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Projection of tourist scenarios onto fragility maps: Framework for determination of provisional tourist carrying capacity in a Brazilian show cave

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HIGHLIGHTS

- ► This is the first method tested of simultaneous management of 32 tourist caves.
- ► We changed the traditional deterministic methods of tourist carrying capacity.
- ► The framework created is a decision-making method for tourist carrying capacity.
- ► The method divides the liability of tourism planning among all the stakeholders.
- ► The continuous monitoring of cave environment is a key factor of the method.

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ABSTRACT

Traditionally, the concept of tourist carrying capacity has been understood as a tool for planning tourism in natural areas. As such it has focused on quantifying impacts that are consistent with maintaining a specific environment. In this article tourist carrying capacity is considered from a different viewpoint in a case study of a Brazilian show cave, the Diabo cave, near Eldorado city, São Paulo state. In this instance decisions concerning tourism had been based primarily on the advantages that tourism could provide in maintaining economic-administrative sustainability and community support. More recently, other factors based on natural limitations have been considered in a process of participative discussion among stakeholders seeking to preserve the caves and their sustainable usage. This process led to the conclusion that the carrying capacity of the caves should be flexible, conditioned by protocols of environmental monitoring with reference to levels of demand. Such monitoring, it is hoped, will permit the adjustment of the initial cave limits as a function of changes in the patterns of consumption, local realities, and the identification of unanticipated yet unacceptable environmental impacts.

1. Introduction

Many aspects of nature have a great potential for tourism. Among them we can mention mountains, canyons, islands, beaches, rivers and waterfalls, as well as wildlife and vegetation. In this vast panorama of options, caves stand out due to their unique features, both scientific and esthetic, resulting in a high degree of attractiveness.

On the other hand, subterranean habitats are among the most fragile environments in the world, as a consequence of geographic

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fragmentation, spatial confinement, climatic stability and the permanent absence of light. Caves also depend on the epigean region (surface) for nutrient inputs (Bichuette & Trajano, 2010; Gillieson, 1996).

The management of tourist related activities, in protected areas, requires a solid and scientifically based knowledge of the environment, with special emphasis on the limits of the resilience of the geo and ecosystems directly and indirectly affected by such activities. The interests of the local communities involved in the tourism activities should also be considered.

Subterranean habitats require a special planning if they are intended to a sustainable use. Their unique ecological interactions, as well as their flow of mass and energy, differ from what is observed in other natural environments (Cigna & Forti, 1988; Pulido-Bosch, Martín-Rosales, López-Chicano, Rodríguez-Navarro, & Vallejos, 1997). The confined space, in conjunction with limitations in geological and biological processes make the anthropogenic impacts last longer, and in some cases forever.

The most frequently used procedure to reduce the magnitude of direct human disturbance is the regulation of public use, by setting limits on time, space, and behavior (Lobo, 2011). Such limits would be stipulated as a function of the theoretically acceptable variations in the key parameters of the affected environment, which are known to be related to the level of the anthropic pressure, thus leading to the idea of environmental fragility (Trajano, 2010).

The analysis of limitation of use based on fragility, associated with procedures for the evaluation of the tourist potential of caves, as developed in Brazil by Lino (1988), Labegalini (1990), Marinho (2002) and Lobo (2007), was the basis of this proposal for tourist planning and management for caves, which was designed to identify a starting point for visitation. The method herein presented was developed for the first step in tourist planning: the establishment of the provisional tourist carrying capacity of caves (PTCC).

Traditionally, carrying capacity is a quantitative approach used to justify limitations for tourist use, based on the maximum magnitude of human impacts within the resilience limits of the environment. Cigna (1993), Gillieson (1996) and Hoyos, Soler, Cañaveras, Sánchez-Moral, and Sanz-Rubio (1998) established a conceptual basis for caves. Practical methodologies are presented in Cifuentes (1992), Hoyos et al. (1998) and Calaforra, Fernández-Cortés, Sánchez-Martos, Gisbert, and Pulido-Bosch (2003), among others. In the case that Cifuentes (1992) studied, the method that was developed initially to be used in trails and was adapted to caves in the studies by Boggiani et al. (2007) and Lobo (2008). Originally, Cifuentes proposed an addition of the factors considered to be critical. This operational logic considerably reduces the number of visitors without considering a direct cause between the problems and the intensity of the visitation.

On the other hand, Hoyos et al. (1998) and Calaforra et al. (2003) adopted a linear perspective of cause and effect between cave atmospheric parameters and the presence of visitors, focusing on the size of the visiting groups in specific situations, such as in the presence of rupestrian art.

The establishment of the carrying capacity depends on the environmental diagnoses, which incorporate data related to monitored visitations (Fernández-Cortés, Calaforra, & Sánchez-Martos, 2006). In underground systems, different levels of exchange of mass and energy are involved (Calaforra et al., 2003; Cigna & Burri, 2000; Heaton, 1986; Hoyos et al., 1998) and the environmental processes take place over long periods of time, making especially difficult to establish the exact number of visitors desired for a given cave. Traditional methods are based on the notion of fixed situations and definitive numbers, without a continuous feedback provided by regular monitoring. These methods have been used merely to satisfy planning needs and obligations in the development of management plans (Cigna & Burri, 2000). In fact, in many places the carrying capacity, simply reduced to a numeric issue, is used to obtain permanent numbers of visitors, leaving aside the seasonal dynamics of the environment and the tourist seasonality, which are very important issues in caves.

One of the challenges for the management of show caves is the determination of numerical and spatial limits for the routes to be designed. The starting point is the understanding of the concept of the carrying capacity as a tool for the improvement of the use of natural attractions for tourism purposes compatible with the environmental conservation. The carrying capacity concept was not designed to simply limit the massive access of people, but rather to identify a rate of visitation which would be acceptable in relation to the anthropically-induced changes in an area (Boggiani et al., 2007; Cifuentes, 1992; Cigna & Forti, 1988; Stankey, Cole, Lucas, Petersen, & Frissell, 1985). Moreover, the concept of carrying capacity cannot be reduced to a numerical calculation just to provide a single result, but rather, it should be a means for supporting management decisions. It is a dynamic technique, whose outcome may change as a result of the variables being analyzed (Cifuentes, 1992; Lobo, 2008). Although carrying capacity is usually based on the natural characteristics of the environment, there are authors (e.g. Gillieson, 1996; Lobo, 2008; Santana-Jiménez & Hernández, 2010) who agree that the point of view of the visitors should also be taken into account. Physical levels of comfort, psychological limits for group density, as well as preferences for types of activities should also be taken into consideration.

The method herein presented is different from the other methods traditionally used in caves (e.g. Boggiani et al., 2007; Calaforra et al., 2003), in its theoretical conceptualization and procedural logics. Leaving aside the search for “magical numbers”, the adopted approach was closer to the decision-making frameworks, as the Limits of Acceptable Changes (LAC), proposed by Stankey et al. (1985). However, the LAC framework requires a wide range of financial, human and time resources, hampering its application in countries such as Brazil, as previously pointed by Ceballos-Lascuráin (1998).

The first step was the delimitation of the hypothetical scenarios, initially designed to meet the social, economic and psychological needs of various stakeholders involved in tourism, including scientists, environmental authorities, local leaderships, park managers and others. Proposals for visitation schedules are submitted to analysis as a function of feasibility, especially in relation to bottlenecks established from diagnostic maps outlining the fragility of the environment. Discussions between the stakeholders define spatial and temporal limits, which generates modifications in the scenarios previously projected by specialists in tourism management. Issues to be discussed include the size of the groups of tourists, their routes, the pre-requisites to allow the visitation of relative more fragile areas and the limitations for daily visitation, resulting in the establishment of the provisional carrying capacity.

2. Methodology

2.1. Study area

The present method was applied in 50 proposed tourist scenarios in 32 caves located in a mosaic of natural protected areas. Those areas were designed to preserve significant remnants of the Atlantic Coastal Rain Forest, covering the Upper Ribeira Valley, in the Southern State of São Paulo, SE Brazil (Fig. 1). They are situated in the transition from the Atlantic Forest to the Araucaria Forest

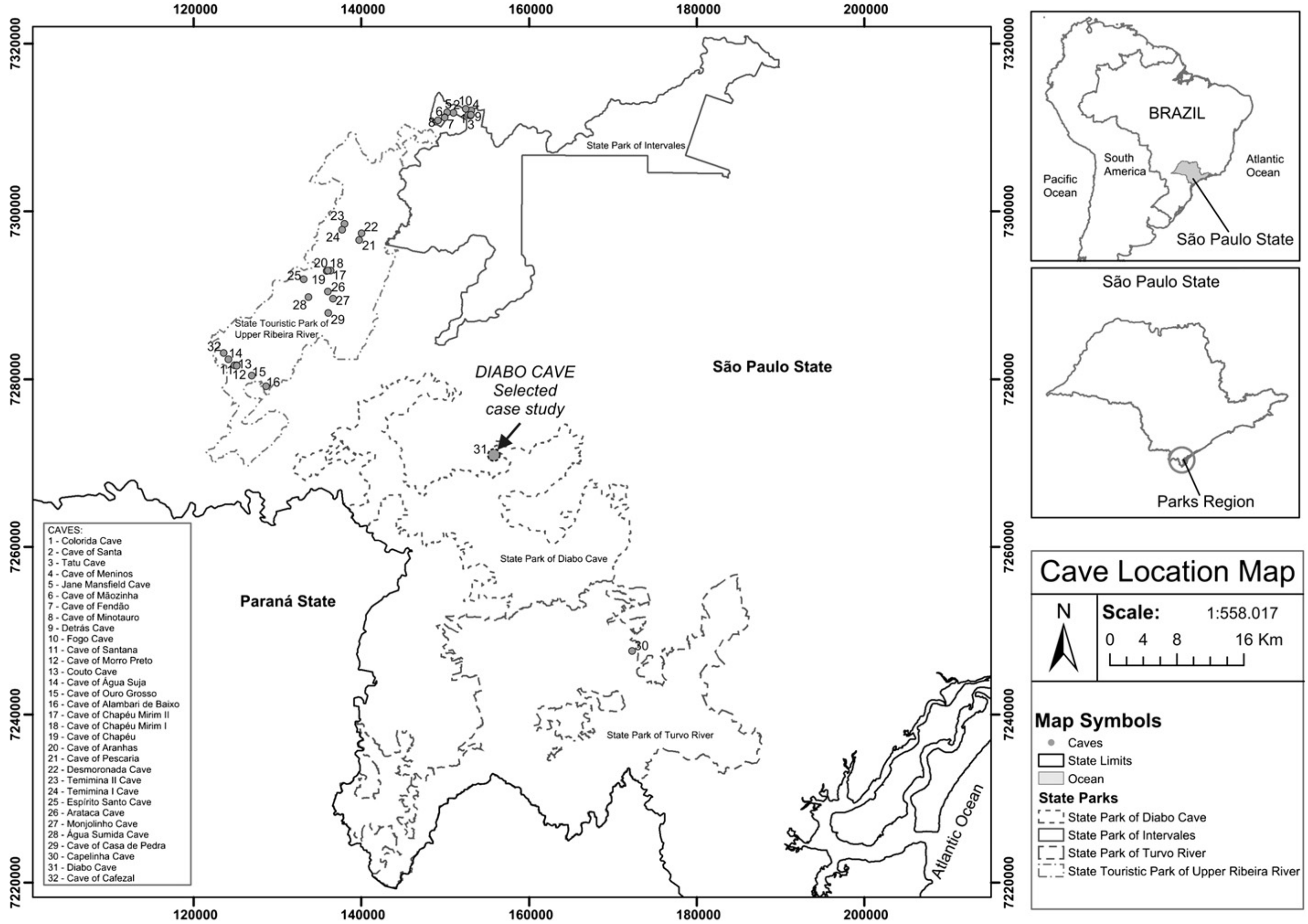

Fig. 1. Localization of the studied caves in the Upper Ribeira Valley, with special emphasis to Diabo cave.

domains (*sensu* Ab'Saber, 1977); the climate is subtropical humid, without a typical dry season. There is a significant variation in altitude, from 1040 m to 137 m in the karst area of the Intervales State Park (Sallun Filho, Ferrari, Hiruma, Sallun, & Karmann, 2010), that is one of these protected areas where the caves are located.

In the Alto Ribeira karst area, there are more than 500 caves so far recorded, many located in protected areas. This karst area is formed by Middle Proterozoic carbonate rocks of the Açungui Group, comprising lenses of metamorphic limestone and dolomitic limestone intercalated with lenses of insoluble rocks, all intensively folded. The area features different stages of development of the karst, beginning with fluvial valleys, which then become segmented by closed depressions, and then evolve to a classical polygonal karst (Auler & Farrant, 1996). Geomorphologically, as well as in phytogeographic and climatic terms, this area is different from the most extensive karst areas in Brazil.

The unique combination of geomorphological, phytogeographic and climatic features, in a relatively small geographic area, makes the Alto Ribeira a most relevant area for Conservation, imposing the need of a very careful planning for any kind of human use, including tourism.

The caves in this area started being regularly visited in the mid-1960's, with the pioneering initiatives exploring the Diabo and Santana caves (Le Bret, 1995). Organized tourism was intensified in the 1980s, with the creation of three State Parks and other categories of natural protected areas in the region (Marinho, 2002). Some caves, such as Diabo, Santana, Água Suja and Morro Preto, received an average of 30,000 tourists/year in the last decade.

In 2008, after years of visitation, the tourist caves of the above mentioned region were closed by a judicial determination, since no management plans had been developed, either for the parks or the caves. Moreover, accidents involving tourists had roused public concerns about safety. This prevention of visitation, however, was extremely harmful to local communities which depend on the resources from tourism, once the flow of visitation was reduced to practically zero for months (Lobo, 2008). These events led to the elaboration of plans for the speleological management of 32 caves in four state parks in the region (Fig. 1).

The method herein described was developed and applied to those 32 caves based on environmental studies conducted from January 2009 to December 2010, complemented by data previously available for most of them. As an example, we present the results of its application to the Diabo cave (also known as Tapagem cave), one of the most important of all the Brazilian show caves.

2.2. A new approach to tourist carrying capacity: provisional tourist carrying capacity in caves (PTCC)

The application of the traditional carrying capacity indexes is not the scope of the present study, due to doubts as to their practical application and usefulness for long-term conservation. It is necessary, however, to have a procedure to provide practical responses to legal, social and environmental questions about the management of cave tourism. From a theoretical point of view, the limitations in the definition and application of carrying capacity indexes discussed by Cifuentes (1992), Gillieson (1996), Lindberg, McCool, and Stankey (1997) and Simón, Narangajavana, and Marqués (2004) were fundamental to develop this new approach aiming to establish a provisional carrying capacity under a new logic. Instead of trying to find the limitations imposed by natural phenomena, this approach starts with the projection of hypotheses of the ideal routes for visitation.

The change is not only semantic, but also conceptual: the new proposal abandons the perspective that it is possible to obtain answers directly from the environment about the expected limits for tourism. Instead, it assumes that whatever carrying capacity is established, it has to focus on the idealized options in relation to visitation, including a follow-up program for the monitoring of fundamental variables related to each scenario. As Simón et al. (2004) suggested, carrying capacity numbers should be flexible, varying as a function of environmental, social and practical management factors.

These idealized routes are initial hypotheses for the determination of scenarios, tested as a function of the environment, using maps to identify points of environmental fragility. Thematic maps have been elaborated by specialists in the various fields related to Speleology. They were then integrated to identify bottlenecks of greater fragility for each one of them. These maps were discussed in participative workshops involving scientists, technicians, park managers and representatives of the local communities and the tourist trade. So that numerical limits and behavioral norms could be established. The final results were referred to as “provisional carrying capacities”, because they were linked to monitoring protocols based on environmental parameters which would lead, in the long run, to adjustments increasing or decreasing the number of visitors and modifying the behavioral norms.

2.2.1. *Analysis of speleotourist potential and projection of visitation scenarios*

The identification of the potential for use and the projection of idealized scenarios for cave visitation are the first steps in the methodology herein developed. Studies of the environmental fragility are required to monitor the level of the anthropic pressure proposed in these scenarios. Thus, any change in the visitation scenarios implies a complete revision of the levels of fragility.

These scenarios start to be envisioned with the spatial delimitation of the proposed routes. Such routes should integrate the interests of various segments of the population with the conditions observed in the caves, paying special attention to the intrinsic vulnerability of this environment. In the present method, the proposal of routes is based on the methods and analysis suggested by Lino (1988), Labegalini (1990), Marinho (2002) and Lobo (2007). In general terms, these methods differ from the traditional way of to identify the tourist potential of caves and other natural resources based on pilot tests. The frameworks developed by Lino (1988) and Lobo (2007) propose a multidisciplinary environmental analysis, encompassing measurable indicators, both qualitative and quantitative, related to a wide set of geological, climatic and biological fragilities.

A proposed route includes a delimited pathway (Boggiani et al., 2007; Lobo, 2009, 2011), with points where dispersion is permitted (Lobo, 2009, 2011) and is identified on a topographic map. This pathway should be accompanied by a detailed description of the location and the types of intervention which are necessary. Once the potential routes are physically defined, their utilization by visitors must be delimited. These numerical limits are based on the profile of the intended public and its needs, as well as its purpose for visitation: contemplation, adventure, education for school children and adolescents, research and religious events (marriages and/or parties). For example, groups of tourists aiming to look to the cave environment may be larger than study groups, which require more attention to the learning process, or than adventure groups. For a deep qualitative experience in participative tourism, it is mandatory to decrease the size of the groups, for safety and qualitative reasons. Physically handicapped visitors, especially those confined to wheel chairs, should also be considered. The importance in defining different groups and types of public use is based on the fact that they will influence the intensity and nature of the impact to be generated.

Visitation must also be scheduled, and the number of individuals per group must be previously defined. Such limit should be based on safety, comfort level, activities, and also, as suggested by Santana-Jiménez and Hernández (2010), on the perception of the tourists about the maximum acceptable number of people per group.

In the methodology presented here, such criteria led to the establishment of the sizes of the groups according to the different types of activities, as shown in Table 1. Visitation to fragile areas, as well as adventure activities, should occur in the scales herein defined as restricted (up to 7 visitors) or low (up to 10) – those are arbitrary numbers, based on previous experiences in speleotourism, thus prone to revision. These small scales are not feasible for teaching activities, since the learning process includes the interaction of all the students among themselves and with the teacher. In such cases, and also for most of the contemplative tourist routes, medium and high scales (11–30 visitors), are advised. The actual number of visitors per group may vary, considering issues of safety and spatial availability in the cave, mainly in dispersion areas. Finally, the extreme cases are those when the environment and the visitation pathway allow larger groups, in an intensive scale of visitation (up to 50 visitors). These cases, considered as exceptional, must be analyzed in a more critical process, due to the high degree of environmental impact and also because large groups always pose serious difficulties to the tourist guides to control them.

The projection of scenarios also considers other aspects of a more qualitative or subjective nature. This approach requires extensive group discussions to obtain a result coherent with the reality being studied. These discussions should include the following aspects:

- Time required to complete the visitation route, taking into account the composition of the group and the purpose of visitation;
- Environmental information to be provided, with specific points where pauses will be made to call the attention to aspects of the underground environment and to explore the ideas of the visitors in relation to caves;
- Expectations and needs of the target population;
- Pre-existing infrastructure adapted for visitation;
- Safety issues, which involve maps locating potential risks and the establishment of contingency plans;

Table 1
Scales of visitation used to the projection of visitation scenarios.

Visitation scale	Number of visitors (with tour guides)/group
Restricted	Up to 7
Low	Up to 10
Medium	Up to 20
High	Up to 30
Intense	Up to 50

- Demand, since certain routes revealing specific curiosities will drive greater interest than others; moreover, some routes should be limited to visits of more experienced speleological tourists;
- Needs of local communities and tourist agents, since the concept of carrying capacity is also designed to guarantee more sustainable and lasting use.

2.2.2. Analysis of fragility of cave environment

Based on the evaluation of the anthropic impacts on specific characteristics of the environment, the classification of its fragilities is the second step to organize potential routes and pathways. It is noteworthy that fragility is a relative concept, not designed to identify intrinsic susceptibility of specific elements in karst systems (cf. Ford & Williams, 2007) but, rather, to relate causes to effects as a function of quantitative levels and qualitative aspects of the human presence (Lobo, 2011; Trajano, 2010). A similar perspective for analysis in relation to the human presence was adopted by Arrowsmith and Inbakaran (2002) in their study of the environmental resilience of biotic and abiotic factors related to tourism in a National Park in Australia.

The fragilities of the underground environment are identified after diagnoses made by professionals in different fields of speleology, usually based on scientific studies designed specifically fort this purpose, following the appropriate procedures of data collection, analysis and interpretation. The fragilities identified for each area of the caves are showed on the thematic maps.

All the studies are necessarily governed by the norms of the distinct thematic studies. The results are presented in various forms of evaluation and classification of the cave's environment, which certainly complicates any attempt to compare the importance and/or weight of the specific data. Thus, the first methodological premise adopted was the definition of levels of fragility, corresponding to values expressed as percentages, allowing for the comparison of independent types of data. The classification of levels of fragility herein defined is presented in Table 2.

The scale of fragility levels may be applied to the whole cave (in small or homogeneous caves) or to some sections, such as a large room, a conduit, a stream, or a climatic zone. These fragility units are established based on the interpolation or extrapolation of the data from the surveyed points. It must be stressed that the level referred as "unclassified/inexistent" does not necessarily imply the absence of fragility, because in some instances, it is not scientifically possible to prove it. In such cases, this classification indicates the need of more research in that specific region of the cave.

The classification of the levels of fragility based on specific criteria for each of the four thematic areas considered is showed on Table 3.

The total fragility in relation to each thematic study is then estimated for each zone or for the cave as a whole. At first, the sum of the values attributed by each area is divided by the total number of criteria (Equation (1)):

Table 2
Levels of fragility considered in the present study.

Fragility level	Values (%)[a]	Color of legend	Brief description
Absolute	75.01–100	Black	Incompatibility of the specific area for tourist use.
High	50.01–75	Red	Relative compatibility of a specific area for a projected scenario of tourism.
Medium	25.01–50	Yellow	
Low	0.01–25	Green	
Unclassified/inexistent	–	Translucent	Absence of studies and/or undetected fragilities.

[a] The four levels of fragility reflect an arbitrary division of the totally 100%.

Table 3
Criteria used in analysis of underground environments in relation to visitation.

Thematic study	Examples of criteria used
Speleogeology	Total extension of the cave conduits Total depth of the cave Volume of large rooms Presence, variety, location and rarity of morphological features Presence of clastic deposits Potential of clastic deposits for sedimentology studies Existence, variety and location of speleothems and mineralogy involved Geological singularities
Paleontology and archeology	Presence of remnants Existence of previous studies and rescue of remnants in some cases
Microclimate[a]	Climatic connectivity with the outside Carbon dioxide concentration
Speleobiology[b]	Presence and richness of troglomorphic species Occurrence of species with low population densities Presence of putative new species Presence of species indicating good quality of water (Megaloptera, Trichoptera, Ephemeroptera, Plecoptera, Odonata and Decapoda Aeglidae, Amphipoda) Granulation of substrate in streams Granulation along river banks

[a] Other atmospheric parameters, such as the concentration of radon, wind flow, and condensation rates, in addition to the temperature of the water and cave walls, should be considered in microclimatic studies. However, the time and expenses involved in such studies tend to render the use of these parameters unfeasible in the present method.
[b] The classification of subterranean organisms into the Schiner–Racovitza system followed Trajano (2005).

$$\mathrm{FTx} = \frac{\mathrm{IF}_1 + \mathrm{IF}_2 + \mathrm{IF}_3 \ldots + \mathrm{IF}_n}{\sum \mathrm{IFs}} \tag{1}$$

where, FTx = Fragility of zone x of a cave for the thematic area, $\mathrm{IF}_{1,2,3\ldots n}$ = Values and/or weights for each criteria of fragility, $\sum \mathrm{IFs}$ = Total number of criteria utilized in classification of each zone or cave.

The results obtained will invariably fit into one of the categories showed on Table 2.

2.2.3. Integration of the thematic maps

The next step in the analysis of the fragilities involves the overlapping of the thematic maps, producing integrated maps for each cave or cave section. Two types of maps were drawn:

- Maximum fragility maps, corresponding to the greatest fragility identified from any scientific point of view;
- Average fragility maps, by averaging the values obtained from the assessment of various areas.

These maps create zones in each cave, depending on the percentage scores of levels of fragility from Table 2, once a final score has been obtained for each cave or cave zone.

2.2.4. Provisional tourist carrying capacity (PTCC)

The results from these integrated fragility maps can be used in two ways: a) in discussions amidst specialists attempting to reach a consensus, or b) the application of indices for the reduction the original amount of visitors proposed in the scenarios, to compensate the fragility of specific academic studies, using a calculation similar to that proposed for the carrying capacity of Cifuentes (1992).

The preferred procedure is the consensus reached after some discussions, because the methodology hereby described was designed to provide support for the decision-making, rather than a deterministic calculation. This discussion should involve the higher number possible of specialists in different disciplines of speleology (biologists, geologists, geographers, climatologists, paleontologists, archaeologists, tourist managers and other scientists, when needed) as well as stakeholders involved with the public use of the cave, such as environmental managers, government representatives, research workers familiar with the region, tourist agencies and local guides. To properly conduct the discussion, the following outline was prepared:

1. Presentation of the thematic maps showing the idealized route(s), and also tables and boards explaining the projected scenarios for visitation, so that everybody can understand the level of impact to be expected;
2. Presentation of the thematic maps showing the fragility of the different zones of the cave based on studies by specialists, who should identify the points of the greatest fragility and justify their inclusion, one by one;
3. Presentation of the integrated fragility maps, showing both maximum and average fragilities, so that the areas that are the most susceptible to environmental disturbance can be identified.

At the end of the presentation of these materials, the discussion among all the stakeholders begins, aiming to verify the pros and cons about the implementation of each tourist scenario. The main goal of the discussion is to reach a consensus about a specific tourist scenario, focused on:

- The definitive tourist route and pathway;
- The isolation of specific areas of higher fragility levels, or even the incompatibility with the visitation;
- The number of tourists and tour guides per group, in view of the difficulties of the tour routes, and also of the quality of the services to be rendered; These numbers may vary in function of many factors, such as the day of the week (e.g. different groups for each tourist profile, in working days and in weekends);
- The final identification of the PTCC allowed, considering group sizes, duration of the tour and the total time of visitation in a day.

If no consensus is reached, an alternative, less desirable strategy to determine the PTCC would involve the application of the indices of average fragilities or the use of indices of maximum fragility. Mathematically, this second way is expressed by the Equation (2):

$$PTCC_{Det} = F_z(\text{MAX or AVG}) * CV \quad (2)$$

where, $PTCC_{Det}$ = Provisional tourist carrying capacity determined, F_z (MAX or AVG) = Index of maximum fragility or average fragility, CV = Scenarios for visitation as proposed.

3. Results and discussion

In order to show the applicability of the PTCC, the results obtained for Diabo cave are reported below. All the materials produced by the specialists were presented in a meeting of scientists, environmental authorities and local stakeholders. The presentation started with four tourist scenarios designed to the cave (Table 4; Fig. 2).

Fig. 2 represents a stretch of approximately 700 m of the nearly 6 km of mapped passageways of the Diabo cave. In addition to the traditional pathway, including the highly-impacting concrete structures constructed during the 1960s, two of the potential new routes described in the Table 4 are shown, one as an extension of the traditional pathway, but following the Ostras river, and other as the route through the Erectus hall.

Table 4
Previous tourist scenarios projected to Diabo cave.

Tourist scenario	General description
Tradicional (Traditional)	Visitation of 500 m on the old-traditional pathway, with footbridges, stairways and fixed lighting. The wide pathways allow the adoption of larger scales of visitation, and the existence of guard-rails in part of the tour route makes the control of visitors easier. Under these conditions groups up to 30 visitors would be acceptable, accompanied by at least one tourist guide. The average visitation time is 1 h long, and simultaneous groups are accepted inside the cave, since the 5 min interval of entrance between groups is respected.
Tradicional e Rio (Pathway & River)	An adventure tour route providing the opportunity of a deeper contact with different environmental conditions in the cave, in both anthropic and pristine areas. The tourist groups start the tour on the traditional route and then go down to the Ostras river conduit, using helmets with headlamps for a 500–600 m long wet way. In this scenario, a group of 10 visitors was designed (8 tourists and 2 tourist guides). The additional support of ropes in some strategic points is necessary to increase security. This scenario is not recommended in the raining season, because of the flooding risk close to the river. The total tour route takes 1 h 30 min.
Salão Erectus (Erectus Hall)	An upper dry gallery, richly ornamented with a big variety of speleothems, as helicites, cave pearls, draperies and an extensive group of wonderful stalagmites. This hall is difficult to access, with slippery or tight passages, as well as small pits. These characteristics provide the tourists the opportunity to feel as a speleologist in a typical exploration research, using helmets, special suits and other speleological equipment. The high fragility of the environment, together with the difficult access, conditioned the size of groups to up to 6 visitors, including one tourist guide. This tour requires at least 2 h to be completed.
Travessia (Crossing the cave)	An extreme adventure scenario, with the complete crossing of the main gallery of Diabo cave (not represented in Fig. 2). This route is almost 3 km long, most of which along the river. It is a very technical crossing, with swimming, rappel and other specific techniques used to move forward into caves. It takes about 6 h for a group of 6 visitors to complete this transect (4 tourists and 2 speleo-experienced tourist guides).

Three fragility maps were also presented (Fig. 3), respectively for the physical environment (geology, geomorphology and paleontology), biology and microclimate.

The physical fragility of the cave was at the highest degree in the main room, since this is structurally unstable, due to the large number of fallen rocks and boulders, and the presence of chemical and clastic sediments. The microclimate of the Erectus hall caused a special concern, since there is little connection between the internal and the external environment at this zone. Biologically, the Ostras river demands a great concern, given the presence of endemic crustaceans.

The integration of these three thematic maps produced the integrated fragility maps, showing zones of maximum and average fragilities (Fig. 4a and b, respectively).

It is noteworthy that the map of the average fragilities did not present high average values, despite the high fragility of the physical thematic study (in accordance with the predominant

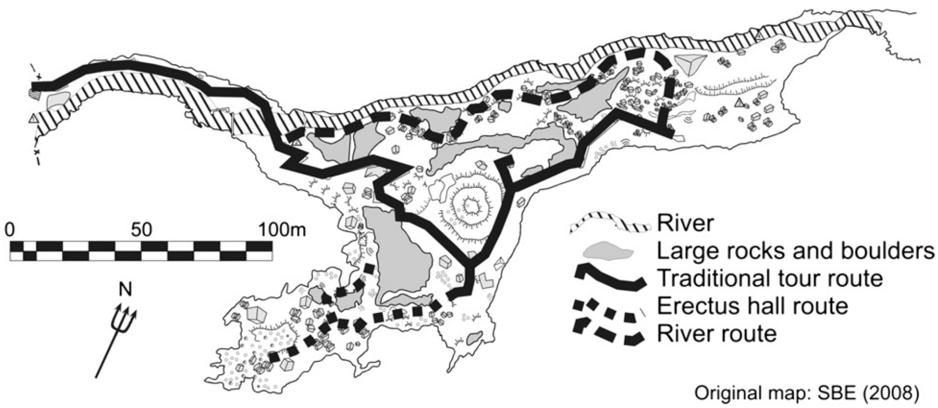

Fig. 2. Partial floor plan of Diabo cave, showing the tourist routes, complementing the exposition of the projected scenarios.

fragility in the map of maximum fragilities). In cases like this, is very important to consider mainly the results of the maximum fragility map, because the average fragility will certainly attenuate the environmental limiting factors.

Fig. 4 shows not only the integrated fragility of the various areas, but also the importance of defining a specific pathway, suspended bridges and handrails to restrict visitation, thus alleviating the potential impact to especially fragile areas. The zone considered to be absolutely fragile (black in the maximum fragility map, Fig. 4) can thus be reduced to a linear zone involving only a relatively low fragility area (green in the same map, Fig. 4). This example shows that, although the construction of a complex infrastructure for visitation, with suspended pathways not in contact with ceiling and walls (with a special microclimate where many animals live and interchange of mass and energy is dominant), may impact the cave during its implementation, it will decrease the impact of visitation in the long run, thus exerting a relatively positive effect on the sustainability of the visitation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The existence of a low fragility zone in the pre-existing traditional route was the main topic to start the dialog in the meeting. The local tourist stakeholders explained the need to raise the number of visitors per group in this scenario, to comply with the high demand of visitors in the Diabo cave, that is, the tour bus excursions. The environmental specialists had no objections to this, considering the low fragility of biotic environment in this section, the protection of the physical environment provided by the structure and the guard-rails and the high level of circulation of mass and energy in the atmospheric dynamics. On the other hand, all participants were concerned with the quality of tourism, which was the reason of the recommendation of a monitoring program about the satisfaction of the tourists in this scenario.

The local stakeholders also requested a new scenario to the cave, a nocturnal visit with local folkloric music presentations, to a group up to 50 visitors. The only objection presented was in the speleobiology field, due to the habits of bats, which leave the cave in the late afternoon and the beginning of the evening, and could be negatively affected by such a show.

The proposed scenario named “Crossing the cave” was not accepted, both by the environmental specialists and the manager of the cave. The scientists responsible by the environmental studies mentioned the absence of detailed studies in the whole cave, which does not allow its tourist visitation. The cave manager also pointed

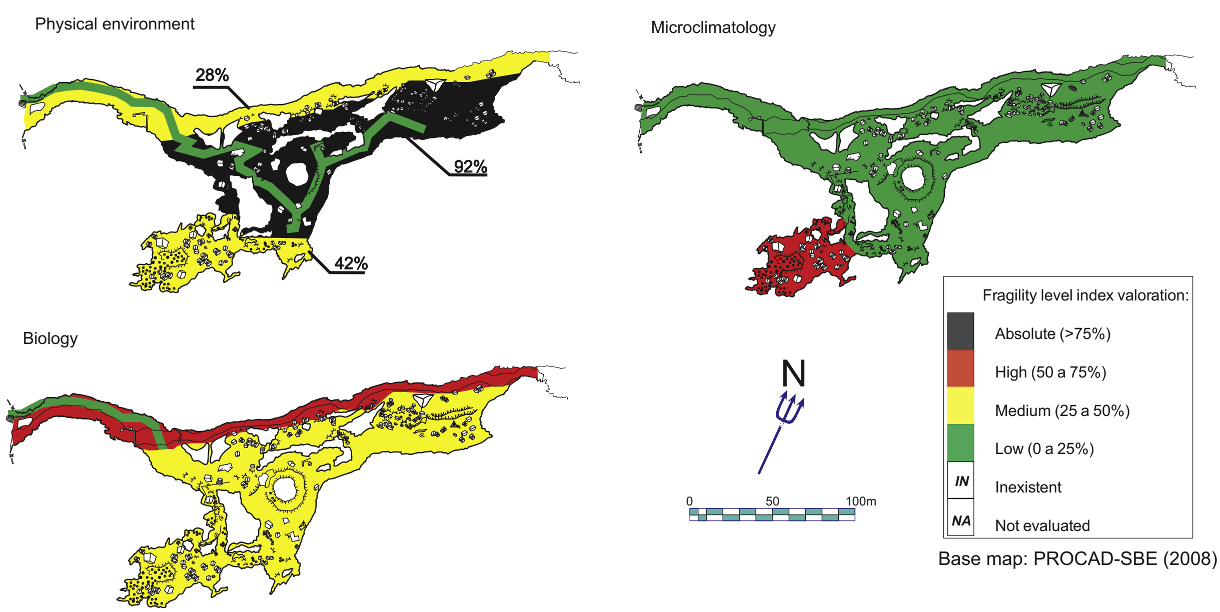

Fig. 3. Thematic maps of fragility from the Diabo cave: A – physical environment; B – microclimatology; C – biology.

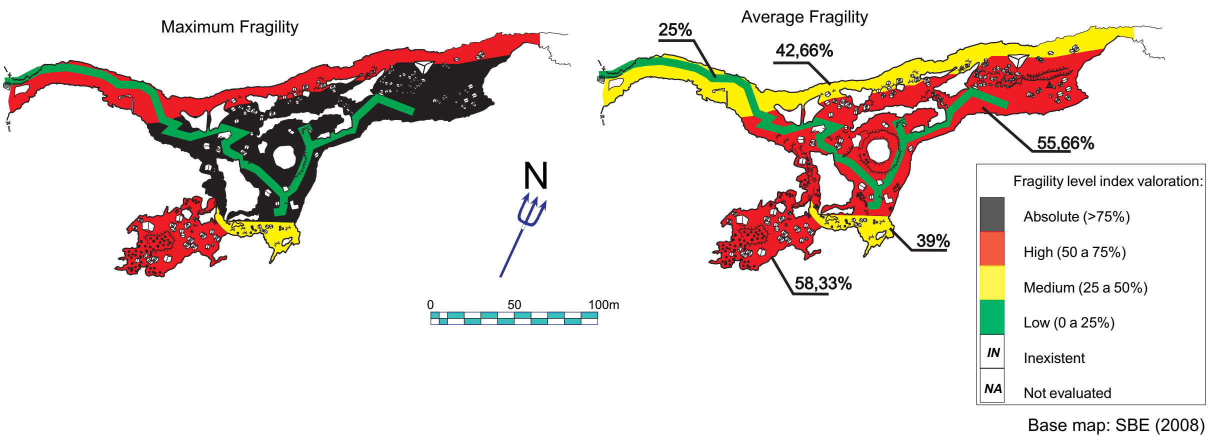

Fig. 4. Integrated maps of the fragility in the Diabo cave: maximum (left) and average (right) fragility.

out safety issues and the preparation of tourist guides, which would be reached in a long term basis. These aspects led to the conclusion that this part of cave should not be used for tourism at the present.

The final results of the meeting are the approved scenarios to the Diabo cave, as presented on Table 5.

In two scenarios (traditional and pathway & river), the projected scale of visitation was increased, due to the socioeconomic issues raised by the local stakeholders, and also by the low fragility of some specific parts of the cave – the pre-existing pathway. These low levels of fragility were not known by the specialists in tourism management which proposed the initial scenario. It happened because the proposed method of PTCC did not allow the specialists in tourism management know those results of the fragility studies before the integration meeting was held. This aspect was considered crucial, to leave the tourist management specialists without interference of previous limits when they are projecting scenarios.

On the other hand, the increase of the interval between visits caused a decrease in the number of visitors in the Erectus hall scenario: the total amount of tourists was reduced, from three to two groups of six visitors, because of the microclimate restrictions on this part of the cave. Moreover, the implementation of this scenario was conditioned to the previous installation of atmospheric monitoring instruments in Erectus hall, as in Boggiani et al. (2007) and Lobo (2011), aiming to continuously register the impacts in thermal conditions and in CO_2 concentration as a consequence of the presence of visitors.

Speleobiological research has shown that, for detection patterns, that usually have strong seasonal, and also infra-annual (cycles with periods superior to one year) components, it is necessary to have long term studies, covering at least three years. For Brazilian caves in general, speleological studies are not sufficient, in most of the cases, to prove the causal nexus between tourists and the variation in the environmental measurable parameters. There are few exceptions, all of them related to microclimate studies, where the environmental response to the anthropic pressure is immediate and measurable (e.g. Calaforra et al., 2003; Fernández-Cortés et al., 2006). There are also cases of direct impacts on the physical environment (e.g. Lobo, 2008), for example, the installation of structures of access causing either accidental or intentional damages to the speleothems. In the absence of previous studies based on methods specifically designed for the determination of fragilities, the principle of precaution, widely used in management processes and frameworks, is of paramount importance.

The PTCC indicators, however, are not the main objective of this framework, but just a consequence of the decisions of all the stakeholders. This is important to set aside the traditional deterministic processes of tourist carrying capacity in caves (e.g. Calaforra et al., 2003) and trails (e.g. Cifuentes, 1992), focused just in numbers, highlighting that the managers are responsible for the management, not for the numbers. Some circumstantial facts, as the lack of resources, increase the importance of the PTCC to an initial delimitation of the rules and provisional limits of visitation.

The focus of the process herein described was in the discussion of the projected scenarios, searching for a common sense which allows the development of tourism in an environmentally responsible way and, at the same time, contributing to the social and economical development of local communities. Therefore it was possible to maintain, within certain limits, the traditional way of a community-based tourism as the main economic activity of the region. The concerns about safety, both of visitors and the environment, were also the strength of the PTCC framework, demonstrating the long term point of view of the local stakeholders, scientists and managers who participated in the planning process.

Table 5
Projected visitation scenarios versus consensual results of PTCC.

Cave	Route	Projected Scenario		PTCC	
		Scale (group size)	Visitors/day	Scale (group size)	Visitors/day
Diabo	Traditional[a]	30	810	50[b] (30)[c]	1100
	Pathway & river	10	80	12	84
	Erectus hall	6	24	6	18
	Cultural presentations at night	–	–	50	50
Total amount of visitors/day		–	922	–	1252

[a] "Traditional" is the route used before the management plan, during the unplanned phase of the speleotourism.
[b] People/group for tourist activities in general.
[c] People/group for educational environmental studies during the week.

3.1. Final remarks

The method proposed for providing support to the decisions aiming to determine the PTCC was based on the integrated contributions from scientists, decision makers and tourism professionals. It allowed a close dialog and the assessment of the parameters determined by the different thematic studies. The social concerns were considered, and the representatives of the local communities had the opportunity to express their views, marked by the ideal of an environmental conservation compatible with the protection of natural areas. Local tourist operators were also able to point their needs in relation to the limits and categories of visitation to be respected. This approach modified the traditional concept of carrying capacity, consolidated as a planning tool designed to open possibilities.

The projected scenarios and the thematic maps that were produced, followed by the wide discussion in a multidisciplinary meeting, showed the applicability of the method. The common sense of stakeholders interested in sustainable tourism in caves, allied to a qualified discussion based on thematic studies, solved the initial problems involved in the limitation of tourist access to caves and the terms to the tourist use. A responsible interaction between all the participants was fundamental to establish the limits and the possibilities of use of sensitive areas, not only for caves but also for other special environments (e.g. coral reefs, archaeological and paleontological sites, snowy mountains etc). In such cases, the central challenge to adapt the present method is the identification of the criteria to analyze the environment in its relationship with the tourist use.

Thus, it is understood that carrying capacities based on a flexible model, aligning an analysis of situations of environmental conservation with the needs of the management and the maintenance of tourism, provides flexible results based on a reasoning which takes the idea of capacity beyond the simple idea of limitation. Thus the concept of carrying capacity is reaffirmed as a possibility for a rational and sustainable use, rather than simply limiting it.

Finally, given the characteristics of the method, it is important to emphasize that the results obtained must always be considered to be provisional. Future developments and the application of protocols for environmental monitoring based are essential, on at least the critical factors identified for each tourist cave, within the acceptable limits for any alteration of the environment. Further studies will allow a more realistic approach to the actual limits which each environment being managed could sustain. Therefore, changes in tourist demand should also be considered, in order to adjust the visitation levels to the prospect number of tourists, without disregarding the needs of local people which depend directly on the community-based tourism, always within the perspective of a long-term use, for the present and the future generations.

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