MODELLING THE DISTRIBUTION OF CRYPTOTHALLUS MIRABILIS MALMB. (ANEURACEAE, HEPATICOPSIDA) IN THE IBERIAN PENINSULA

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ABSTRACT. Cryptothallus mirabilis Malmb. exhibits a specialised ecology and is a non-photosynthetic liverwort. This species was first described for Scandinavia and till now was considered a north oceanic species. The discoveries of C. mirabilis in different localities in Portugal are the first reliable records of the species in southern Europe and represent an extension of its geographical range. In fact, in Portugal C. mirabilis does not seem to be rare in areas with oceanic influence, mainly in wet forestry habitats. It is possibly widespread in the Iberian Peninsula because it is easily overlooked owing to its subterranean growth. The objective of this work is to give new localities which contribute to an evaluation of its ecological requirements, to the definition of its biogeographical distribution in Portugal, and to present a predictive map for the Iberian Peninsula. The aim of the model is to identify the distribution pattern and also some potential places of occurrence in Spain and provide information about the environmental range of the species in order to improve actions for conservation.

KEY WORDS: Cryptothallus mirabilis, ecology, predictive map, conservation, Iberian Peninsula

INTRODUCTION

The discoveries of Cryptothallus mirabilis Malmb. in Portugal (Sérgio & Sénéca 1997, Sergio & Garcia 1999) are the first reliable records of the species in southern Europe and represent an important extension of its geographical range.

At that time, owing to our limited experience of the ecology of this species, the discovery of C. mirabilis was by chance. In the last few years we have again found C. mirabilis in 8 new localities during a survey of material of Hypnum cupressiforme Hedw. used for heavy metal biomonitorization. So we became convinced that it was indeed not a rare species in Portugal and may be present in other localities as well as in the northern part of the Iberian Peninsula. In fact C. mirabilis was considered to be a Boreal species in Europe, relatively rare but with a wide and patchy distribution: Greenland (Petersen 1972), Scandinavia (Dickson et al. 1975), Germany (Wiehle et al. 1989) in Britain (Crundwell in Hill et al. 1991, Paton 1999) and more recently France (Bates & Hodgetts 1995 and Boudier et al. 1999).

The specialised ecology exhibited by C. mirabilis is exceptional among liverworts. It is known that the thalli of this non-photosynthetic liverwort are colonized by fungal hyphae (Ligrone et al. 1993). It was recently demonstrated by Bidartondo et al. (2003) that Cryptothallus...
tothallus associates with fungi of the genus *Tulasnella* and the same fungi have the ability to form ectomycorrhizas on different trees species, for example in *Pinus* and *Betula*. Bidartondo et al. (2003) for the first time confirmed that the source of carbon, which sustains the liverwort, is the fungus mycelium that provides a pathway for transferring it into the thalli. The objective of this work is to give the new localities where it was found so as to increase the definition of its biogeographical distribution in Portugal, as well as to present a first approach to a predictive map for the Iberian Peninsula. The aim of the model is to identify possible areas of occurrence in Portugal and Spain and to provide information about macro-environmental requirements of a species with a significant nature conservation importance.

*Why is it important to know the distribution and ecological requirements of Cryptothallus mirabilis?*

Recent research on the evolution of land plants and advances in DNA studies have led to the realisation of the importance of bryophytes. One crucial species is *Cryptothallus mirabilis* because of its ecology, its primitive characters as well as its mode of nutrition and the phylogeny process. Also it is important through biochemical aspects (Rycroft & Cole 1998). In Europe *C. mirabilis* was considered to be a Boreal species, but in north and central Europe it is apparently confined to mires and bogs, under *Sphagnum*, and associated with *Molinia* litter, and is easily overlooked because of its subterranean growth (Schuster, 1992). In Portugal it seems more usual that *C. mirabilis* can develop below mats of *Hypnum cupressiforme*. The absence of *Sphagnum* species in most of its Portuguese localities may reflect some important differences between its ecology in the northern and the southern areas where it occurs. Also some questions can be asked about the origin of this species in these meridional areas, which no doubt have certain Mediterranean characteristics.

In boreal areas it is apparently confined to mires and bogs in vegetation related to the associations *Salignion cinereum*, *Vaccinio-Betuletum*, and sometimes *Piceion* (Dierfen 2001). In France is reported for the *Alnetea glutinosae* and more particularly in the alliance *Alinion glutinosae* under colonies of *Sphagnum gr. recurvum* P. Beauv., associated with *S. angustifolium* (Russow) C. O. E. Jensen and *S. fallax* (H. Klinggr.) H. Klinggr. (Boudier et al. 1999).

As we have mentioned, in Portugal *C. mirabilis* seems not to be rare in areas with an oceanic influence mainly in wet woodland habitats, and can be widespread there. In fact, with our present knowledge, Portugal is evidently the southern end of its range but perhaps the species can occur in other intermediate areas.

*Ecological and chorological data in Portugal*

Some important differences in the ecology of the species, between the northern and the southern areas of Europe, are evident. The ecological differences of the two areas are obvious but it is important to take into account the differences of climate and vegetation configuration. In the Portuguese territory two main ecological conditions can be described.

1. Littoral areas in Quaternary deposits–Holocene (Beira Litoral: Aveiro–the five first localities in the list).
The majority of localities are in an area of the terminal part of Vouga and Mondego rivers, with a fluvio-lagunar Holocene origin and a strong oceanic influence, and the plants produce abundant sporophytes. These localities have different ecological conditions but in general correspond to *Pinus pinaster* Aiton plantations with very interesting semi-natural scrub vegetation always with *Corema album* (L.) D. Don and *Calluna vulgaris* (L.) Hull and sometimes *Myrica gale* L. and *Stauracanthus lusitanicus* (L.) Cubas.

The ground of the forested areas is very wet, with *Scirpoides holoschoenus* (L.) Sojak, *Erica ciliaris* Loefl. ex L. and is more or less completely covered (80–95%) with bryophytes and lichens (*Hypnum cupressiforme* ±80% of total cover associated with *Dicranum scoparium* Hedw., *Campylopus flexuosus* (Hedw.) Brid., *Polytrichum juniperinum* Hedw. and *Cladonia rangiformis* Hoffm.).

2. Northern and Eastern areas in complex schist-gaywackes – Silurian and Ordovician (Minho, Beira Alta, Beira Baixa and Alto Alentejo – the four last localities in the list).


**Fertility**

In the majority of Portuguese localities the species is fertile, with male and female plants (Fig. 1) and the sporophytes and spores were observed in 5 localities. Some published data indicate the presence of sporophytes in some areas (Pocock & Duckett 1984) and these seem to be common (Crundwell in Hill et al. 1991, Paton 1999, Boudier et al. 1999).

The mature spores appear in Portugal in January to March but seem to be earlier in France (March); but both are different from northern sites (in summer, Hallingback pers.com.). Unfortunately, we had no opportunity to examine fertile material from European herbaria (H, PC, BM, UPS and C). However, the spores represented by Schuster (1992) are apparently not different from Portuguese specimens. The capsule has a very particular dehiscence by 4 lines, little twisted, and the valves are coherent distally. So this opening structure is very interesting and the tendency to be spiralled presents some similarity to that in *Takakia* (Higuchi & Zhang 1998).

**Conservation approaches**

The conservation of a particular species begins with recording its distribution and studying its bioclimatic affinities and environmental requirements. On the other hand the establishment of correlations between distribution patterns and environmental factors could be an appropriate tool for management and conservation programmes (Begon et al. 1990). In a further step, if we know the relationships between the organism and the environmental variable we can predict its distribution (Johnston 1993).
Fig. 1. Fertile plants of *Cryptothallus mirabilis* Malmb. A. Female plants with perianths and immature sporophytes; B. Male plants; C. Mature sporophytes growing up from a carpet of *Hypnum cupressiforme* Hedw.; D. First stage of a capsule opening by 4 twisted lines with dehiscent spores. Material from: Aveiro, Gafanha da Encarnação, Sérgio, 2003 (LISU). Scale: A = 8 mm; B = 8 mm; C = 6 mm; D = 0.8 mm.
Our knowledge of the species' distribution is in some cases extremely poor, particularly in the Iberian Peninsula, and the need for the implementation of a new advance has become urgent. Predictive maps present a new approach in defining the distribution of taxa and they circumvent the lack of distribution data. These predictive maps are commonly applied to other species groups such as vascular plants (Guisan & Theurillat 2000) or animals (Pereira & Itami 1987) as well as to other Iberian bryophytes (Sérgio & Draper 2002, Draper et al. 2003). A particular application of predictive maps in conservation action on endangered bryophytes is the selection of micro-reserves (Draper et al. 2003) or landscape surveys (Vanderpoorten et al. 2005).

Modelling distribution in the Iberian Peninsula

The predictive method was logistic regression (LR) and after that a logistic transformation (Hill & Domínguez 1994; Draper et al. 2003). The variables used were: Altitude; Slope; Aspect; Latitude; Longitude; Radiation; Annual and monthly precipitation; Mean monthly temperature; Maximum and minimum temperature; Thermal amplitude; Angstrom Index; Angot Index; Dantin Index; Emberger Index; Giacobbe Index; Gorezynski Index; Lang Index; Martonne Index.
Climatic data were calculated according to Sanchez Palomares et al. (1999); bioclimatic indexes were based on Tuhkanen (1980). The predictive maps of selected bryophytes in the Iberian Peninsula, based on ecoclimatic variables, were made using a Geographic Information System (GIS). All the records known at present were used to calculate the ecological models. From the initial set of 44 variables only 3 of them were significant at 95%: Gorezynski index (index of continentality); March precipitation; Mean April Temperature. The significance of the model was $p=0.000001$. The resulting model was:

$$y = 5.1831 - 0.030767 \times \text{Gorezynski} - 0.032168 \times \text{March Rainfall} + 0.035708 \times \text{April Temperature}$$

The geographic interpretation of these results (Fig. 2) allows us to consider *C. mirabilis* as an oceanic species but occurs in areas with dry and softly warm springs. The area in Iberian Peninsula that has these characteristics is the coastal north part of Portugal and the Galicia County. The next step could be the implementation of specific fieldwork in order to certify the predictive distribution of this liverwort and to try to find *C. mirabilis* in suitable areas in NW Spain.

In conclusion, the applied methodology for predicting bryophyte distribution is a first step and can give suggestions for the identification of new places where it could be found. It also gives the possibility of analysing the relationships between levels of different environmental variables and the occurrence of a species to determine the main ecological requirements. If we can discover these relationships it will be much easier to find new populations. It could be a useful increment in our knowledge and in future may contribute in knowing the more important traits of habitats where the species could occur. If new localities were obtained, powerful analyses and methods could be applied and re-evaluated.

No geological variables were used in this survey owing to the heterogeneity of classification between Portuguese and Spanish data. But considering that *C. mirabilis* is an acidophytic species it could be important to include lithology or geological data in future surveys. However, the predictive map (Fig. 2), the knowledge of the ecological conditions of the sampled area, the field experience and the features of the places where the species was found (showing a high bryophytes cover of 60–95%), can contribute to finding new populations of this liverwort in the Iberian Peninsula.

*Specimens and localities (F)=fertile*

2. Beira Litoral. Entre Furadouro e Corteça, estrada para Furadouro, $\pm 20$ m, 29TNE2928, 2002 C. Sérgio 12425 (LISU).
3. Beira Litoral. Torrão, a Sul de Furadouro, $\pm 20$ m, 29TNE2751, 2003 R. Figueira & J. Ferreira (LISU). (F)
5. Beira Litoral. Quiaios, Lagoa das Braças $\pm 50$ m, 29TNE1655, 2002, C. Sérgio & J. Ferreira 12212 (LISU). (F)
7. Beira Baixa: 1 km de Proença a Nova, $\pm 500$ m, 29TNE9103, 1997, C. Sérgio & C. Garcia,
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