# INDICATORS OF CONSERVATION VALUE OF AZOREAN CAVES BASED ON ITS BRYOPHYTE FLORA AT THE ENTRANCE

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

1- Universidade dos Açores, Dep. Ciências Agrárias, CITA-A, 9700-851 Angra do Heroísmo, Terceira, Açores, Portugal; Email: rgabriel@notes.angra.uac.pt

2- "Os Montanheiros", Rua da Rocha, 4-8, 9700 Angra do Heroísmo, Terceira, Açores, Portugal.

3- "Amigos dos Açores", Avenida da Paz, 14, 9600-053 Pico da Pedra, S. Miguel, Açores, Portugal.

**Abstract:** Cave entrances in the Azores are particularly humid habitats. These provide opportunities for the colonization of a diverse assemblage of bryophyte species. Using both published data and new field sampling, we evaluated species diversity and rarity of bryophytes at the entrance of all known Azorean lava tubes and volcanic pits with such flora. Frequent species include the liverworts: *Calypogeia arguta*, *Jubula hutchinsiae* or *Lejeunea lamacerina*, and the mosses: *Epipterygium tozeri*, *Eurhynchium praelongum*, *Fissidens serrulatus*, *Isopterygium elegans*, *Lepidopilum virens* and *Tetrastichium fontanum*. Several rare Azorean bryophyte species appear at some cave entrances (e.g. *Archidium alternifolium*; *Asterella africana*; *Plagiochila longispina*), which reinforces the importance of this habitat for the regional conservation of these plants. To produce an unbiased multiple-criteria index (*Importance Value for Conservation*, IV-C), several indices based on bryophyte diversity and rarity, and also geological and management features, were calculated for each cave, and an iterative partial multiple regression analyses was performed. Data sows that three pit caves are particularly diverse in bryophytes (Algar do Carvão, Terceira Island, Bocas do Fogo, S. Jorge and Furna do Enxofre, Graciosa). Lava tubes with a diverse troglobitic fauna also are diverse in terms of bryophyte species (e.g., Algar do Carvão, Gruta dos Montanheiros, Gruta da Agostinha, Furna do Henrique Maciel). We also evaluate the utility of several cave management indices as surrogates of bryophyte diversity in Azorean volcanic cavities.

## 1. INTRODUCTION

The study of the Azorean bryophyte flora started with two expeditions of the "National Geographic Foundation" (1988, 1990), under the co-supervision of Pedro Oromí (Univ. de La Laguna) and Philippe Ashmole (Univ. of Edinburgh) and with the support of the speleological Azorean group "Os Montanheiros" (see Oromí *et al*. 1990, González-Mancebo *et al*. 1991). After those two expeditions, the University of the Azores and "Os Montanheiros" performed most of the bryophyte survey work in the Azores (e.g. Gabriel & Dias 1994, Gabriel & Bates 2005).

Bryophytes include mosses (Class Bryopsida), liverworts (Class Marchantiopsida) and hornworts (Class Anthocerotopsida), all of which are small, non-vascular, primitive plants that occupy a wide variety of habitats and substrates. Bryophytes assume an important functional role in the ecosystems where they occur, performing water interception, accumulation of water and their mineral contents, decomposition of organic matter and physical protection of soils (Longton, 1992). Many bryophyte species are used as bioindicators, and their presence is associated with atmospheric and aquatic purity (e.g. Hylander, Jonsson, & Nilsson 2002).

When air flows into a cave, it carries micro-organisms, leaves, seeds, spores, small arthropods, etc. Some will survive (mainly algae, fungi, ferns and bryophytes), modifying the bare rock. Some will form an important part of the food chain for cave dwelling organisms. In most places, the species found at the caves (either in entrances or areas above) are common species. However, these species add greatly to the diversity of the plant species at the caves and the scenic value of the rocks and rocky outcrops.

Four hundred and thirty eight bryophyte species are given to the Azores (Gabriel *et al*. 2005), but few data are available concerning their relative importance in the Azorean cave environment.

The aims of this manuscript are:

a) To evaluate species diversity and rarity of bryophytes at the entrance of the known Azorean lava tubes and volcanic pits with such flora;

b) To evaluate the utility of several cave management indices as surrogates of bryophyte diversity in Azorean volcanic cavities.

## 2. METHODS

### *Sites and data*

All main literature for the Azorean cave bryophytes was surveyed, and data was updated using the Herbarium of the University of the Azores (AZU). Besides, during the summer of the year 2000, 18 Azorean caves were prospected for bryophytes by FP, searching the main substrata available: rock and soil. Only part of this data was identified. However, the quality of the data only allowed to perform statistical analysis for the 19 caves listed on Table 1.

**Table 1.** List of the Azorean lava tubes (LT), volcanic pits (VP) and other type (OT) of cavities investigated for bryophytes in this article.

| Island | Cave number | Cave | Type |
|---|---|---|---|
| Graciosa | 1 | Furna do Enxofre | VP |
| Pico | 2 | Furna de Henrique Maciel | LT |
| Pico | 3 | Furna do Frei Matias | LT |
| Pico | 4 | Furna dos Vimes | LT |
| Pico | 5 | Gruta da Agostinha | LT |
| Pico | 6 | Gruta das Torres | LT |
| Pico | 7 | Gruta do Soldão | LT |
| Pico | 8 | Gruta dos Montanheiros | LT |
| S. Jorge | 9 | Algar das Bocas do Fogo | VP |
| S. Maria | 10 | Anjos | OT |
| S. Miguel | 11 | Fenda do Pico Queimado | VP |
| S. Miguel | 12 | Gruta da Batalha | LT |
| S. Miguel | 13 | Gruta do Enforcado | LT |
| S. Miguel | 14 | Gruta do Esqueleto | LT |
| S. Miguel | 15 | Gruta do Pico da Cruz | LT |
| S. Miguel | 16 | Gruta de Ponta Delgada | LT |
| Terceira | 17 | Algar do Carvão | VP |
| Terceira | 18 | Gruta do Chocolate | LT |
| Terceira | 19 | Gruta dos Balcões | LT |

### *Data analysis*

For prioritizing the 19 caves we used a multiple criteria index: Importance Value for Conservation (IV-C) (based on Borges et al. 2005). The multiple criteria index was built using 9 different indices (see Table 2), based on the diversity and rarity of bryophytes, but also on geological and management features of the caves (data from IPEA database, Constância et al.

2004). We also used the total number of cave-adapted arthropods in caves based on information obtained from Borges et al. (2007, this volume).

**Table 2.** Explanation of the list of indices used to rank the Azorean caves.

| Code | Index | | Explanation |
|---|---|---|---|
| SBryo | S bryophytes | | The number of bryophyte species |
| SECCB | S ECCB | | The number of rare bryophyte species based on ECCB, 1995 |
| SBryo.end | S endemic bryophytes | | The number of endemic bryophyte species from the Azores and Macaronesia |
| Strogl | S troglobites | | The number of cave-adapted arthropod species |
| Show | Show cave index | 0 | No information available |
| | | 1 | Small cave (less than de 100 x 2 m). |
| | | 2 | Small and simple cave, at least with 100 m but less than 200m |
| | | 3 | Size between 200 and 500 m but few interesting structures |
| | | 4 | Large size cave (more than 500 m) and with a wide diversity of structures |
| | | 5 | Large size cave (more than 1000 m) and with a wide 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) |
| Integrity | Integrity index | 0 | No information available |
| | | 1 | More than 50% of the cavity destroyed |
| | | 2 | Some evidence of destruction (< 50% of the length) |
| | | 3 | More than 90% of the length well preserved but evidence of human alterations or disturbance |
| | | 4 | Well preserved and few signals of Human alterations or disturbance |
| | | 5 | Very well preserved |
| Threats | Threats 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 no potential threat to the cavity |
| | | 5 | Non occurrence of human activity or threats in the area of the cave |
| Access. | Accessibility index | 0 | No information available |
| | | 1 | Very difficult to access, without roads or tracks available |
| | | 2 | Difficult access, far from near locality and more than 45 min 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 |

To avoid 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. The first selected index to be used without any transformation was the total number of bryophyte species ($S_{Bryo.}$), since total 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 $S_{Bryo.}$. Thus, the final Importance Value for Conservation (IV-C) composite index is as follows:

$$IV\text{-}C = [(S_{Bryo} / S_{Bryo}\ max) + (R\_S_{ECCB} / R\_{ECCB}\ max) + (R\_SBryo_{end} / R\_SBryo_{end}\ max) + (R\_S_{trogl} / R\_S_{trogl}\ max) + (R\_Show / R\_Show\ max) + (R\_GEO / R\_GEO\ max) + (R\_Integrity / R\_Integrity\ max) + (R\_Threats / R\_Threats\ max ) + (R\_Access / R\_Access\ max )] / 9$$

in which for a cave, the value of the residual variance (R) of each of the additional indices is divided by the maximum value (max) obtained within all caves. For instance, the residuals of "$SBryo_{end}$" were obtained after the following polynomial model:

$$SBryo_{end} = a + b\ S_{Bryo} + c\ R\ S_{ECCB}$$

in which "a" is the value of the intercept, "b" is the value of the slope of the first variable and "c" is the value of the slope of the second variable.

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

## 3. RESULTS AND DISCUSSION

The majority of bryophytes found at the cave entrances may be found elsewhere in the Azorean islands, and there are no known exclusive cave species. However it is remarkable that 151 species out of the 438 Azorean bryophytes (34.5%) have been recorded for this habitat. For an updated list of bryophytes present at the Azorean caves see Pereira *et al*. (2006, in press). Among the most frequently recorded moss species are: *Eurhynchium*

*praelongum, Fissidens bryoides s. l., F. serrulatus, Tetrastichium fontanum* and *T. virens* while among the most recorded liverworts there may be found *Calypogeia arguta*, *Jubula hutchinsiae* ssp. *hutchinsiae*, and *Lejeunea lamacerina*.

Besides, there are noteworthy occurrences on the Azorean Caves, of either endemic (Azores and Macaronesia) or European red-listed species, and some caves harbour more than 10 classified species according to the ECCB (1995) (see Figure 1). Caves such as "Gruta do Frei Matias" and "Gruta das Torres" (both in Pico) or "Algar do Carvão" and "Gruta dos Balcões" (both in Terceira) contain more than five red-listed bryophytes and only three of the 19 analysed caves ("Furna dos Vimes", "Gruta dos Anjos" e "Gruta de Ponta Delgada") have no classified bryophyte species (see Figure 1, Pereira et al. 2006, in press).

Among the most interesting species that may be found at cave entrances, are the bryophytes *Aphanolejeunea teotonii, Asterella africana, Cephalozia crassifolia, Echinodium renauldii, Plagiochila longispina* and *Radula wichurae*. These European vulnerable species occur at cave entrances at different islands, and for instance *Asterella africana* has not been referred outside that habitat in the Azores, recently. The endemic moss *Echinodium renauldii*, an epilithic species, which is generally found at lower altitudes (below 500 m), has also been referred for at least three caves ("Furna do Henrique Maciel", "Furna da Agostinha" e "Gruta das Torres" – all in Pico Island). Thus, caves may serve as a refuge to some species that otherwise would not be present at that particular altitude and these data highlight the importance of the habitat for the regional conservation of these plants.

A statistical significant relationship was observed between the diversity of cave-adapted arthropods and the species richness of bryophytes in the Azorean cave entrances ($r = 0.59$; $p = 0.008$) (Figure 2). In spite of the fact that the relationship is not perfect, there are some caves that are diverse both in troglobitic fauna and bryophyte species (e.g., Algar do Carvão, Gruta dos Montanheiros, Gruta da Agostinha, Furna do Henrique Maciel). Bryophyte richness could, with caution, be used as an indicator of the diverse cave adapted arthropods.

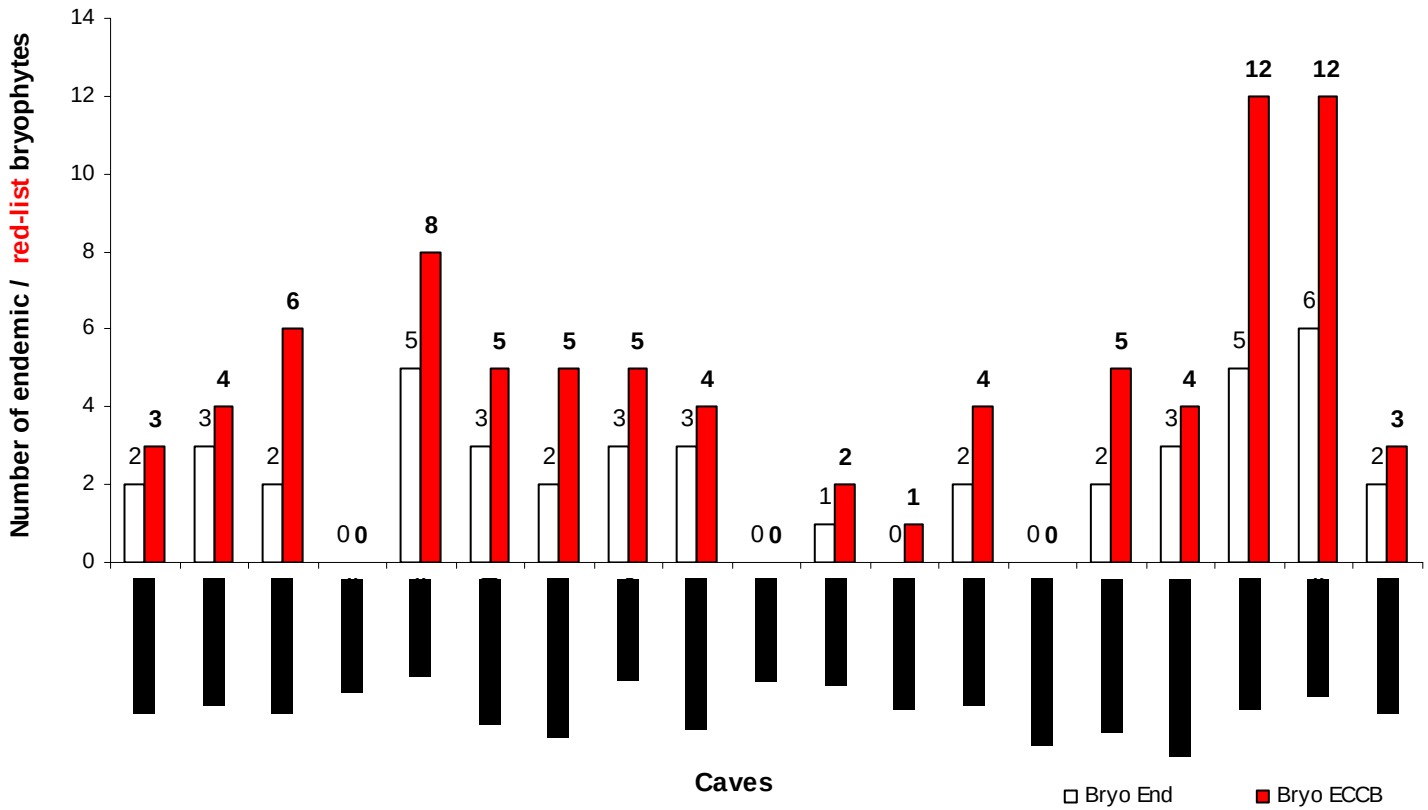


**Figure 1**. Number of endemic (Azores, Macaronesia) or red-listed (ECCB, 1995) bryophyte species present at the entrances of the studied Azorean caves.

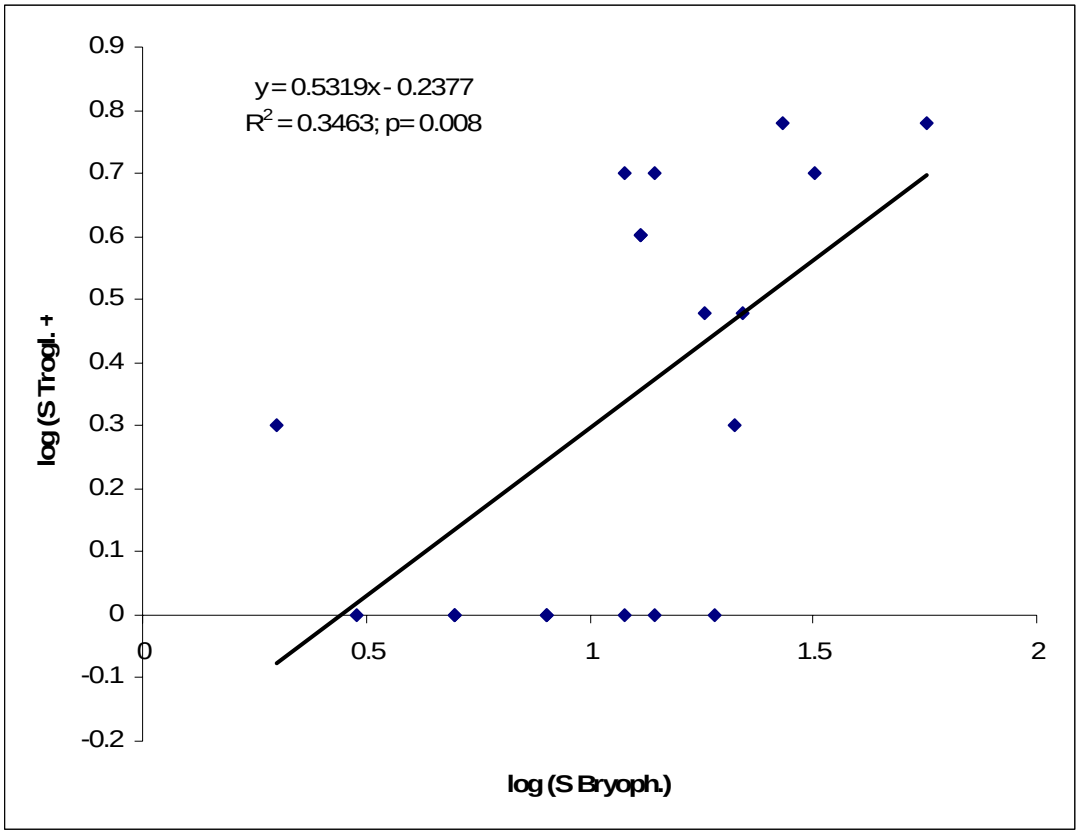


**Figure 2.** Relationship verified between the logarithm of the number of troglobian arthropod species (S Trogl) and the logarithm of the number of bryophyte species (S Bryoph) found at the entrance of caves.

The ranking obtained with the multiple criteria index, Importance Value for Conservation (IV-C) for the 19 caves may be observed in Table 3. Eight caves, have IV-C values equal or above 0.50 (maximum value is 1.00). All of these caves are located in Pico, Terceira and Graciosa Islands.

Considering the present state of speleological and biospeleological knowledge of the Azores, none of the most interesting caves are to be found on S. Miguel Island, the largest and most populated island of the Azorean archipelago. Cave entrances in S. Miguel are highly disturbed, mainly due to land use changes in the surrounding areas.

Also in view of the calculated index, none of the top five caves are show-caves, at the present. This indicates that there are other caves with potential for tourism exploitation, and

that their biological value should be highlighted. Care should be taken when developing show-cave projects, in order to preserve their biological and geological features.

**Table 3.** Ranking of the 19 caves using the multiple criteria index, Importance Value for Conservation (IV-C)
.

| Cave | Island | IV-C |
|---|---|---|
| Furna de Henrique Maciel | Pico | 0.57 |
| Gruta dos Balcões | Terceira | 0.55 |
| Gruta dos Montanheiros | Pico | 0.54 |
| Gruta da Agostinha | Pico | 0.53 |
| Gruta do Chocolate | Terceira | 0.52 |
| Gruta das Torres | Pico | 0.51 |
| Gruta do Soldão | Pico | 0.50 |
| Furna do Enxofre | Graciosa | 0.50 |
| Algar do Carvão | Terceira | 0.46 |
| Gruta do Pico da Cruz | S. Miguel | 0.45 |
| Algar das Bocas do Fogo | S. Jorge | 0.44 |
| Furna do Frei Matias | Pico | 0.39 |
| Gruta da Batalha | S. Miguel | 0.38 |
| Gruta de Ponta Delgada | S. Miguel | 0.36 |
| Gruta do Esqueleto | S. Miguel | 0.36 |
| Furna dos Vimes | Pico | 0.32 |
| Fenda do Pico Queimado | S. Miguel | 0.31 |
| Gruta do Enforcado | S. Miguel | 0.30 |
| Gruta dos Anjos | S. Maria | 0.20 |

## 4. CONCLUSIONS

Unlike other cave entrances, Azorean caves bear an exquisite and wonderful bryophyte flora. Many species commonly found in this habitat are endemic or red-listed and their populations are important to the survival of the species in the Azores. These species add greatly to diversity of the plant species at the caves and the scenic value of the rocks and rocky outcrops.

In the Azores, the importance of cave entrances to bryophytes is twofold: i) since these are particularly humid, sheltered habitats, they support a diverse assemblage of bryophyte species; in fact circa 35% of the Azorean bryophytes is referred to this habitat and ii) species,

either endemic or referred in the European Red List (ECCB 1995) due to their vulnerability or rarity (19 species).

Bryophyte diversity was shown to be a surrogate of cave adapted arthropods, indicating that well preserved caves have a global importance for both the organisms living inside the cave system and to those adapted to cave entrances, hence bryophytes.

In view of the calculated conservation index (IV-C), none of the top five caves are show-caves, at the present. This indicates that there are other caves with potential for tourism exploitation, and that their biological value should be highlighted. Care should be taken when developing show-cave projects, in order to preserve their biological and geological features.

## 5. ACKNOWLEDGEMENTS

We wish to thank to Azorean Government for supporting our trip to Pico Island to participate on the XI$^{nd}$ International Symposium on Vulcanospeleology (Madalena, Pico, Açores, Portugal. May 2004).

We wish to acknowledge “Centro de Investigação e Tecnologia Agrária dos Açores (CITAa/UAçores)” for supporting our fieldwork in Pico Island (2000).

## 6. REFERENCES

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., Pereira, F. & Constância, J.P. (2007). Indicators of conservation value of Azorean caves based on its arthropod fauna. Proceedings of the Xth, XIth and XIIth International Symposium on Vulcanospeleology.

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).

ECCB (1995). *Red data book of European bryophytes*. European Committee for the Conservation of Bryophytes. Trondheim.

Gabriel, R. & Bates, J.W. (2005) Bryophyte community composition and habitat specificity in the natural forests of Terceira, Azores. *Plant Ecology*, **177**, 125-144.

Gabriel, R. & Dias, E. (1994). First approach to the study of the Algar do Carvão flora (Terceira, Azores). in: Actas do 3º Congresso Nacional de Espeleologia e do 1º Encontro Internacional de Vulcanoespeleologia das Ilhas Atlânticas (30 de Setembro a 4 de Outubro de 1992), pp. 206-213. Angra do Heroísmo.

Gabriel, R., Sjögren, E., Schumacker, R., Sérgio, C., Frahm, J.-P. & Sousa, E. (2005) List of bryophytes In *A list of the terrestrial fauna (Mollusca and Arthropoda) and flora (Bryophyta, Pteridophyta and Spermatophyta) from the Azores* (eds P.A.V. Borges, R. Cunha, R. Gabriel, A.M.F. Martins, L. Silva, & V. Vieira). pp. ???, Direcção Regional de Ambiente e do Mar dos Açores and Universidade dos Açores, Horta, Angra do Heroísmo and Ponta Delgada.

González-Mancebo, J.M., Losada-Lima, A. & Hérnandez-Garcia, C.D. (1991). A contribution to the floristic knwoledge of caves on the Azores. *Mémoires de Biospéologie*, 18: 219-226.

Hylander, K., Jonsson, B. G. & Nilsson, C. 2002. Evaluting buffer strips along boreal streams using bryophytes as indicators. *Ecological Applications*, 12 (3): 797-806.

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

Longton, R. E. 1992. 2. The role of bryophytes and lichens in terrestrial ecosystems. in: Bates, J. & Farmer, A. (eds.) 1992. *Bryophytes and Lichens in a changing environment*. pp.: 32-76. Claredon Press. Oxford.

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.

Pereira, F, Borges, P A V, Costa, M P, Constância, J P, Nunes, J C, Barcelos, P Braga, T & Gabriel, R (2006, in press). Catálogo das cavidades vulcânicas dos Açores (grutas lávicas, algares e grutas de erosão marinha). Direcção Regional do Ambiente, Horta, 286 pp.