TOURIST CARRYING CAPACITY IN CAVES: MAIN TRENDS AND NEW METHODS IN BRAZIL[1]

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Abstract: The establishment of touristic carrying capacity is one of the greatest challenges facing environmental planners and managers. In relation to caves, the question is especially complicated due to the unique characteristics of the environment, such as spatial confinement, absence of light, and a lower dispersive flow of mass and energy. The present article presents the main tendencies in the limitation of the visitation of caves, with emphasis on Brazilian examples. Five conceptual trends were presented, including two new ones, developed recently in Brazil. It is concluded that any values obtained from any calculation of carrying capacity should be understood as a starting point for what must then be subjected to constant monitoring so that the causal network between variability in critical factors and human presence can be identified and more adequate solutions found. Thus the carrying capacity should be studied as a function of variation, intensity and frequency of demand, as well as of seasonal dynamics in the resilience of caves environment.

Keywords: carrying capacity, caves of Brazil, management of caves, environmental conservation, tourist caves

INTRODUCTION

Speleotourism is a segment of tourist activity which is widely exploited internationally. Cigna and Burri (2000) list more than 200 caves adapted for tourist visitation around the world, especially in Europe and Asia; only 20 of these are located in Brazil. However, this paper refers only to caves with institutionalized tourism. Lobo *et al.* (2008) present a list of some 200 caves in Brazil subject to some sort of tourist visitation, especially in regions such as the national parks (Serra da Bodoquena, Peruaçu, Ubajara, and Chapada Diamantina) and state parks (Touristic Park of the Upper Ribeira [PETAR], Intervales, Diabo Cave, Campinhos, Sumidouro and Terra Ronca) and natural monuments (Lago Azul cave, Maroaga cave, Peter Lund, and Rei do Mato cave), as well as other cavities in private lands.

In this universe, less than 40 caves maintain some sort of control of daily visitation (provisional or permanent); most of them, no specific management plan has yet been elaborated to regulate speleological tourism.

Moreover, a still small number of caves – less than 10 – are adapted for mass tourism – or large scale tourism, as it called in Brazil. The average of visitors in these caves is 20,000 – 50,000 per year (Lobo *et al.* 2010a).

One of the fundamental steps in the planning for the tourist use of a cave is the determination of the quantitative and qualitative limits for visitation, which must be based on physical, biological and social environmental factors. Reference studies on the subject on an international level have been made by Cigna and Forti (1988), Cigna (1993), Hoyos *et al.* (1998), Calaforra *et al.* (2003), and Fernández-

1 The presentation of this article is available at ttp://www.sbe.com.br/diversos/Loboetal_ISCA2010.pdf>.

Cortes *et al.* (2006a, b). In Brazil the main papers published were those of Boggiani *et al.* (2001, 2007) for the caves of the Natural Monument Lago Azul Cave in Bonito city, in the state of Mato Grosso do Sul, and of Lobo (2005, 2008) for the cave of Santana in Iporanga city, in the state of São Paulo.

In this scenario, and based on secondary studies and field work in Brazilian caves, the present article provides a synthesis of the methods for determining the carrying capacity of a cave, who was established on the basis of different environmental realities of caves and considering the possibilities and limitations of managing agencies.

CONCEPTS OF CARRYING CAPACITY IN CAVES

The carrying capacity is an idealized planning tool to permit managers of an area or tourist attraction to make decisions about the maximum intensity of visitation to be allowed in a given interval of time (Cifuentes 1992; Hoyos *et al.* 1998; Carranza *et al.* 2006). In relation to management, it is the maximum acceptable flow of visitors for a cave without causing irreversible alterations in the natural environmental dynamics (Mangin *et al.* 1999; Boggiani *et al.* 2007; Lobo 2008). In general, the carrying capacity is understood as a way

> of identifying the quality of recreational experience which is appropriate to a particular cave environment, and determining the environmental conditions consistent with that use. Thus the question has moved away from just simple numbers of people in caves to the social and environmental conditions which should prevail. Several complementary management tools have emerged. All of them involve the translation of qualitative management goals to quantitative management objectives using environmental indicators and standards (Gillieson 1996: 250–251).

Another more operational definition considers the fact that impact is inevitable and will be acceptable up to a given limit; the carrying capacity for speleotourism is thus defined as:

> The possibility of temporal-spatial limitation for the use of a cave so that environmental damages be avoided, with the resilience as key factor. Its origin derives from the possibilities for the management of an area so that the broader negative impacts of tourism on a larger scale could be mitigated or diluted, based on environmental fragility and in the possibilities of visitation (Lobo 2008: 383).

The determination of carrying capacity depends on the investigation of environmental parameters under natural conditions – including environmental seasonality –, as well as responses to monitored visits (Fernandez-Cortés *et al.* 2006a). These relationships of cause and effect may vary as a function of different levels of exchange of mass and energy in underground systems (Heaton 1986) and the inherent complexity of environmental systems (Bertalanffy 1972).

The methods of calculating carrying capacity tend to be centered on the theoretical modeling of the physical space, with rare exceptions based on the consideration of specific aspects of the biological aspects (Lobo 2008; Silva & Ferreira 2009). However, it is important that the determination of the carrying capacity of a cave be based on multidisciplinary studies, rather than merely on parameters of the physical aspects (Hoyos *et al.* 1998; Boggiani *et al.* 2007). In practice, the papers consulted (e.g. Cigna & Forti, 1989; Pulido-Boch *et al.* 1997; Hoyos *et al.* 1998; Cigna & Burri 2000; Cigna 2002; Calaforra *et al.* 2003; Fernández-Cortés *et al.* 2006a,b; Boggiani *et al.* 2007; Lobo 2008; Russell & McLean 2008) consider climatic monitoring as the minimal study for the identification of the carrying capacity in caves, since the alteration of atmospheric parameters such as temperature and relative humidity of the air can generate negative consequences throughout the environment.

Despite the clear theoretical understanding of the characteristics of carrying capacity, no standard procedure for its determination has been established (Lobo 2008), and various different methods are used on a local, regional, or continental scale; they depend on: a) the characteristics of the cave; b) the kind of visitation practiced; and c) the management capacity of the responsible environmental agency.

In the literature, three main tendencies for the determination of carrying capacity were found: control based on a coefficient of rotation; environmental parameters; or the Cifuentes method. The latter was, however, developed for the management of trails, but applicable with certain limitations for itineraries in caves. In addition to these well-known and widely applied models, other two possibilities can be added, both developed in Brazil: the confrontation of environmental fragility with projected scenarios and a time-based option.

VISITATION TURNOVER COEFFICIENT (VTC)

The VTC is the simplest form of controlling visitation for touristic itineraries and can also be utilized in caves. In essence, it calculates the number of people who could physically occupy a given surface area at a given unity of time, and then establishes the number of times that a visitation event could occur. It is thus a basic relationship between spatial and temporal feasibility.

An example of this kind of limitation, developed in Brazil, is quite useful for the management of vertical caves. In the case of the Anhumas pit (Figure 1a), located in Bonito city, in the state of Mato Grosso do Sul, Brazil, the limit for visitation is established as a function of the technical difficulty and the time necessary to traverse the 72 meters of vertical drop from the entrance, both for entering and for leaving, as well as the time spent in floating in the lake in the interior of the cave. In this case, visitation limits are very low – 18 persons per period of a day – although the cave is so large that if only environmental aspects were considered, many more people could visit it during any one day.

CONTROL OF ENVIRONMENTAL PARAMETERS

The determination of carrying capacity via the control of environmental parameters is necessary when some critical environmental factor of known fragility exists which should limit visitation. Moreover, it is useful when there is a linear relationship between cause and effect for the presence of visitors and variation in some identified critical factor. Its use is common in caves which shelter archeological remains, such as rupestrian paintings (e.g. Hoyos *et al.* 1998), or which contain rare minerals whose conservation depends on the stability of the atmospheric medium (e.g. Fernandez-Cortes *et al.* 2006b).

Hoyos *et al.* (1998) determined a numerical limit of 32 people at any one time in the Candamo cave in Spain, based on the impact of the temperature of the air. A similar principle was used by Calaforra *et al.* (2003) in the Cueva de Agua de Iznalloz in Spain. These authors arrived at a limit of 53 visitors at the same time in the cave, based on temperature alterations of 0.1 °C. For the giant geode of Pulpi, also in Spain, Fernandez-Cortes *et al.* (2006b) explain the unfeasibility of visitation, not only due to the direct impact of trampling of the gypsite crystals, but also to the great probability of an increase in the rate of water condensation on the surface of the speleothems, which could lead to condensation corrosion. These authors point out that the presence of only three people in a period of less than 10 minutes was sufficient to trigger this mechanism of condensation. Moreover, the time required for normalization of atmospheric parameters exceeds 24 hours, making constant visitation unfeasible.

Another characteristic associated with these methods is the regular use of statistical procedures in the analysis of results, such as time series analysis based on descriptive statistics (Hoyos *et al.* 1998; Boggiani *et al.* 2007), Fourier transformations, and spectral analysis (Mangin *et al.* 1999; Calaforra *et al.* 2003; Fernández-Cortés *et al.* 2006a), trend surface analysis (Fernández-Cortés *et al.* 2006a; Lobo & Zago 2010) and correlation coefficients (Liñán *et al.* 2008; Lobo *et al.* 2009).

Such a means of obtaining the carrying capacity of a cave is linked to the identification of a maximum number of visitors per group, which does not necessarily reflect the accumulated total of daily visits possible.

CIFUENTES CARRYING CAPACITY

The carrying capacity of Miguel Cifuentes Arias is a method published in 1992 (Cifuentes 1992) and republished with slight adaptations in 1999 (Cifuentes-Arias *et al.* 1999). It was originally planned for the management of trails in tropical forested areas in Costa Rica and considered the limitations of human and material resources in countries or regions with few resources (Cifuentes 1992). The first adaptation known for use in caves was that adopted for the Lago Azul cave (Figure 1b) in Bonito city (Mato Grosso do Sul state, Brazil) in 1999 (Boggiani *et al.* 2001; 2007). Other examples are the cave of Terciopelo in Costa Rica (Carranza *et al.* 1996), the cave of Santana in Brazil (Lobo 2005, 2008), and the caves of Phong Nha and Tien Son, in Vietnam (Nghi *et al.* 2007).

This method consists of three stages. In the first stage, that of physical carrying capacity (CCR), a VTC is established for the itinerary of visitation. In the second, the Real Carrying Capacity (CCR) is established by the insertion of correction factors (reflecting problem situations such as the fragility of the environment and aspects which make visitation more difficult) which are used to reduce the CCR by a given percentage for each of the limiting aspects identified. In the final phase, the Effective carrying capacity (CCE) is determined. This either maintains the total number of visitors allowed by the CCR or reduces it as a function of the capacity for management (either existing or desired) of the managing agency responsible for the itinerary under study.

In the management plan of the Lago Azul cave, the main limiting aspects considered were those of an anthropic nature, such as the difficulty of access along the itinerary. Microclimatic studies were also conducted in the cave, but they were not actually utilized in the calculations due to the dynamics of the exchange of gases between the underground medium and the external environment. In the cave of Santana (Figure 1c), the used limiting aspects involved the comfort of the visitors and the energy flow level, using the concept of Heaton (1986) as a basis, as well as a practical application of the concept developed by Lobo and Zago (2007).

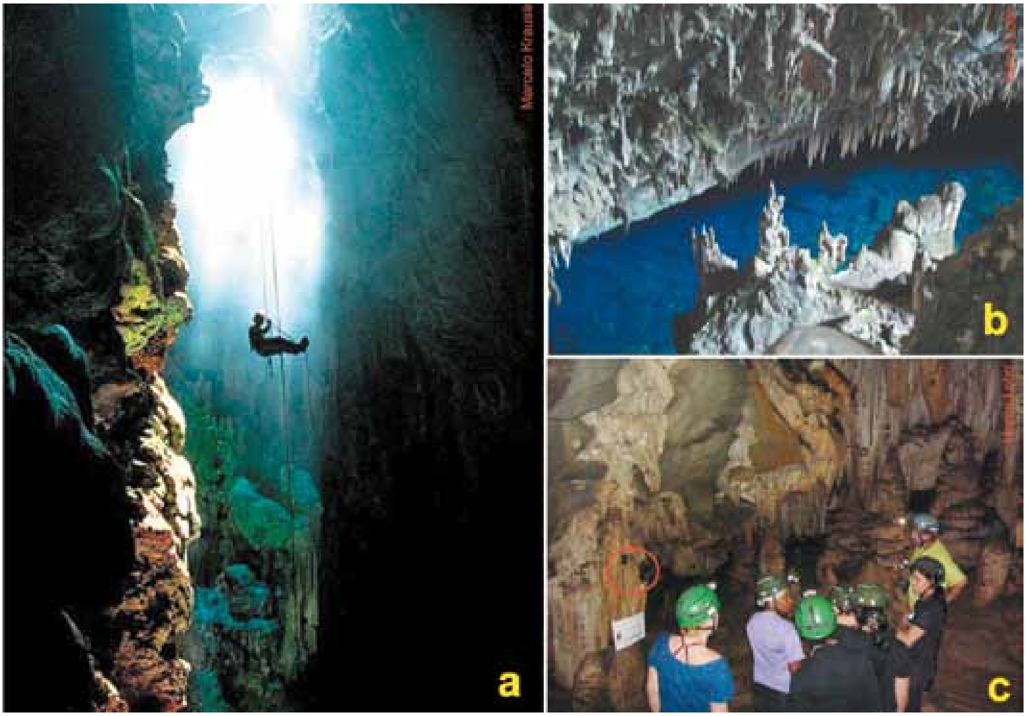

Fig. 1 a) Tourist entering by rappel in the Anhumas pit (city of Bonito, Brazil); b) Partial view of the lake and speleothems of Lago Azul cave (city of Bonito, Brazil); c) A tourist group with a tour guide in the Encontro hall, in the cave of Santana (Iporanga city, Brazil) – one of the monitored places of this cave (the red circle shows the datalogger, who is monitoring the relative humidity and the temperature of the air and the cave wall, with an external probe)

The difficulties in the application of the Cifuentes method are: a) the fact that it was originally designed for trails in tropical forests, and it loses much in its adaptation to cave environment; b) the system of calculation adopted juxtaposes factors and does not permit the identification of a single critical factor; and c) the lack of a causal nature between the limitations generated and the parameters analyzed.

NEW BRAZILIAN PERSPECTIVES IN SPELEOTOURISTIC CARRYING CAPACITY

In addition to these established methods used for determining the carrying capacity of caves which are widely utilized in the most diverse political-socioenvironmental contexts, two new approaches are under development in Brazil. These consider various realities of touristic-speleological management, such as the limited time available for the studies, the lack of human resources, and the unfeasibility of constant review of established standards.

SCENARIO PROJECTION AND LIMITATION BASED ON ENVIRONMENTAL FRAGILITY

The confrontation of an idealized scenario for the visitation of caves with the actual fragilities encountered in the environment has recently been proposed in Brazil (Lobo *et al.* 2010b). It requires the collaboration of a multidisciplinary team composed of professionals in tourism, geographers, geologists, biologists, and environmental managers, and was applied in 30 caves opened to visitation in State Parks of São Paulo, Brazil. The first step is a survey of the possibilities of what would be desirable for each cave, considering both the preferred scale of visitation (size of groups) and intensity of use (total number of visitors per day). This scale of visitation contemplates different kinds of visitation (school groups, ecotourists, adventurers etc), with this profile influencing the difficulty of the proposed itinerary, and the aspects of environmental conservation focused on.

This projected scenario is then submitted to an analysis of the fragilities of the environment, considering various aspects of the portion of the cave to be included in an itinerary, including morphology; the number, location, and composition of the speleothems; the presence of archeological or paleontological remnants; the stability of the microclimate; and the fauna found in the aquatic, terrestrial and aerial biotas. These factors of fragility are integrated using two criteria: maximum fragility (calculated for each portion of the cave) and weighted fragility (a weighted average for all of the fragilities analyzed). Fig. 2 and Table 1 provide some examples from Diabo cave, as well as values projected for the scenarios and the final carrying capacity established.

Lobo *et al.* (2010b) point out that the limits established are provisional and that the results must be monitored, with future modifications to be made as necessary based on the realities of each itinerary. The need for modification is to be identified via continuous reports of environmental conditions.

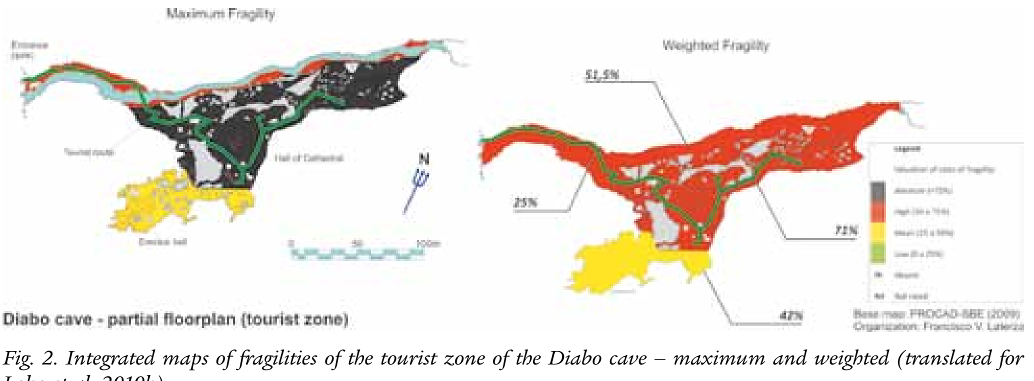

Fig. 2. Integrated maps of fragilities of the tourist zone of the Diabo cave – maximum and weighted (translated for Lobo et al. 2010b)

Table 1. Projected scenarios and provisional carrying capacity of the Diabo cave

Route	Projected scenario (visitors/day)	Visitors/ group	Provisional carrying capacity (visitors/day)	Recommendations for environmental monitoring
Tour route	1300	50	1100	air temperature and relative humidity
River route	100	10	80	aquatic fauna in the river
Erectus hall	30	6	18	physical damages in the speleothems; carbon dioxide concentration

CARRYING CAPACITY BASED ON LIMITATION OF VISITATION TIME ALLOWED

The final method for determining touristic carrying capacity in caves is also being developed in Brazil. Studies have been conducted in the cave of Santana, with atmospheric monitoring including parameters of temperature (of air, water and rock), relative humidity, CO_2, atmospheric pressure and wind (Lobo 2010). The operational logic of the method is based on control via limitation of visitation time based in the main environmental parameter – which can be changed for each cave. No attempt is made, however, to totally eliminate impacts, as is attempted in the case of most environmental control methods, but rather to limit them. The main characteristics of this new method are:

– delimitation of the path for visitation.
– simultaneous monitoring of the atmosphere in various points of the cave,
– the limits are based on the capacity of the environment to disperse the impacts generated so there will be no daily accumulations.

Considering this, correlation formulas between the visitors flow and their respective impacts are been developed, especially in caves where the dynamics of the environment do not permit identification of a linear relation of cause-effect between visitors and specific environmental impacts.

FINAL CONSIDERATIONS

Based on the examples in Brazil and abroad, it was concluded that each of the methods is useful in specific situations, since each reflects in some way a series of environmental fragilities that are related to the management of the relevant agencies.

For some situations, the VTC, the determination of a provisional carrying capacity (Lobo *et al.* 2010b) or the Cifuentes method (1992) are sufficient for the initial organization of speleotouristic use. Techniques such as these can be used to establish temporary limits, but these must be refined on the basis of more detailed technical-scientific studies.

In caves of greater morphophysiographic, microclimatic, and biotic complexity, or when specific aspects of extreme fragility require special protection, other methods are necessary for the establishment of public utilization. These should be based on critical environmental factors, and a carrying capacity based on the impact on these specific factors is called for, either based on linear correlations between stimulus and response or on seasonal variation.

The carrying capacity must be flexible and change as a function of the reaction of the cave to the differences in the planned visitation. The establishment of fixed quantities of visitors as a function of fluctuations of pressure or the profile of demand or based on temporal or environmental cycles is inefficient. It should be remembered that the natural environment changes everytime, renews itself constantly. Establishing a fixed criterion for the management of a natural resource implies the ignoring of this fundamental and universal principle.

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