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Research Article

Microclimate characteristics and tourist carrying capacity of Phong Nha cave, Phong Nha - Ke Bang National Park

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Abstract: Cave tourist carrying capacity is the maximum number of people who can visit a cave at certain time without causing irreversible damage to the natural environment. The tourist carrying capacity of Phong Nha Cave was determined for the first time based on the cave's microclimate indicator using the Lobo method. The temperature, relative humidity (RH), and carbon dioxide (CO_2) concentrations in the Phong Nha cave were regularly measured during the summer and winter of 2023. Continuous monitoring of the cave temperature was also conducted, with measurements taken every 5 minutes. The results of regular and continuous temperature monitoring in Phong Nha Cave in 2023 indicated that the total time for temperature recovery in summer and winter was 497 minutes and 318 minutes, respectively. The limit of visitor according to three tourism scenarios is 1260, 2520, and 3780 people per day, respectively. The average time of stay at Dong Tien is 7.8 minutes in summer and 12.7 minutes in winter. These new results provide valuable reference information for the management and conservation of Phong Nha - Ke Bang National Park and should be recommended for use in assessing tourist carrying capacity in other show caves in Vietnam.

Keywords: Microclimate; Temperature; Tourist carrying capacity; Phong Nha cave.

1. Introduction

Tourist carrying capacity is defined by the UN Tourism Organization as the he maximum number of people that may visit a tourist destination at the same time, without causing the destruction of the physical, economic and sociocultural environment and an unacceptable decrease in the quality of visitors satisfaction. Another definition by [1] describes tourism capacity as the maximum number of people who can use a tourist site without causing unintended impacts on the environment and while still meeting the needs of visitors. Therefore, tourism carrying capacity is an effective tool in management to determine the maximum number of visitors allowed within a specific timeframe. The study [2] summarized the concept of cave tourism carrying capacity as determining the number of visitors who can experience tourism in a manner that is compatible with the specific cave environment, while also identifying the environmental conditions that are suitable for such an experience. From this perspective, tourist cave carrying capacity is the maximum number of visitors that can be accommodated in a cave without causing irreversible changes to the natural environment. Tourist cave carrying capacity represents the time-space limits for the use and exploitation of caves in order to prevent environmental damage, with the recovery process being a key determining factor [3–4].

The IUCN Guidelines for the protection of Karst and Caves [5] indicated that human activities can lead to changes in cave structure, hydrological conditions, the destruction of stalactites, flora and fauna, and various types of pollution. Among these, changes in microclimate conditions and airflow are some of the most evident impacts of human activities inside caves [6–8]. The study of tourist cave carrying capacity based on monitoring microclimate parameters, along with various qualitative and quantitative methods, had been applied in many places worldwide [9]. Changes in climatic conditions in caves being used for tourism are regularly monitored over long period as a groundwork for managing tourism activities [7, 10–13].

The tourist cave carrying capacity calculation method [14] was approached based on climatic monitoring parameter and the tourism exploitation strategy of stakeholders. This method has been applied to ascertain tourist capacity for management purposes in several karst areas in Brazil and Indonesia [4, 14–15]. The carrying capacity was calculated following the recovery of the defined climate factors inside the cave for each specific tourism scenario and was expressed in terms of the maximum number of visitors per day and the maximum time allowed for staying at a specific location.

In Vietnam, the tourist carrying capacity assessment method of Cifuentes had been applied to compute the natural carrying capacity and the effective real carrying capacity (ERCC) at several ecotourism destinations, including the Ban Lac Ecotourism Area in Hoa Binh, the Ho Nui Coc National Tourism Area in Thai Nguyen province, Cuc Phuong National Park, and the Tam Coc Bich Dong cave system (Hoa Lu - Ninh Binh) [16], as well as at the Thung Nham Ecotourism Area in Ninh Bình [17]. The tourist capacity at Phong Nha - Ke Bang National Park has been determined using both qualitative methods [18] and quantitative assessment methods [19] based on the calculation approach [20]. The research outcome from [21] had identified the physical carrying capacity (PCC) and the effective real carrying capacity (ERCC) for several tourism sites in the Quang Bình province. However, there was still a lack of studies assessing the tourism carrying capacity of show caves based on environmental climate parameters inside the cave, considering their recovery ability and the unique characteristics of each cave a current research trend.

The Phong Nha - Ke Bang National Park has been twice recognized by UNESCO as a World Natural Heritage Site for its outstanding universal values in geology- geomorphology and biodiversity. The tourism activities play an important role in the socio-economic development of Quang Binh province but also poses significant pressure on the management of natural resources and the environment of the park. Assessing the carrying capacity of caves is necessary for effectively management, conservation, and promotion the values of this World Natural Heritage site.

This paper presents the results of temperature monitoring data inside Phong Nha cave and an evaluation of its tourist carrying capacity to provide valuable information for the management, conservation, and promotion of the World Natural Heritage values of Phong Nha - Ke Bang National Park. This assessment of tourist carrying capacity, based on cave climate indicators, has been applied for the first time at Phong Nha - Ke Bang National Park in particular and in Vietnam in general.

2. Materials and method

2.1. Study area

Phong Nha cave is located in the World Natural Heritage Phong Nha - Ke Bang National Park, Quang Binh province; the cave is 8.329 m long, entrance is 20-25 m wide and 10 m high, the section currently opened for tourism is about 1.500 m long (Figure 1). The cave was formed in the Phong Nha carbonate block including limestone, caviar limestone, siliceous limestone, clay lime, and calcareous clay belonging to the Bac Son formation (C-Pbs) [22].

Phong Nha is called “The first cave of Indochina” with unique stalactites named based on natural shapes such as “lion”, “unicorn”, “adoration”, “palace” or “buddha”. In the cave, there is an subterranean river and a large sandbank [23]. In terms of morphology, the cave has many chambers, both dry and wet [24]. The dry part is located at an altitude of 4-100 m with the end of the touristic part (Dong Tien) and a branch called Bi Ky; the wet part was discoverd at the local erosion level and flows in a northeast - southwest direction to the Son River. Phong Nha cave had been open tourism since 1991, and is a famous destination for tourism in Quang Binh province. Recently, to manage and preserve its outstanding values, Phong Nha cave has a tourist route with wooden floors and a lighting system using LED lights. On average, Phong Nha cave welcomes 300000-350000 visitors/ year, of which the summer from May to August is the peak tourist season (Figure 2). In addition to the positive impact of tourism development, the largest number of mass tourists during the peak season puts pressure on the karst environment and presents challenges for the management and conservation of Phong Nha cave in particular and the World Natural Heritage Phong Nha - Ke Bang National Park in general.

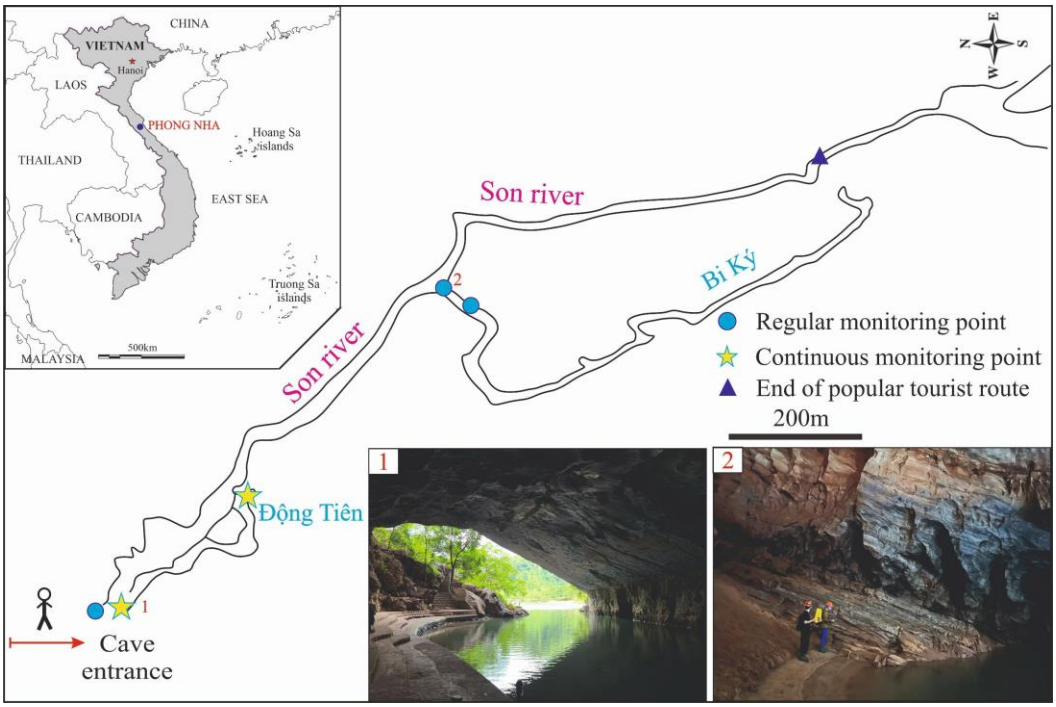

Figure 1. Sketch map of Phong Nha cave and location of microclimate monitoring points.

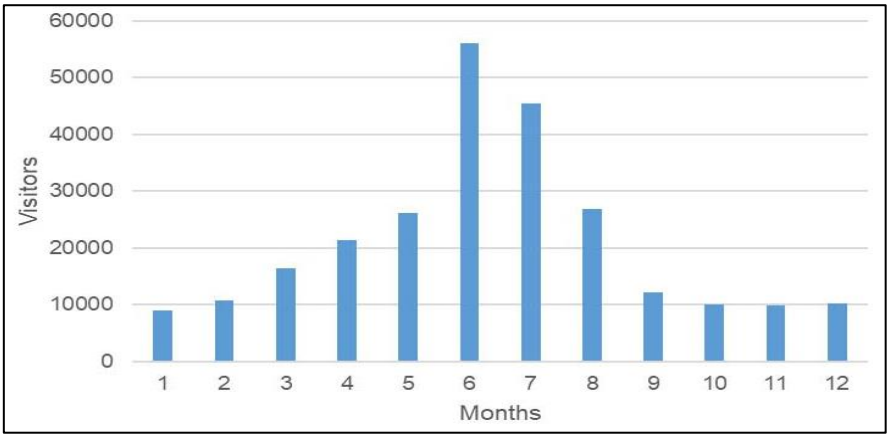

Figure 2. Tourist numbers at Phong Nha cave during the period 2015-2022 (Source: Phong Nha - Ke Bang Tourism Center).

2.2. Assessment cave tourist carrying capacity using Lobo method

According to [14], the cave tourist carrying capacity depends on the spatial extent, the limits of the tourism route, and the stop duration for visitors to observe the cave. The tourist carrying capacity was determined through the following steps (Figure 3): (1) Determining the maximum number of visitors allowed per day; (2) Determining the maximum time allowed for visitors to stop at a point inside the cave.

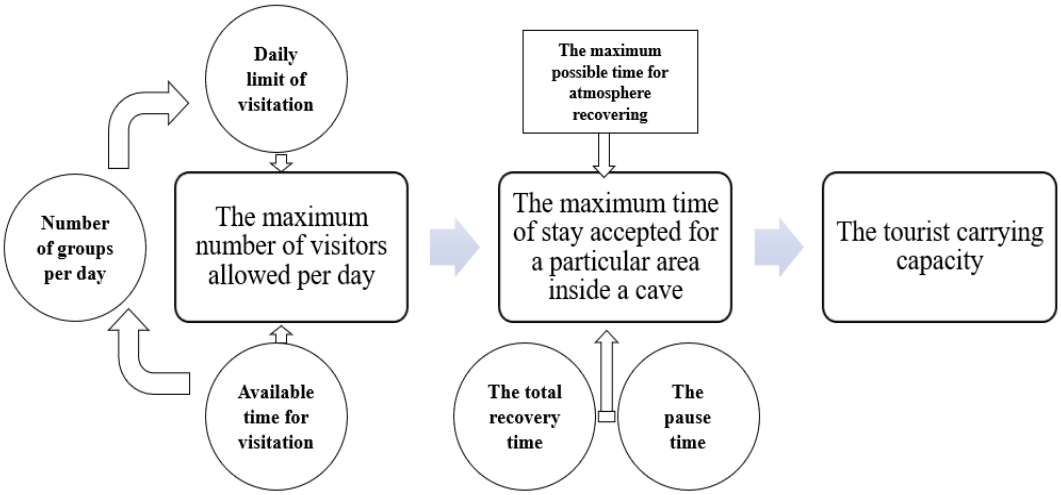

Figure 3. Assessment the tourist carrying capacity using the Lobo method.

a) Determining the maximum number of visitors allowed per day

- A time lapse that should be enough to complete the route before the park closing hours, which is represented by Eq. (1).

$$at\upsilon = tt\upsilon - rd \quad (1)$$

where $at\upsilon$ is the available time for visitation, $tt\upsilon$ is the total time for visitation (difference between opening and closing hours) and rd is the route duration: the time spent to walk the visitation route. Time units were calculated in minutes.

- Afterwards, the number of groups of visitors per day (ng) to get into the tourist route was calculated, based on Eq. (2).

$$ng = \frac{at\upsilon}{tbg} \quad (2)$$

where ng is the number of groups that is supposed to daily visit the cave; tbg is the lapse of time between groups to enter into the cave's tourist route (field survey information), stated in minutes

- The daily limit of visitation (dlv) by Eq. (3).

$$dl\upsilon = ng \times sg \quad (3)$$

where sg is the maximum size of groups of visitors.

b) The maximum time of stay accepted for a particular area inside a cave by Eq. (4)

$$mt = \frac{pt \times mrt}{trt} \quad (4)$$

where (1) the pause time (pt), which is the duration of the stay in an interpretative stop, in minutes; (2) the total recovery time (trt), which is required after the impact of the visitation, for a specified atmospheric parameter; and (3) the maximum possible time to the atmosphere to recover (mrt), which is obtained from the time the visitation is closed to the opening hours the following day.

The results will determine the maximum time (mt) allowed for visitors to stay in a specific area of the cave and prevent cumulative impacts on the cave's climatic parameters.

2.3. Measurement, monitoring of microclimatic parameters

Regular measurements microclimate parameters including temperature, humidity, and carbon dioxide (Temp, RH, CO_2) were conducted in February 2023 and August 2023 using a handheld AZ Instrument model 77597 device. The locations of the regular monitoring points are shown in Figure 1. Three points in Phong Nha cave were monitored during both winter and summer time including Dong Tien, Bi Ky sandbank, and Bi Ky cave. On the outside of the cave which is entrance, microclimate parameters were also measured simultaneously with the inside either. All measurement points were positioned approximately 1m above the cave floor or ground surface.

Temperature variations were recorded with a frequency of every 5 minutes using a Diver datalogger device by Van Essen, model D1502, at Dong Tien (inside the cave) and the cave entrance. The monitoring device inside the cave was protected in a small perforated metal box with a lock, fixed at a cavity about one meter above the cave floor, while the external monitoring device was suspended on a pole around 2.2 m above the ground.

3. Result and Discussion

3.1. Microclimate condition in Phong Nha cave

The microclimate condition (temperature, humidity, and CO_2 levels) in Phong Nha cave were surveyed and measured at the end of winter (February) and summer (August) in 2023, corresponding to periods of low and high tourist activity, respectively. The measured data for the microclimate parameters in Phong Nha cave are presented in Table 1.

The measurement results indicated that the microclimate conditions in Phong Nha cave varied according to the measurement location and differ between winter and summer. During the winter, the temperature inside the cave fluctuated slightly between 22.9°C and 23.6°C, while in the summer, it ranged from 24.5°C to 26.6°C. Therefore, the temperature inside the cave in summer was about 2°C to 3°C higher than in winter. Compared to the external temperature, the inside value in winter is typically higher but in summer months, the situation was reversed. Relative humidity (RH) varied spatially within Phong Nha cave but usually remains above 95%, even reaching nearly 100% during both periods. RH in the cave was higher in summer than in winter and was also greater than the humidity outside the cave at the same monitoring time (84.2% vs 76.4%). Similarly, CO_2 levels showed significant variation both between different locations in the cave also the same location with different times in year. During the measurement periods, CO_2 levels (ppm) ranged from 554 ppm to 1144 ppm in winter and from 466 ppm to 907 ppm in summer. CO_2 concentrations increased in proportion to the distance from the cave entrance, with CO_2 levels rising as one moved deeper into the cave (from Dong Tien to Bi Ky). This increase in CO_2 levels at longer distance inside the cave was due to reduced ventilation, leading to a buildup of CO_2 in these areas.

Table 1. Results of regular microclimate measurements in Phong Nha cave, 2023.

Position	Date	Temperature (ºC)	Relative Humidity (%)	CO_2 concentration (ppm)
Dong Tien	2/13/2023	23.2	95.5	836
	2/14/2023	22.9	97.3	554
	8/28/2023	25.7	99.9	466
Bi Ky sandbank	2/13/2023	23.6	93.5	902
	2/14/2023	23.4	95.0	560
	8/28/2023	26.6	95.5	701
Bi Ky	2/13/2023	23.3	95.9	1144
	2/14/2023	23.0	98.0	737
	8/28/2023	24.5	99.9	907

3.2. Determination of total recovery time

3.2.1. Characterization of temperature in Phong Nha cave

Continuous monitoring data showed that in summer, the air temperature inside Phong Nha cave did not follow a clear phase relationship with the outside temperature but it was always lower than the outside temperature (Figure 4a). The daily temperature fluctuation in summer ranged from 0.2°C to 0.4°C. Temperatures decreased from night to morning, reaching their lowest point between 23:00 and 06:00, then rose and hit their highest values between 10:00 and 16:00. The temperature trend inside the cave from 8 August 2023 to 15 August 2023 increased in line with the rising number of tourists, from 1034 to 2299 visitors per day (source: Phong Nha - Ke Bang Tourism Center) during this period, clearly showing the impact of tourism activities in raising the temperature inside the cave.

In winter, the temperature inside Phong Nha cave was typically higher than the outside temperature and showed a clear phase correlation with it. The daily temperature fluctuation ranged from 0.2°C to 0.3°C. The temperature reached its lowest point between 23:00 and 05:00, then rose and reached its highest values between 10:00 and 14:30 (Figure 4b). Due to ventilation, the microclimate conditions inside the cave during winter are significantly influenced by the external climate. The temporal variation of temperature in Phong Nha cave depended on the location within the cave, the direction of ventilation, the distance from the entrance, and was also affected by tourism activities inside the cave.

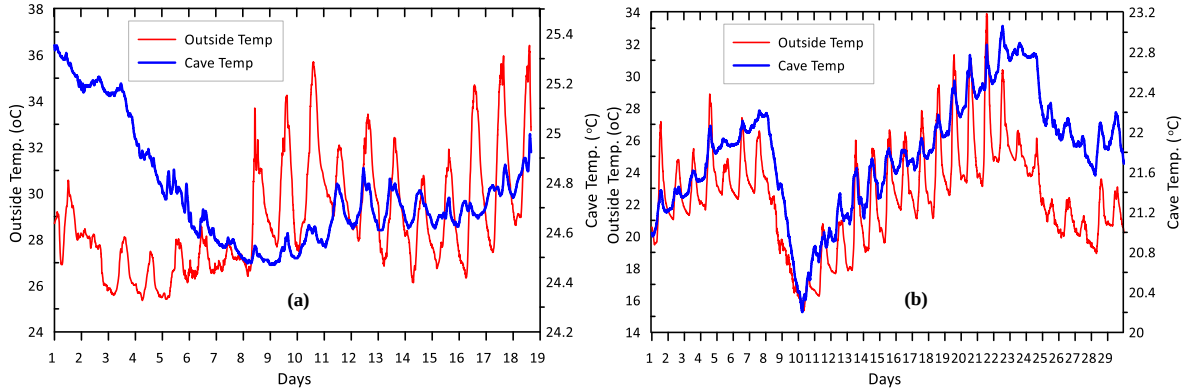

Figure 4. Variation of temperature at Dong Tien (Phong Nha cave) in August 2023 (a), February 2024 (b).

3.2.2. Determination of total recovery time (trt)

The total recovery time (trt) refers to the duration required for the microclimate conditions inside the cave to return to normal after being disturbed. In this study, the recovery time was one of the parameters used to calculate the cave carrying capacity according to Lobo's method [14]. It was defined as the duration from when the temperature inside the cave gets its highest value during the day to a stable, normal conditions.

The recovery time for temperature in Phong Nha cave at the Dong Tien changed significantly from summer to winter (Table 2). Based on the temperature monitoring data in August 2023 and February 2024, it was found that in summer, the longest recovery time for temperature is 765 minutes, and the shortest is 255 minutes. In winter, the longest recovery time is 510 minutes and the shortest is 110 minutes (Table 2). Therefore, the average recovery time for temperature conditions inside the cave is 497 minutes in summer and 318 minutes in the other. On average, the “trt” for the temperature inside Phong Nha cave is longer than the time required for temperature stabilization at Santana cave, Brazil (264.1 minutes) [14], but shorter than at Gelatik cave, Indonesia (670 minutes) [15]. The total recovery time for climatic parameters in Phong Nha cave, based on the monitoring data, represented the first quantitative information used to assess the tourist cave capacity. These data provided a

scientific foundation for the exploitation, management, and conservation of the Phong Nha - Ke Bang National Park's natural heritage values.

Table 2. Total temperature recovery time at Dong Tien, Phong Nha cave.

Date	Temperature pre-visitation	Maximum temperature	Temperature peak time	Temperature stabilization time	Minimum temperature	Total recovery time (min)
8/9/2023	24.48	24.6	15:15	21:45	24.47	390
8/10/2023	24.57	24.63	10:30	17:45	24.55	435
8/11/2023	24.65	24.8	11:30	20:05	24.65	575
8/12/2023	24.68	24.86	10:45	20:00	24.61	555
8/13/2023	24.67	24.82	10:15	23:00	24.62	765
8/14/2023	24.65	24.77	11:55	23:10	24.62	675
8/15/2023	24.67	24.74	13:25	21:25	24.62	480
8/16/2023	24.7	24.72	9:45	15:30	24.66	345
8/17/2023	24.78	24.87	16:35	20:20	24.75	255
2/1/2024	21.09	21.4	12:30	16:55	21.24	235
2/2/2024	21.29	21.44	10:00	17:20	21.35	440
2/3/2024	21.45	21.59	11:45	16:55	21.51	310
2/4/2024	21.63	22.04	13:10	18:55	21.79	345
2/7/2024	22.06	22.22	14:20	18:45	22.16	265
2/10/2024	20.28	20.6	14:50	17:00	20:00	130
2/12/2024	20.92	21.39	13:35	19:00	21.11	324
2/13/2024	21.24	21.64	13:50	21:40	21.28	470
2/14/2024	21.48	21.73	12:05	20:05	-	480
2/15/2024	21.54	21.84	13:35	22:05	-	510
2/16/2024	21.74	21.81	13:40	15:30	21.66	110
2/17/2024	21.68	21.94	13.35	17:00	21.79	205

The results of the tourist carrying capacity of Phong Nha cave applied Lobo's method [14] are presented in Table 3. Field survey information determined the total time from the opening of the cave for visitors to the closing time (ttv), which is calculated from 7:00 to 18:00, 660 minutes in total. The travel time by boat from the Phong Nha Tourism Center to the cave entrance (rd) is 30 minutes. The duration allocated for the visit inside Phong Nha cave (atv) is 630 minutes. The time gap between groups of visitors (tbg) varies from 5 to 10 minutes, depending on the time of day. The number of visitor groups per day is 105 groups. According the first scenario each group of tourists uses one boat with a capacity of 12 people. The maximum number of visitors per day in Phong Nha cave is 1260 people. For the 2nd scenario each group consists of 24 people using two boats. The maximum number of visitors per day in Phong Nha cave is 2520 people. Last, the 3rd scenario on high peak holiday period, each group consists of 36 people using three boats. The maximum number of visitors per day in Phong Nha Cave can reach 3780 people. This evaluation provided the maximum number of visitors/day under different tourism management scenarios, supporting the planning and management of the cave's tourism carrying capacity.

Table 3. Daily visitor limit of Phong Nha cave with different tourism scenarios.

	ttv (minute)	rd (minute)	atv (minute)	tbg (minute)	ng	sg	dlv (tourist)
1st scenario	660	30	630	6	105	12	1260
2nd scenario	660	30	630	6	105	24	2520
3rd scenario	660	30	630	6	105	36	3780

With the maximum daily visitor capacity above, to prevent negative impacts on the microclimate conditions inside the cave, it is necessary to determine the maximum time (mt) that visitors paused at any given location. The calculated maximum duration that visitors can remain at the Dong Tien was presented in Table 4. Analyzing temperature fluctuations had

shown that the time required for the temperature inside Phong Nha cave to return to normal (trt) in summer is longer than in winter (Table 2). Using Lobo's method [14], the maximum time that visitors can stay at Dong Tien is determined to be 7.8 minutes in summer and 12.7 minutes in winter.

Table 4. Maximum duration of stay for tourists at Dong Tien, Phong Nha.

Period	trt (minute)	pt (minute)	mrt (minute)	mt (minute)
Summer	497	5	780	7.8
Winter	318	5	810	12.7

3.3. Discussion

The regular measurement results indicated that the microclimate conditions inside Phong Nha cave had values around 30 to 39, corresponding to a low to moderate discomfort level according to the Euroweather Discomfort Index (DI) classification. Compared to other show caves in Southeast Asia, the DI of Phong Nha cave is lower than that of Gelatik cave in Indonesia [15] and Nang Fa and Sua Noi caves in Thailand [25]. Therefore, the microclimate conditions inside Phong Nha cave are suitable and quite comfortable for tourist activities.

The results of the tourism carrying capacity assessment for Phong Nha cave according to three tourism scenarios (1260, 2520 and 3780 visitors/day), are fully aligned with the results presented by [19], which have calculated the physical carrying capacity (PCC) at 3354 visitors/day and the effective real carrying capacity (ERCC) at 1463 visitors/day. Furthermore, on the basis of temperature recovery, this study also determines the maximum time visitors can stay at Dong Tien without negative impacts on microclimate-environment. The maximum time stay in the Dong Tien varies between 7.8 minutes and 12.7 minutes. This is new and useful information that can support to managers in determining sustainable exploitation strategies and preserving the Phong Nha cave. However, the current research mainly focuses on determining the time stay at the Dong Tien, thus, it is also necessary to determine the stay duration at several other specific points from the cave entrance to the Dong Tien by adding more continuous temperature monitoring points.

Due to the morphological characteristics of Phong Nha cave, which includes many large and high chambers, as well as its unique microclimate conditions, the tourist cave carrying capacity was much higher compared to the obtained results of [14–15, 26]. However, it should be emphasized that, according to [26] in management and policy planning, the tourist carrying capacity of a cave is not a fix number but should be adjusted flexibly, taking into account the interaction of natural conditions in the cave with different tourism scenarios.

4. Conclusion

The microclimate parameters (temperature, relative humidity, CO_2) of Phong Nha cave varied seasonally and spatially within the cave. The temperature inside the cave fluctuated between 21°C and 26°C from winter to summer, with a variation of around 0.5°C between different areas of the cave. Compared to the outside temperature atmosphere, the temperature inside the cave is typically higher in winter and lower in summer. Continuous temperature monitoring in 2023 showed that the air circulation inside and outside the cave entrance was more pronounced in winter than in summer. The average recovery time for the temperature to return to normal conditions inside Phong Nha cave in the summer and winter were 480 minutes and 321 minutes, respectively. The tourist carrying capacity of Phong Nha cave was quantitatively assessed based on temperature indicator monitored in selected location of the cave, using the method of Lobo [14]. The evaluation results have determined the daily limit

of 1260, 2520, and 3780 visitors according to three tourism scenarios respectively. The average time stay at the Dong Tien was 7.8 minutes in summer and 12.7 minutes in winter.

Although microclimate parameters were monitored at a single point during a winter-summer, the results of present study provide useful "reference" information to support the development of a management and conservation plan for Phong Nha cave in accordance with UNESCO recommendations. With the encouraging findings from this study, it is necessary to continue monitoring protocols at Phong Nha cave and expand the microclimate monitoring in other show caves in the Park. This will contribute to ensuring the sustainable management of the site and provide quantitative data to support the conservation of the valuable World Natural Heritage Phong Nha - Ke Bang National Park.

Author Contribution: Constructing research idea; Select research method: V.T.M.N., V.P.H., H.T.L.; Data processing; Data analysis; Writing original draft preparation: V.T.M.N., V.P.H., H.V.T., H.T.L., B.V.Q.; Writing review and editing: V.T.M.N., V.P.H.

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Conflicts of Interest: The authors declare that this article was the work of the authors, has not been published elsewhere, has not been copied from previous research; there was no conflict of interest within the authors.

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