of the group.

4.2. Pál-völgy cave

The Pál-völgy cave, also situated within the Duna-Ipoly National Park, constitutes one of the largest thermal-origin cave systems in the Buda Mountains. Its total length spans 13,465 meters, with a depth of 86.7 meters, a height of 27.2 meters, and a vertical extent of 113.9 meters. A designated section of approximately 500 meters has been developed for visitor access, encompassing over 400 steps and featuring a 7-meter ladder. Notably, cave exploration is not permitted for individuals below 5 years of age or with a height below 115 centimeters.

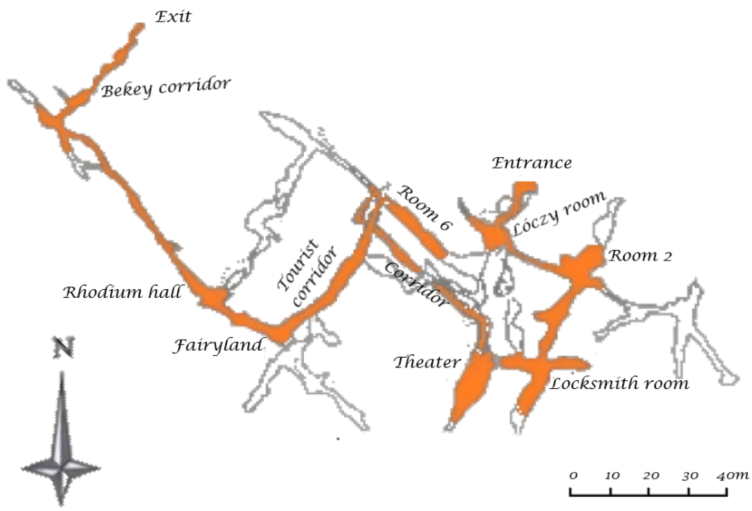
Figure 5: Pál-völgy cave. Detail of the Tourist corridor

Source: own archive

The measurements conducted in this location were significantly more intricate than those in the previous cave. The cave's characteristics posed considerable challenges due the narrow passages, tight corridors, and elongated chambers (Figure 5). The designated stopping points were strategically arranged to allow visitors to disperse somewhat while still enabling pauses and exploration in the more spacious areas. Figure 6 illustrates these sections, highlighting the various chamber names.

Like the previous cave, the passages here are also not overly spacious; in fact, in some areas, they barely reach a width of 25-30 centimeters. Visits occur in guided groups with stops strategically placed in more spectacular and roomier locations or chambers. Each tour accommodates a maximum of 35 individuals, resulting in a potential daily capacity of 245 visitors, considering tours commence every hour. During weekends in the summer season, with an 8-hour opening program, this number could even reach 280.

Figure 6: Tourist section of the Pál-völgy cave



Source: http://lazarus.elte.hu/cavescan/terkep.html with own editing

Table 2: Physical carrying capacity of the Pál-völgy cave

Room name	***A (m²)***	***RA (m²/pers.)***	***GS (pers.)***	***OH (h)***	***NVD (pers.)***	***RD (pers.)***
"Lóczy" room	33.58	1.13	29	7	203	245
Room 2	42.94		38		266	
Locksmith room	68.39		60		420	
Theater	39.98		35		245	
Corridor	40.95		36		252	
Room 6	34.19		30		210	
Tourist corridor	25.72		22		154	
Fairyland	32.28		28		196	
Rhodium hall	28.04		24		168	
Bekey corridor	29.51		26		182	
	A	**RA**	**NTA**	**OH**	**NTAD**	**RD**
The tourist section total area	587.76	1.13	520	7	3640	245

Source: own editing

The **physical carrying capacity** of the cave is exemplified by **Table 2**, where the value **22** stands out. This number represents the maximum group size for the **Tourist corridor,** allowing **22 individuals** to comfortably traverse that section.

Considering that the maximum group size is **22 persons**, the cave can host **154 visitors** within the **7-hour daily opening program**. However, when compared to the actual capacity of **245 visitors,** this value is significantly smaller. Consequently, the current visitation format may lead to overcrowding in that specific section. Such congestion could result in the guide losing attention to individual group members, who, in their eagerness to advance, might inadvertently damage the cave's morphology. The simultaneous presence of **24 visitors** and the daily count of **168** in the **Fairyland II. section** further confirms that the cave's constriction is not limited to a single point but extends across multiple areas. Therefore, it is advisable to exercise caution when increasing group sizes to preserve the cave and prevent accidents.

4.3. Súgó cave

The **Súgó cave is** the largest dripstone cave in Szeklerland (Figure 7). It is situated between 1,000 and 1,060 meters above sea level within the Sipos massif of the Gyergyó Mountains. Its exploration history dates back to legends from before the 1900s, with scientific research beginning in the 1930s.

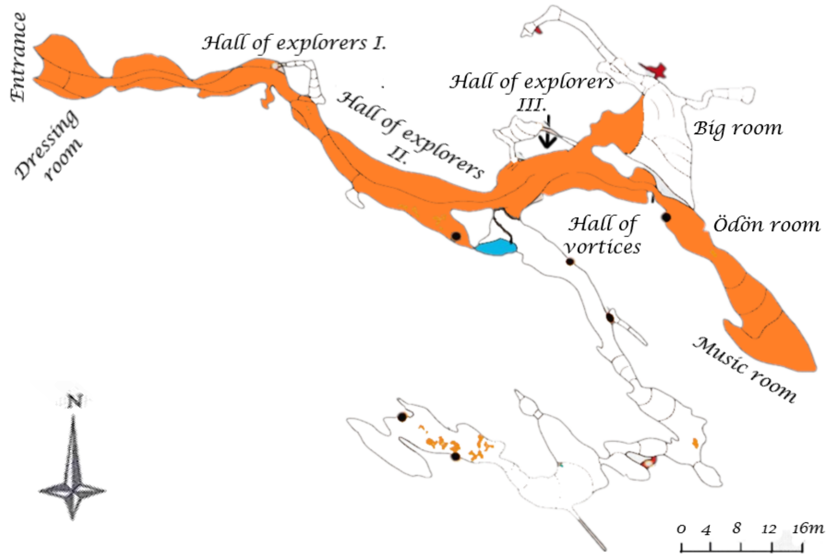
Figure 7: Súgó cave. Hall of vortices

Source: personal archive

In terms of dimensions, the Súgó cave is relatively small, with a total length of 1,024 meters spread across four different levels. Visitors can access approximately 170 meters of the cave through the uppermost and oldest dry passage (see Figure 8). The cave's tourism is seasonal, with weekend visits during spring and autumn, and daily openings in the summer from 10:00 AM to 5:00 PM. In winter, it remains closed due to accessibility challenges and bat protection.

Its physical capacity does not come as a surprise, as a small cave can only accommodate a small number of visitors. Its seasonal operation limits the visitation period, during which two guides lead tourist groups for 7 hours a day. A group can have a maximum of 25 people, for whom it takes approximately 45 minutes to explore the cave; however, the average number of people is between 15 and 20, as two groups can enter the cave within an hour, thus avoiding a large number of groups starting every hour. It is therefore difficult to determine the number of daily visits, as it can vary greatly. On a peak season weekend, with 25-person groups and an average of 7 tours, this could result in approximately 175 visitors to the cave in one day.

Figure 8: Tourist section of the Súgó cave



Source: own reediting after András (2016)

Table 3: Physical carrying capacity of the Súgó cave

Room name	***A*** ***(m^2)***	***RA*** ***(m2/pers.)***	***GS*** ***(pers.)***	***OH*** ***(h)***	***NVD*** ***(pers.)***	***RD*** ***(pers.)***
Dressing room	33.09	1.13	29	7	203	175
Hall of explorers I.	18.92		16		112	
Hall of explorers II.	18.25		16		112	
Hall of explorers III.	25.03		22		154	
Hall of vortices	22.10		19		133	
Big room	15.97		14		98	
Ödön room	23.35		20		140	
Music room	82.09		72		504	
	A	**RA**	**NTA**	**OH**	**NTAD**	**RD**
The tourist section total area	396.58	1.13	351	7	2457	175

Source: own editing

According to the values in Table 3, the Big room of the Súgó cave does not live up to its name. It is actually the smallest for visitors and is partially closed and restricted from tourists. With an area of approximately 16 square meters, it can accommodate a maximum of 14 people. During the 7-hour daily visits, with one tour per hour, a total of 98 individuals could explore the cave. This arrangement would allow the guide to keep an eye on each person, preventing congestion or overcrowding at narrower points. The proximity of formations to tourists would not raise concerns about damage.

4.4. Orbán Balázs cave

The Orbán Balázs cave, also known as the Almási cave, is the largest cave in Szeklerland. It is situated within the Vargyas Gorge, which stretches through the Rika Mountains, providing a home not only to the Orbán Balázs cave but also to 123 other caves. The total length of the Orbán Balázs cave reaches 1527 meters.

Figure 9: Orbán Balázs cave. Entrance Hall

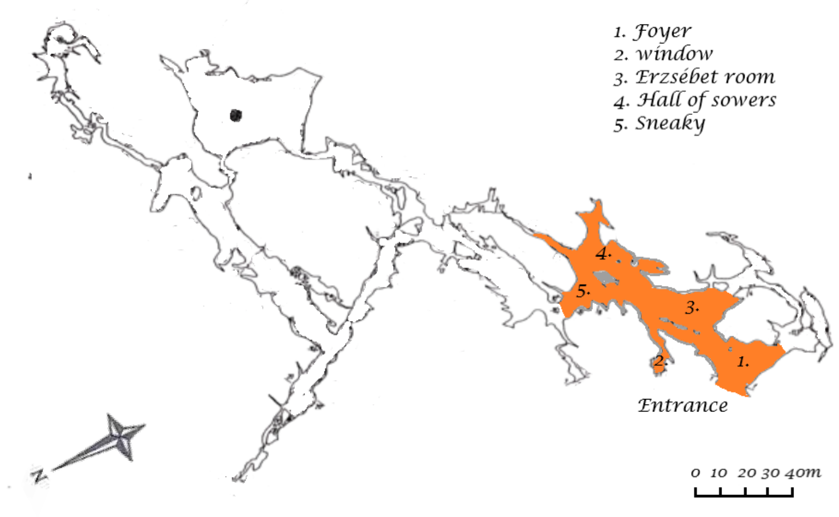
Source: own editing

Certain parts of the cave have been closed off recently due to conservation efforts and bat protection. As a result, visitors can only admire the first few larger chambers of the cave: Foyer, Window, Erzsébet room, Hall of sowers, and Sneaky.

This cave differs significantly from the previous three in terms of visitation. While restrictions only affect the deeper parts, the entrance part is free and can be visited by anyone at any time (see Figure 9). Therefore, we cannot talk about opening hours, as the cave is open all day, and we cannot talk about groups and maximum numbers, as there are no groups organized with a permanent system. Thus, a huge number of tourists can enter and admire the cave 24 hours a day. To avoid this, cave guiding would be the best solution, which Table 4 would help to set up.

Considering the size of the accessible rooms (Figure 10), a group of 84 people would be the maximum number that the cave's features allow. However, from a tour guide's perspective, this is too large a number, so it would be necessary to reduce the number of visitors or introduce a second guide. With this group of 84, a guide could lead as many as 672 people into the cave in a day with 8 hours of opening time, avoiding damage. The size of the passage would allow multiple groups to stay inside at the same time, so the number of two groups per hour would be 168, and in a day, it would allow 1,344 people to visit.

Figure 10: Tourist section of the Orbán Balázs cave



Source: own editing

Table 4: Physical carrying capacity of the Orbán Balázs cave

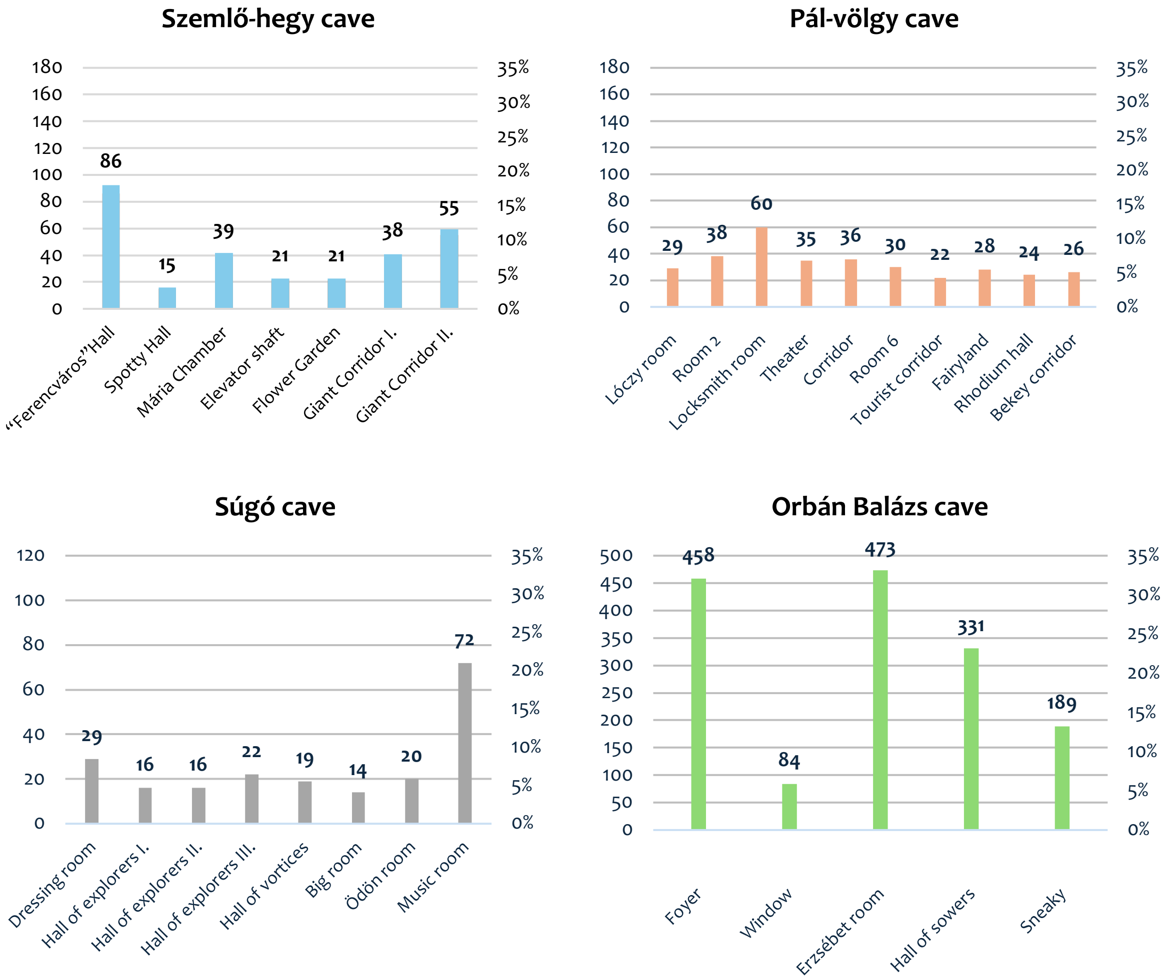
Room name	***A* (*m*²)**	***RA* (*m*²/*pers.*)**	***GS* (*pers.*)**	***OH* (*h*)**	***NVD* (*pers.*)**	***RD* (*pers.*)**
Foyer	517.87		458		3664	
Window	95.74		84		672	
Erzsébet room	534.00	1.13	473	8	3784	∞
Hall of sowers	373.81		331		2648	
Sneaky	213.92		189		1512	
	A	**RA**	**NTA**	**OH**	**NTAD**	**RD**
The tourist section total area	1735.35	1.13	1536	8	12 288	∞

Source: own editing

4.5. Discussion

Figure 11 presents the physical carrying capacity of each room in all four caves along the left axis. It also illustrates the spatial proportion of each chamber room to the entire cave area along the right axis. The diagrams in all four cases share a consistent scale on the right axis, allowing for a comparison of chamber sizes across different caves.

Figure 11: Cave rooms' physical carrying capacity expressed as people (left axis) and as percentage (right axis)



Source: own editing

Based on the distribution of room sizes in different caves and the number of tourists that can be present in various rooms, it is evident that the Pál-völgy cave enjoys the most balanced situation. Here, the average tourist number per room is 32.8, with a standard deviation of 10.3. In contrast, the variability index (standard deviation / mean) for the Súgó cave is 0.69, which differs significantly from the Pál-völgy cave's index of 0.31.

The distribution of room sizes and their corresponding capacities provides valuable insights into the usability of caves. For instance, despite having the smallest maximum group size in the Great Hall, the Súgó cave is surprisingly well-suited for hosting events. The Music Hall in the Súgó cave can accommodate up to 72 people. Notably, this room lies deep within the cave, allowing visitors to marvel at its beauty as they trek toward the event venue. Similarly, the Pál-völgy cave exhibits balanced room capacities, with a single larger chamber. This type of usability pattern is evident from statistical analyses, where both caves exhibit extreme values in the Box-Whisker plot (Figure 12). Furthermore, the diagram highlights that, in all three caves, the average capacity of the chambers exceeds their medians, indicating a right-skewed distribution – more smaller rooms alongside a few larger ones.

Figure 12: Statistical characterization of caves' individual room capacity

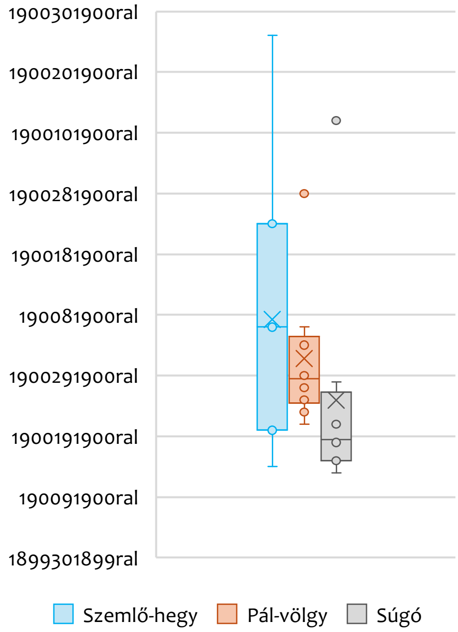
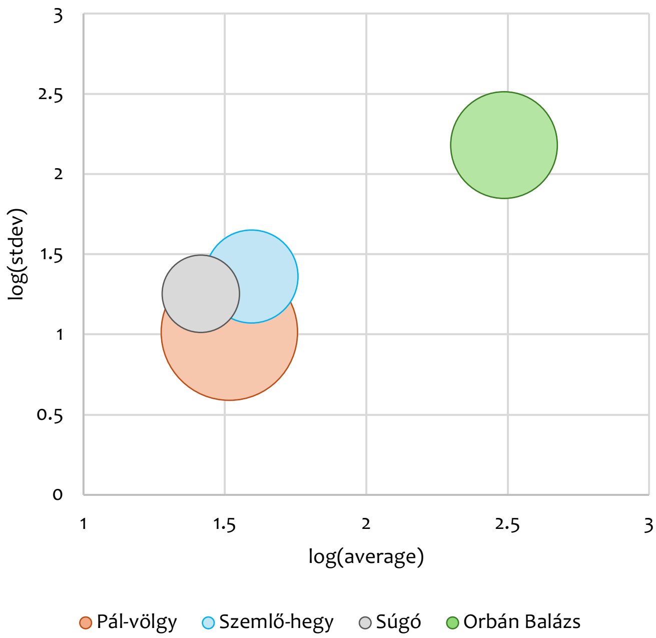


Figure 13: Relation between average capacity of caves and their standard deviation (logarithmical scale) – the circles' radius is proportional with the variability index



Source: own editing

Based on Figure 13, it is evident that the structural characteristics of three of the four examined caves are very similar, except for the Orbán Balázs cave, which deviates from the others due to its dimensions having a comparable variability index with the Szemlő-hegy cave. This indicates a proportionally similar room size distribution. Smaller variability index values indicate a more balanced room size and therefore a more advantageous situation for optimal tourist group size selection.

5. Conclusions

Comparing Budapest's two most renowned caves with the two largest tourist potential caves in Szeklerland, our results indicate the need for adjustments, particularly in ecotourism activities. In the cases of the Szemlő-hegy and Pál-völgy caves, it is advisable to reduce the maximum group sizes. Current visitation data exceed our research findings, resulting in overcrowding, increased accident risks, diminished guide attention, and potential harm to cave preservation and sustainability.

The Súgó cave, the smallest in this study, requires some tightening of regulations. Limiting group sizes would result in smaller, more disciplined groups, facilitating guide management and cave preservation. Non-hourly group departures encourage smaller groups but also complicate guide responsibilities, potentially leading to less organized group management.

The Orbán Balázs cave’s results diverge entirely from the previous three caves. There, it is essential to establish at least a rudimentary visitation program, restricting daily visitor numbers and safeguarding the cave from anthropogenic damage and pollution.

In summary, constructive modifications are warranted for all four tourist caves. At each location, heightened attention should be devoted to preservation and sustainable operation. Reducing group sizes should not be dismissed; perhaps the most sensible solution lies in more frequent tours with smaller groups. The cumulative insights from the aforementioned considerations, along with the comparative objectives of our research, do not show inadequate cave management or neglect of guardianship at present. Rather, they facilitate informed decisions regarding ecotourism sustainability, ensuring the long-term preservation and sustainable development of these natural attractions and protected areas for future generations.

The encouraging results from this research suggest the method's potential for broader application. Testing it in diverse caves all round the world with existing visitor management practices would allow for further validation and refinement, ultimately improving the method's effectiveness.

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