Indicators of Conservation Value of Azorean Caves Based on its Arthropod Fauna

Paulo A.V. Borges [1,2], Fernando Pereira [2], and João P. Constância [3]

[1] Universidade dos Açores, Dep. Ciências Agrárias, CITA-A, 9700-851 Angra do Heroísmo, Terceira, Açores; pborges@mail.angra.uac.pt.
[2] "Os Montanheiros", Rua da Rocha, 9700 Angra do Heroísmo, Terceira, Açores.
[3] "Amigos dos Açores", Avenida da Paz, 14, 9600-053 Pico da Pedra, S. Miguel.

Abstract

All Azorean lava-tubes and volcanic pits with fauna were evaluated for species diversity and rarity based on arthropods. To produce an unbiased multiple-criteria index (*importance value for conservation*, IV-C) incorporating arthropod species diversity based indices and indices qualifying geological and management features (e.g. diversity of geological structures, threats, accessibility, etc.), an iterative partial multiple regression analysis was performed. In addition, the complementarity method (using heuristic methods) was used for priority-cave analyses. Most hypogean endemic species have restricted distributions, occurring only in one cave. It was concluded that several well-managed protected caves per island are absolutely necessary to have a good fraction of the endemic arthropods preserved. For presence/absence data, suboptimal solutions indicate that at least 50% lava-tubes with known hypogean fauna are needed if we want that 100% of endemic arthropod species are represented in a minimum set of reserves. Based both on the uniqueness of species composition and/or high species richness and geological value of the caves, conservation efforts should be focused on the following caves: Gruta da Beira, Algar das Bocas do Fogo (S. Jorge); Montanheiros, Henrique Maciel, Soldão, Furna das Cabras II and Ribeira do Fundo (Pico); Algar do Carvão, Balcões, Agulhas and Chocolate (Terceira); Água de Pau (S. Miguel); Anelares and Parque do Capelo (Faial).

Introduction

Caves as islands are isolated entities, and, as a consequence, they lack the "rescue effect": only "source" species can be maintained in ecological and evolutionary time (Rosenweig 1995). Thus, cave species could be considered as very restricted in distribution due to their low dispersal abilities and cave isolation. However, cave-adapted species could disperse between cave systems throughout the MSS ("Milieu souterrain siperficiel" or "Mesovoid Shallow Substratum" sensu CULVER, 2001). This is the case of *Trechus terceiranus*, a troglobian species found in many caves from Terceira island (Azores) but also in the MSS (Borges 1993). Than, it is important to investigate how widespread are cavernicolous fauna to better conserve it.

The conservation of the rich Azorean cave-adapted fauna (Borges & Oromí 1994) is urgent but the resources are not enough to protect all caves. Consequently, there is a need to set priorities for conservation. The aim of this study was to examine the faunistic relative value of a set of well sampled lava tubes and volcanic pits in the Azorean islands as a management tool to improve the conservation of Azorean cave-adapted arthropod biodiversity. We examined the following hypotheses:

(a) Using an iterative partial regression analyses to produce a multiple-criteria index incorporating diversity and rarity based indices, at least one cave per island will be highly ranked. This follows the assumption that the dispersal rates of species are low and consequently there is a high level of island-restricted endemism.

(b) The restricted distribution of endemic species will imply that most caves are unique and largely irreplaceable. Consequently, most caves will be needed to ensure each species is included at least one time in a complementary based approach.

Methods

Sites and data. This study was conducted in the Azores, a volcanic Northern Atlantic archipelago that comprises nine islands, as well as several islets and seamounts distributed from Northwest to Southeast, roughly between 37° and 40° N and 24° and 31° W. The Azorean islands extend for about 615 km and are situated across the Mid-Atlantic Ridge, which separates the western group (Flores and Corvo) from the central (Faial, Pico, S. Jorge, Terceira and

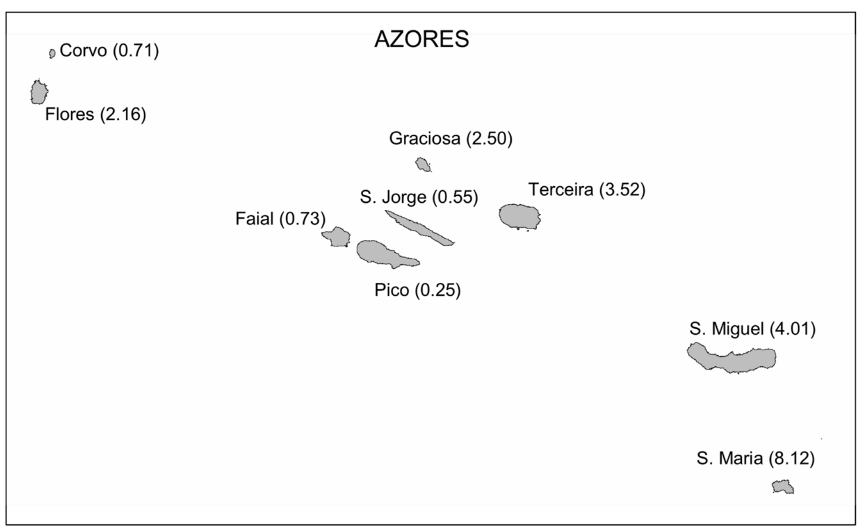

Figure 1. The nine Azorean islands with indication of their geological age based on data from Nunes (1999).

Graciosa) and the eastern (S. Miguel and S. Maria) groups (Figure 1). All these islands have a relatively recent volcanic origin, ranging from 8.12 Myr B.P. (S. Maria) to 250 000 years B.P. (Pico) (Nunes 1999).

In this study a total of 37 volcanic cavities distributed on six of the nine Azorean islands (excluding S. Maria, Flores and Corvo) were surveyed and are listed in Table 1. Some of those caves were surveyed intensively during 1988 and 1990 with two expeditions of "National Geographic" under the supervision of Pedro Oromí (Univ. de La Laguna) and Philippe Ashmole (Univ. de Edinburg) (see Oromí *et al.* 1990). However, many of the caves were also sampled by investigators of the University of the Azores and "Os Montanheiros" (see Borges & Oromí 1994). Part of the arthropod data on the presence/absence in the caves is unpublished and resulted from recent surveys performed by PB and FP. Arthropods were classified to one of three colonization categories: natives, endemics and introduced. In cases of doubt, a species was assumed to be native. Moreover, following information available in Borges & Oromí (1994) all the species were also classified as cave-adapted (troglobites) and non cave-adapted.

Data analysis. For prioritizing the 37 caves two techniques were used: i) indices for scoring conservation priorities based on comparative analyses; ii) the complementarity method.

i) Scoring method. Due to its simplicity a scoring approach was used with 9 different indices, incorporating arthropod species diversity based indices, but also indices qualifying cave geological and management features (data from IPEA database, Constância et al. 2004). (see Table 2). However, as the several indices give quite different ranking of the caves results a multiple criteria index was applied.

Multiple criteria Index: Importance Value for Conservation (IV-C). When different values or criteria are combined in a single index, it is difficult to know what the single value obtained from it represents (see Borges et al. 2005). Moreover, the different indices used to describe a cave value may not be unrelated, thus leading to the possibility of giving a higher weighting to a given feature in the construction of the complex index. To avoid possible problems of collinearity we have used partial regression analysis techniques (Legendre & Legendre 1998, see also Borges et al. 2005), which allow the separation of the variability of a given predictor that is independent (i.e., non related) from the variability of another variable, or set of variables. To do this, we applied generalised linear models (GLM) with natural logarithm link functions, in which the predictor is regressed against this variable, or group of variables, and the resulting residuals are retained as the independent term of the variable. In this particular case, we have developed iterative partial regression analyses, each time extracting the variability of a predictor that is independent of the formerly chosen indices. That is, after selecting a first index (A), which is used without any transformation in the Importance Value for Conservation (IV-C) calculations, we regressed the second one (B) against A, obtaining its residuals (rB). In successive steps, each index (e.g., C) is regressed against the formerly included (in this case, A and rB) in a multiple regression analysis, obtaining its residuals (rC). The first selected index to be used without any transformation was the total number of endemic species ($S_{trogl.}$), since cave-adapted species richness was considered to be of major importance to cave conservation. The other indices entered in the model by decreasing order of their r^2 values of a GLM regression of each index with $S_{trogl.}$. Thus, the final Importance Value for Conservation (IV-C) composite index is as follows:

$$
\begin{aligned}
\text{IV-C} = [&(S_{trogl.} / S_{trogl.}\ \text{max}) \\
&+ (RS_{end.} / RS_{end.}\ \text{max}) \\
&+ (\text{RShow} / \text{RShow max}) \\
&+ (\text{RSrare} / \text{RSrare max}) \\
&+ (\text{RGEO} / \text{RGEO max}) \\
&+ (\text{RDif.Expl.} / \text{RDif.Expl. max}) \\
&+ (\text{RIntegrity} / \text{RIntegrity max}) \\
&+ (\text{RThreats} / \text{RThreats max}) \\
&+ (\text{RAccess.} / \text{RAccess max})] / 9
\end{aligned}
$$

in which for a reserve the value of the residual variance (R) of each of the additional indices is divided by the maximum value (max) obtained within all reserves. For instance, the residuals of "Show" were obtained after the following polynomial model:

$$\text{Show} = a + b\, S_{trogl.} + c\, RS_{end.}$$

This composite index has a maximum value of 1 (see also Borges et al. 2005).

ii) Complementarity. To obtain the minimum set of caves that combined have the highest representation of species we applied the complementarity method (Williams 2001). We used a heuristic suboptimal simple-greedy reserve-selection algorithm in an Excel Spreadsheet Macro. First, the cave with the highest species richness was selected. Then, these species are ignored and the cave with the highest complement of species (that is, the most species not represented in the previous selected cave), and so on, until all species are represented at least once. This method was applied to a dataset comprising only presence-absence data for the cave-adapted arthropods, to have the minimum set of caves to represent all species at least once.

Results

We recorded 35 species of endemic arthropods in the 37 caves (see Appendix 1). From those species, 19 (54%) are

Table 1. List of the lava tubes (LT) and volcanic pits (VP) investigated.

Island	Cave	Type
Faial	Furna Ruim	VP
Faial	Gruta das Anelares	LT
Faial	Gruta do Cabeço do Canto	LT
Faial	Gruta do Parque do Capelo	LT
Graciosa	Furna do Enxofre	VP
Pico	Furna da Baliza	LT
Pico	Furna de Henrique Maciel	LT
Pico	Furna do Frei Matias	LT
Pico	Furna dos Vimes	LT
Pico	Furna Nova I	LT
Pico	Furnas das Cabras II (terra)	LT
Pico	Gruta da Agostinha	LT
Pico	Gruta da Ribeira do Fundo	LT
Pico	Gruta das Canárias	LT
Pico	Gruta das Torres	LT
Pico	Gruta do Mistério da Silveira I	LT
Pico	Gruta do Soldão	LT
Pico	Gruta dos Montanheiros	LT
S. Jorge	Algar das Bocas do Fogo	VP
S. Jorge	Gruta da Beira	LT
S. Miguel	Fenda do Pico Queimado	VP
S. Miguel	Gruta de Água de Pau	LT
S. Miguel	Gruta do Enforcado	LT
S. Miguel	Gruta do Esqueleto	LT
S. Miguel	Gruta do Pico da Cruz	LT
Terceira	Algar do Carvão	VP
Terceira	Furna de Santa Maria	LT
Terceira	Gruta da Achada	LT
Terceira	Gruta da Madre de Deus	LT
Terceira	Gruta da Malha	LT
Terceira	Gruta das Agulhas	LT
Terceira	Gruta do Caldeira	LT
Terceira	Gruta do Chocolate	LT
Terceira	Gruta do Coelho	LT
Terceira	Gruta do Natal	LT
Terceira	Gruta dos Balcões	LT
Terceira	Gruta dos Principiantes	LT

Table 2. The list of indices used to rank the caves.

Code	Index		Explanation
Strogl	S trogobites		The number of cave-adapted species
Send	S endemics		The number of endemic species
Srare	S rare		The number of rare species (those that occur in only one cave)
Show	Show cave index	0	No information available
		1	Small cave (less than de 100 x 2 m).
		2	Small and simple cave but with at least 100 m and less than 200m
		3	Size between 200 and 500m but few interesting structures
		4	Large size caves (more than 500m) and with diversity of structures
		5	Large size caves (more than 1000m) and with diversity of structures
GEO	Geology index	0	No information available
		1	Relevant geological structures not present
		2	Presence of very common geological structures (e.g. lava stalactites)
		3	Presence of common geological structures (e.g. benches, striated walls)
		4	Presence of rare geological structures (e.g. Secondary deposits, levees, different levels of tunnels, etc.)
		5	Presence of very rare geological structures (e.g. Gas bubbles, stalagmite, columns)
DIF.Expl.	Difficulty of Exploration Index	0	No information available
		1	Lava tube or pit of difficult exploration due to difficulty of progression
		2	Lava tube or pit of difficult exploration in some parts due to difficulty of progression
		3	Cavity with some obstacles
		4	Presence of some obstacles but easy to transpose
		5	No obstacles - all people could visit the cave
Integrity	Integrity index	0	No information available
		1	More than 50% of the cavity destroyed
		2	some evidences of destruction (< 50% of he length)
		3	More than 90% of the lenght well preserved but presence of Human alterations or disturbance
		4	Well preserved and few signals of Human alterations or disturbance
		5	Very well preserved
Threats	Treats index	0	No information available
		1	The cavity has destroyed parts due to epigean land-use changes and disturbance
		2	Well known epigean Human activities are identified and could cause near-future disturbance
		3	Well known epigean Human activities are identified and could cause future disturbance
		4	Well known epigean Human activities are identified but with non potential threat to the cavity
		5	Non occurrence of Human activity or threats in the area of the cave
Acess.	Acessibility index	0	No information available
		1	Very difficult to access - no roads or tracks available
		2	Difficult access, far from near locality and more than 45 m walk
		3	Difficult access, far from near locality or need of special permission of the property owner
		4	Easy access, with available public transport
		5	Easy access, easy to locate, near a locality

cave-adapted species. Most hypogean endemic species have restricted distributions, occurring only in one cave (Fig. 2).

Table 3 shows that the first ten caves using the multiple criteria index (IV-C) belong to four out of the six studied islands. No caves from Graciosa and Faial were included in the top ranked list. On the other hand, Pico and Terceira have the highest number of cavities elected in the top ten cavities. The 10 top caves include both large caves (e.g. Montanheiros, Balcões, Henrique Maciel) and small caves. Three currently protected caves, also used as Show-caves, (Algar do Carvão, Torres, Furna do Enxofre), are not listed in the top 10, but Algar do Carvão (Terceira) and Torres (Pico) are 11th and 13th, respectively.

Using presence/absence data, heuristic (suboptimal) solution show that only 9 caves are needed to have all cave-adapted species represented at least once (Table 4). Moreover, five out of the six islands have at least one cave represented in the minimum complementary set of caves (Table 4).

Table 3. Ranking of the 37 caves in terms of the multiple criteria index, Importance Value for Conservation (IV-C).

Cave	Island	IV-C
Gruta dos Montanheiros	**Pico**	**0.63**
Gruta de Água de Pau	**São Miguel**	**0.62**
Gruta das Agulhas	**Terceira**	**0.58**
Gruta do Chocolate	**Terceira**	**0.56**
Algar das Bocas do Fogo	**S. Jorge**	**0.55**
Gruta dos Balcões	**Terceira**	**0.53**
Furna de Henrique Maciel	**Pico**	**0.53**
Gruta do Soldão	**Pico**	**0.51**
Furnas das Cabras II (terra)	**Pico**	**0.51**
Gruta da Ribeira do Fundo	**Pico**	**0.50**
Algar do Carvão	Terceira	0.47
Furna Nova I	Pico	0.46
Gruta das Torres	Pico	0.43
Gruta da Beira	S. Jorge	0.43
Gruta das Anelares	Faial	0.42
Gruta da Achada	Terceira	0.42
Gruta da Madre de Deus	Terceira	0.42
Furna do Frei Matias	Pico	0.42
Gruta do Pico da Cruz	São Miguel	0.42
Gruta do Coelho	Terceira	0.42
Gruta da Malha	Terceira	0.41
Furna do Enxofre	Graciosa	0.41
Gruta das Canárias	Pico	0.41
Furna de Santa Maria	Terceira	0.41
Gruta do Natal	Terceira	0.41
Gruta do Mistério da Silveira I	Pico	0.41
Furna Ruim	Faial	0.41
Gruta do Caldeira	Terceira	0.41
Gruta da Agostinha	Pico	0.39
Gruta do Enforcado	São Miguel	0.39
Gruta do Cabeço do Canto	Faial	0.38
Gruta dos Principiantes	Terceira	0.37
Furna dos Vimes	Pico	0.36
Fenda do Pico Queimado	São Miguel	0.35
Gruta do Esqueleto	São Miguel	0.35
Furna da Baliza	Pico	0.34
Gruta do Parque do Capelo	Faial	0.33

Conclusions

In this study we aimed to quantify the relative value of Azorean caves using both arthropods and cave geological features. Interestingly, data from this study shows that a regional conservation approach, which value at least one cave per island, will be required to conserve arthropod biodiversity in the Azores (see Tables 3 and 4).

Remarkably, Gruta dos Montanheiros was ranked first using two completely different selection approaches, which highlight the importance of this beautiful lava tube located in the island o Pico.

Using a single criterion may not allow us to cover all conservation goals. Therefore, based both on the uniqueness of species composition and/or high species richness and geological value of the caves (Tables 3 and 4), conservation efforts should be focused on the following caves: Gruta da Beira, Algar das Bocas do Fogo (S. Jorge); Montanheiros, Henrique Maciel, Soldão, Furna das Cabras II and Ribeira do Fundo (Pico); Algar do Carvão, Balcões, Agulhas and Chocolate (Terceira); Água de Pau (S. Miguel); Anelares and Parque do Capelo (Faial).

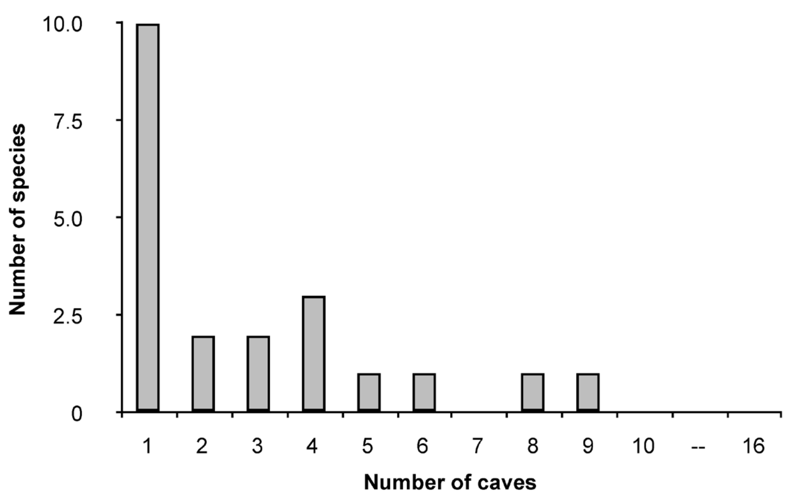

Figure 2. Frequency distribution of Azorean troglobitic species in volcanic caves.

Acknowledgements

We wish to thank to Azorean Government for supporting our trip to Pico to participate on the XInd International Symposium on Vulcanospeleology (Madalena, Pico, May 2004).

References

Borges, P.A.V. (1993). First records for the Mesocavernous Shallow Stratum (MSS) from the Azores. *Mémoires de Biospéologie*, 20: 49-54.

Borges, P.A.V., Aguiar, C., Amaral, J., Amorim, I.R., André, G., Arraiol, A.,. Baz A., Dinis, F., Enghoff, H., Gaspar, C., Ilharco, F., Mahnert, V., Melo, C., Pereira, F., Quartau, J.A., Ribeiro, S., Ribes, J., Serrano, A.R.M., Sousa, A.B., Strassen, R.Z., Vieira, L., Vieira, V., Vitorino, A. and Wunderlich, J. (2005). Ranking protected areas in the Azores using standardized sampling of soil epigean arthropods. *Biodiversity and Conservation*, 14: 2029-2060.

Borges, P.A.V. & Oromí, P. (1994). The Azores. *In*. C. Juberthie & V. Decu (Eds.) *Encyclopaedia Biospeleologica*.

Table 4. Minimum complementarity set of caves to have all troglobian species represented at least once.

Step	Cave	Island	S	S Accumulated
1	Gruta dos Montanheiros	Pico	5	5
2	Algar do Carvão	Terceira	5	10
3	Gruta da Beira	S. Jorge	2	12
4	Gruta das Agulhas	Terceira	2	14
5	Gruta das Anelares	Faial	1	15
6	Gruta do Parque do Capelo	Faial	1	16
7	Furnas das Cabras II (terra)	Pico	1	17
8	Algar das Bocas do Fogo	S. Jorge	1	18
9	Gruta de Água de Pau	S. Miguel	1	19

Tome I . pp. 605-610. Sociétè de Biospéleologie, Moulis.

Constância, J.P., Borges, P.A.V., Costa, M.P., Nunes, J.C., Barcelos, P., Pereira, F. & Braga, T. (2004). Ranking Azorean caves based on management índices. Abstract book of the XIth International Symposium on Vulcanospeleology (Pico, Açores).

Culver, D.C. (2001). Subterranean Ecosystems, in S. Levin (ed.) *Encyclopaedia of Biodiversity*, Volume 5, pp. 527-540, Academic Press.

Legendre, P. & Legendre, L. 1998. *Numerical Ecology,* Second english edition edn. Elsevier, Amsterdam.

Nunes, J.C. (1999). *A actividade vulcânica na ilha do Pico do Plistocénico Superior ao Holocénico: mecanismo eruptivo e Hazard vulcânico*. Ph.D Thesis, Universidade dos Açores, Ponta Delgada.

Oromí, P., Martin, J.L., Ashmole, N.P. & Ashmole, M.J. (1990). A preliminary report on the cavernicolous fauna of the Azores. *Mémoires de Biospéologie*, 17: 97-105.

Rosenzweig M.L. (1995). Species diversity in space and time. Cambridge University Press, Cambridge.

Whittaker, R.J. (1998). Island Biogeography – Ecology, Evolution and Conservation. Oxford University Press, Oxford.

Williams P. 2001. Complementarity. In: Levin S. (ed.), Encyclopaedia of Biodiversity, Volume 5. Academic Press, pp. 813-829.

Appendix 1. List of the species endemic species recorded in the Azorean caves. The cave-adapted species are also marked (C).

List of species	Taxonomic group	Troglobian
Calyptophthiracarus maritimus	ACARI-Oribatei	
Damaeus pomboi	ACARI-Oribatei	
Dorycranosus angustatus	ACARI-Oribatei	
Galumna rasilis	ACARI-Oribatei	
Galumna sp. (n sp.)	ACARI-Oribatei	
Hermanniella sp. 1 (n sp.)	ACARI-Oribatei	
Hermanniella sp. 2 (n.sp)	ACARI-Oribatei	
Nothrus palustris azorensis	ACARI-Oribatei	
Phthiracarus falciformis	ACARI-Oribatei	
Tritegeus (n. sp.)	ACARI-Oribatei	
Xenillus discrepans azorensis	ACARI-Oribatei	
Turinyphia cavernicola n. sp.	ARANEAE	C
Lepthyphantes acoreensis	ARANEAE	
Porrhomma n.sp.	ARANEAE	C
Rugathodes acoreensis	ARANEAE	
Rugathodes pico	ARANEAE	C
Lithobius obscurus azoreae	CHILOPODA	C
Lithobius obscurus borgei	CHILOPODA	
Thalassophilus azoricus	COLEOPTERA	C
Trechus jorgensis	COLEOPTERA	C
Trechus montanheirorum	COLEOPTERA	C
Trechus picoensis	COLEOPTERA	C
Trechus terceiranus	COLEOPTERA	C
Trechus oromii	COLEOPTERA	C
Trechus pereirai	COLEOPTERA	C
Onychiurus sp.	COLLEMBOLA	C
Pseudosinella ashmoleorum	COLLEMBOLA	C
Pseudosinella azorica	COLLEMBOLA	
Gen. sp. indeterminado	CRUSTACEA	C
Macarorchestia martini	CRUSTACEA	C
Orchestia chevreuxi	CRUSTACEA	
Cixius azopicavus	HOMOPTERA	C
Cixius cavazoricus	HOMOPTERA	C
Pseudoblothrus oromii	PSEUDOSCORPIONES	C
Pseudoblothrus vulcanus	PSEUDOSCORPIONES	C