Characterisation of a basin mire in the Azores archipelago

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SUMMARY

The Azores archipelago in the North Atlantic is an extremely important area for biodiversity because it is rich in rare species and habitats, and almost undisturbed. The Lagoa do Madruga is a small basin mire located at 956 m a.s.l. on Santa Bárbara Mountain, Terceira Island. It is an extremely good example of a peatland type that was first discovered in 1998, and has not previously been described in the international literature. This paper provides baseline information on its flora, vegetation communities, structure and hydrology. Thirty-one plant species including eight *Sphagnum* species and nine endemic vascular plants have been recorded, and four plant communities are distinguished. The maximum peat depth is three metres. The mire receives flowing water from its margins and from a small stream entering at its eastern end, in addition to intercepted precipitation and fog. The accumulated water forms pools and soakways which feed other wetlands downstream. The conservation status of the mire is good, but it is subject to increasing pressure from garbage generated during maintenance operations at a nearby antenna array.

KEY WORDS: European Habitats Directive, North Atlantic, peatland vegetation, surface hydrology.

INTRODUCTION

The Azores (Portugal) is the most northerly Macaronesian archipelago, comprising nine volcanic islands scattered over area of approximately 1,000 km^2 in the North Atlantic at latitude 36º56'–39º42'N and longitude 25º5'–31º12'W. The east-most island, Santa Maria, is located approximately 1,400 km from mainland Europe and the west-most island, Flores, lies 1,900 km from the North American continent.

These islands host the most westerly mires in Europe. Exploration of these rare landforms was first proposed in 1922 (Zbyszewski 1979), and some of their plant associations are included in the phytosociological system of Lüpnitz (1975). Otherwise, almost nothing was known about them until the mid-1990s, and they have not previously been described in the international literature.

The European Union (EU) Habitats Directive requires the establishment and maintenance of a pan-European habitat network known as 'Natura 2000' for nature conservation purposes. Annexes I and II of the Directive list respectively the natural habitats and species for which protection through site designations is necessary, and awards 'priority' status to those that are closest to extinction (EU 1992). Management plans for the Azorean Natura 2000 areas were completed in 2004 and approved by the regional government in 2005. The information presented in this paper was compiled as part of the underpinning data collection exercise.

Dias (1996) developed the first classification of Azorean wetland vegetation, describing six distinct communities of which four are *Sphagnum*-dominated; whilst Mendes (1998) distinguished five *Sphagnum* mire types - namely basin, transition, raised, valleyside and blanket. The basin mires occur in strongly endorreic depressions. Although the water supply is predominantly meteoric, arriving as precipitation and intercepted thick fog, the mire margins are rich in hummocks with characteristic vascular species whose development can be attributed to the ingress of water with entrained oxygen and nutrients from the surrounding mineral catchments. The hummocky peripheral zone is less extensive in steep catchments than in locations where the surrounding hillsides slope gently and thus drain sluggishly. Water is stagnant and the water table is usually at ground level in the lawn areas at the centres of the basins.

This paper presents a first description of the vegetation and surface hydrology of an Azorean basin mire, as a foundation for further research and publications.

SITE AND METHODS

Study area

Terceira Island is located near the centre of the Azores archipelago and extends to approximately 402 km^2. Its highest mountain, the Santa Bárbara volcano (1,023 m), hosts the largest concentration of

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biodiversity within the natural areas of the Azores, and most of its biotopes are in excellent conservation condition. Thus the Natura 2000 Site of Community Importance (SCI) "Santa Bárbara Mountain and Pico Alto" is one of the biodiversity hotspots of the Macaronesian biogeographic region. In terms of the designation criteria, 18 Annex I habitats and 10 Annex II species, of which five habitats and two species have priority status, have been identified within the SCI.

The Lagoa do Madruga (Madruga's Mire) (Figure 1) is a basin mire located at an altitude of 956 metres above sea level within the SCI (Figure 2) and is regarded as an example of the Annex I(b) priority habitat 7110 ('active raised bogs', i.e. acidophilous mires that are fed principally by rainwater). The area of the mire is 32,760 m^2, and its surface catchment extends to 318,516 m^2.

Figure 1. View across the Lagoa do Madruga from the north-east. Image from the AZU (Azorean Herbarium) photo database.

The soil of the study area is classified as a histosol (see Montanarella *et al*. 2006), giving way at its margins to andosols with placic horizons. The latter are modern soils with high organic matter content, developed from volcanic pyroclastic material in a wet temperate Atlantic climate (Pinheiro 1990, Madruga 1995). The presence of a placic horizon (Bsm horizon characterised by the accumulation of iron and magnesium, also known as an 'iron pan' or 'iron band') is an important ecological factor because it restricts soil drainage.

Precipitation ranges from 4,109 mm yr^{-1} at 600 m a.s.l. to 13,054 mm yr^{-1} at 980 m a.s.l. (Dias 1996). The ecological conditions at altitudes above 500 m are so favourable for the development of wet vegetation complexes that, with some exceptions like lava domes (Dias 1996, Dias *et al.* 2004, Elias & Dias 2004), the majority of the vegetation consists of mire communities or is directly dependent on mires.

Most of the catchment has natural land use, but there is an array of radio antennae on one of the hillsides overlooking the mire. An increasing accumulation of rubbish is being generated by personnel who visit this installation to carry out maintenance work.

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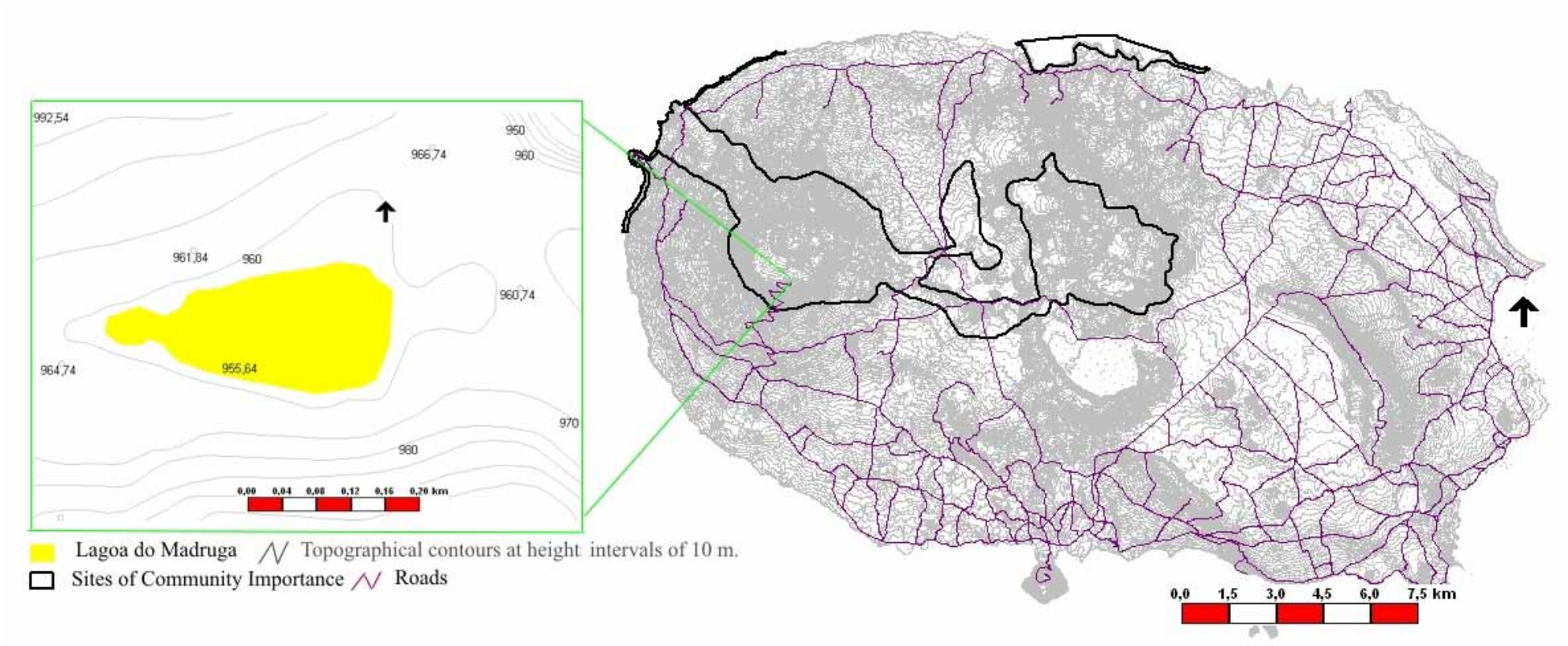

Figure 2. Map of Terceira Island showing SCI boundaries, together with the location and topographical setting of the Lagoa do Madruga.

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Sample collection and analysis

The vegetation of the mire was mapped from aerial photographs, then the map was adjusted using data collected in the field. The floristic composition of each plant community was recorded in a single 5 m x 5 m relevé using the cover classes of Braun Blanquet (Westhoff & Maarel 1978). Nomenclature followed Dias (2004) for vascular plants, and Smith (1980) and Sjögren (2001) for mosses. Plant communities were identified on the basis of the species with the highest cover values. Each community was also characterised in terms of its dominant micro-relief. The vegetation map was developed from aerial and local photographs and GPS points in a Geomedia environment by GEVA, an Intergraph Registered Research Laboratory.

The depth of peat was used to assess the maturity of the mire. For this purpose, two profiles were laid out and marked with PVC tubing, along the major and minor axes of the mire respectively (Figure 3).

Ecological attributes of wetlands such as floristic diversity, vegetation and peat characteristics depend upon the maintenance of their hydrology. Therefore a preliminary analysis of surface water movement was carried out using the Watershed Delineator extension to the ArcView GIS package (see e.g. Romanek 1998).

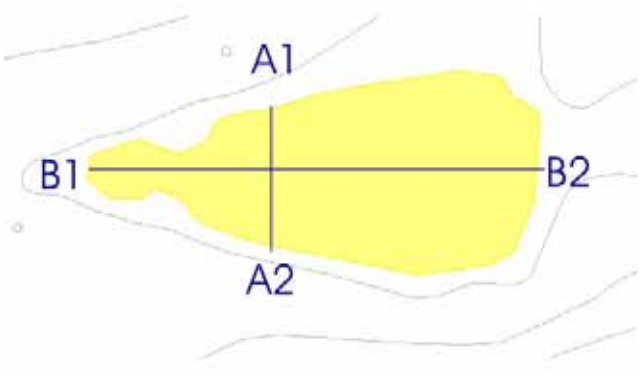

Figure 3. Positions of the peat depth profiles on the Lagoa do Madruga.

RESULTS

Vegetation

The vegetation survey of the Lagoa do Madruga recorded 31 species, including eight species of *Sphagnum*. One species, *Culcita macrocarpa* C. Presl, is listed in Annex II of the EU Habitats Directive and another nine are listed in Annex V of the Directive. Four plant communities were distinguished (Figure 4, Table 1).

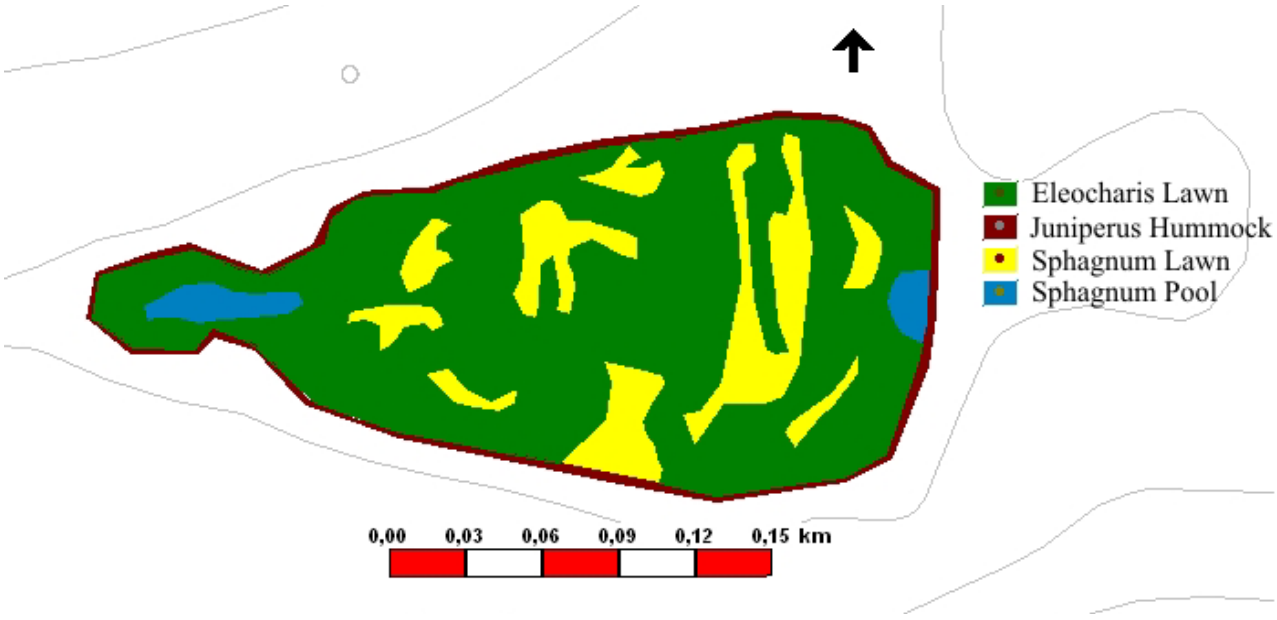

Figure 4. Vegetation map of the Lagoa do Madruga. Details of plant communities are given in Table 1.

The *Juniperus* community (Figure 5) occurs at the margins of the mire and covers 6% of its area. It is waterlogged for most of the year, but in summer the water table falls and the substrate dries, allowing some peat decomposition which releases plant nutrients. Hummocks are the predominant microforms, and the community is characterised by high cover of the vascular plants that grow on them. This is a shrub community with 15 species, including the two indicator mosses *Leucobryum glaucum* (Hedw.) Angstr and *Campylopus setaceus* Card. Cf. Frahm.

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Table 1. Plant species and communities of the Lagoa do Madruga. Species cover is shown according to the Braun Blanquet scale, and community names indicate the dominant genus and micro-relief for each community. For each species, status (E: endemic; I: indigenous; N: naturalised) and frequency (F: frequent; R: rare) for the Azores is shown, based on the data of Sjögren (2001), Shäfer (2002) and Dias (2004). Species listed in Annexes of the EU Habitats Directive are also indicated; Annex II: species of Community interest whose conservation requires the designation of Special Areas of Conservation; Annex V: species of Community interest whose taking in the wild and exploitation may be subject to management measures (EU 1992).

plant species	vegetation communities				Azores status	Azores frequency	Habitats Directive
	Juniperus hummock	*Eleocharis* lawn	*Sphagnum* lawn	*Sphagnum* pool			
Juniperus brevifolia (Seub.) Antoine	4	+	+	.	E	F	
Vaccinium cylindraceum J. E. Sm.	1	.	+	.	E	F	
Eleocharis multicaulis (Sm.) Desv.	1	4	+	.	I	F	
Agrostis gracililaxa Franco	+	+	.	.	E	F	
Blechnum spicant (L.) Roth	+	+	.	.	I	F	
Juncus effusus L.	+	+	+	.	I	F	
Culcita macrocarpa C. Presl	+	+	.	.	E	F	Annex II(b)
Deschampsia foliosa Hack.	+	+	+	.	E	F	
Luzula purpureo splendens Seub.	+	+	+	.	E	F	
Lysimachia azorica Hornem. ex Hook.	+	.	+	.	E	F	
Myrsine africana L. Var. *retusa* (Aiton) DC	+	.	+	.	I	F	
Calluna vulgaris (L.) Hull	.	.	+	.	I	F	
Carex tumidicarpa Anderss. ssp. *cedercreutzii* Fagerstr.	.	.	+	.	I	F	
Hydrocotyle vulgaris L.	.	+	+	.	I	F	
Hypericum foliosum Ait.	.	+	+	.	E	R	
Juncus bulbosus L.	.	+	.	.	I	F	
Platanthera micrantha (Hochst. ex Seub.) Schlecht.	.	.	+	.	E	R	
Potentilla anglica Laich.	.	+	+	.	N	F	
Sphagnum palustre L.	2	+	+	+	I	F	Annex V(b)
Sphagnum compactum DC. in Lam. & DC.	+	.	+	.	I	R	Annex V(b)
Leucobryum glaucum (Hedw.) Angstr	+	.	.	.	I	F	Annex V(b)
Campylopus setaceus Card. cf. Frahm	+	.	.	.	I	F	
Sphagnum subnitens Brid.	.	2	2	.	I	F	Annex V(b)
Sphagnum auriculatum (Schimp.) Lindb.	.	2	2	3	I	F	Annex V(b)
Sphagnum lescurii Sull.	.	1	1	.	I	F	Annex V(b)
Polytrichum commune Hewd.	.	+	.	.	I	F	
Hypnum cupressiforme Hedw.	.	+	+	.	I	F	
Rhytidiadelphus squarrosus (Hedw.)Warnst.	.	+	+	.	I	F	
Sphagnum capillifolium (Ehrh.) Hedw.	.	+	+	.	I	R	Annex V(b)
Sphagnum cuspidatum Hoffman	.	.	1	2	I	R	Annex V(b)
Sphagnum magellanicum Brid.	.	.	+	.	I	R	Annex V(b)

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Figure 5. Marginal *Juniperus* community on the Lagoa do Madruga. Source: AZU photo database.

Figure 6. *Eleocharis* lawn community on the Lagoa do Madruga. Source: AZU photo database.

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Figure 7. *Sphagnum* pool community on the Lagoa do Madruga. Source: AZU photo database.

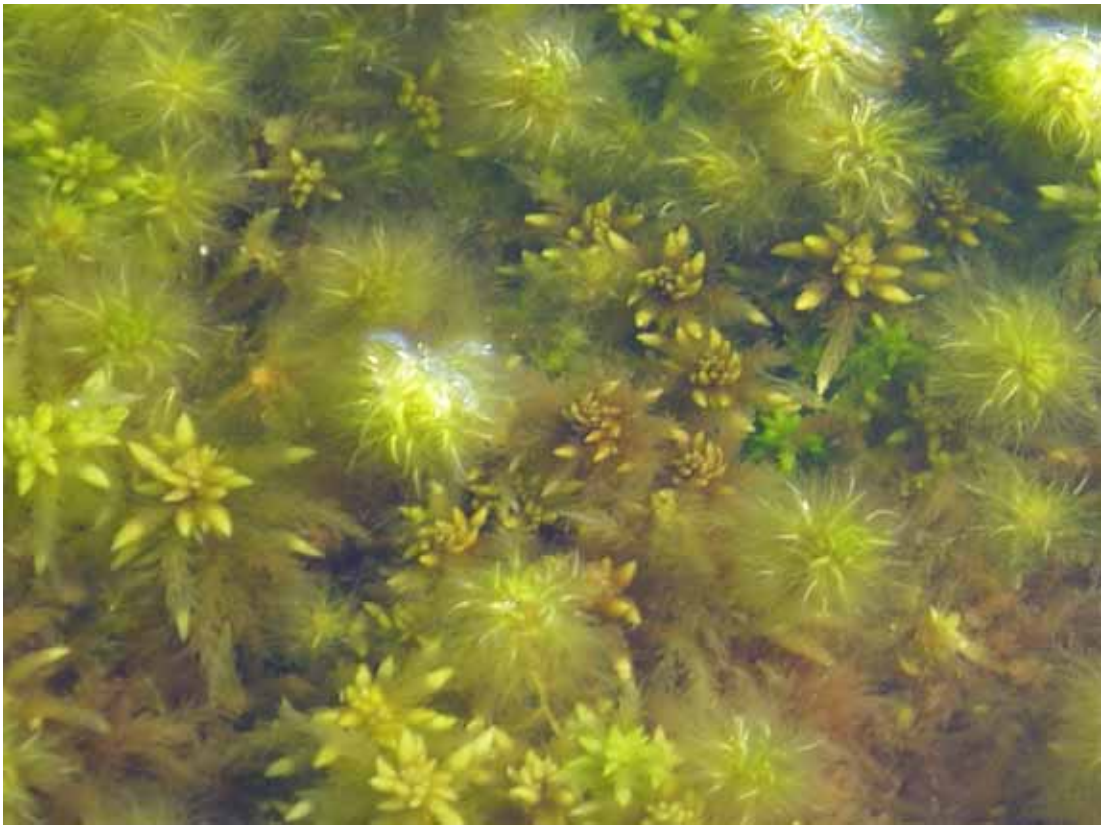

Figure 8. *Sphagnum* lawn community (*S. auriculatum* and *S. cuspidatum*) on the Lagoa do Madruga. Source: AZU photo database.

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The *Eleocharis* community dominates the mire, occupying 73% of its area. It forms remarkably homogeneous lawns (Figure 6) which are perennially waterlogged, with a maximum summer water table depth of 10 cm. It has low cover of vascular plants but the greatest number of species (20) of the communities identified.

The other two communities are *Sphagnum*-dominated. Small pools (Figure 7) with three *Sphagnum* species (including *S. cuspidatum*, which is an Azorean rarity; see Table 1) cover 3% of the mire area. The remaining 19% of the of the mire is covered by a *Sphagnum*-dominated lawn community with 24 species including 10 bryophytes and very low cover of vascular species, which occurs in the extremely waterlogged central portion of the site (Figure 8).

Peat

The data collected indicate that the maximum peat depth is 3 m (Figures 9 and 10), the average depth is 1.87 m on the short axis of the mire (Transect A) and 1.46 m on the long axis (Transect B) (Figure 3). The volume of peat accumulated is about 60,000 m^3; this underlines the importance of the basin for water storage.

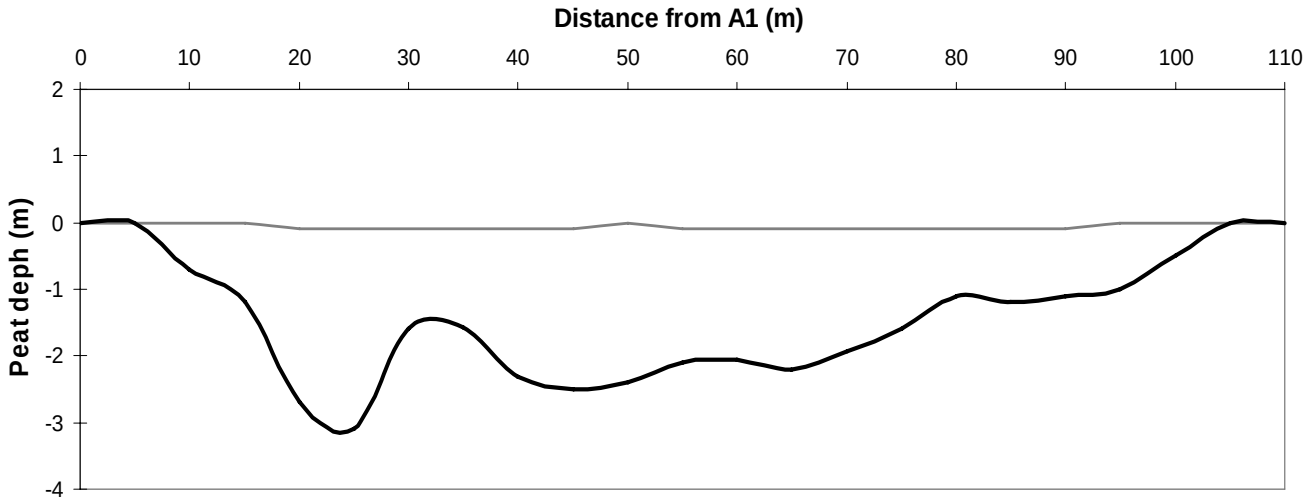

Figure 9. Peat depth profile of the Lagoa do Madruga on Transect A1 (left) – A2 (right) (see Figure 3).

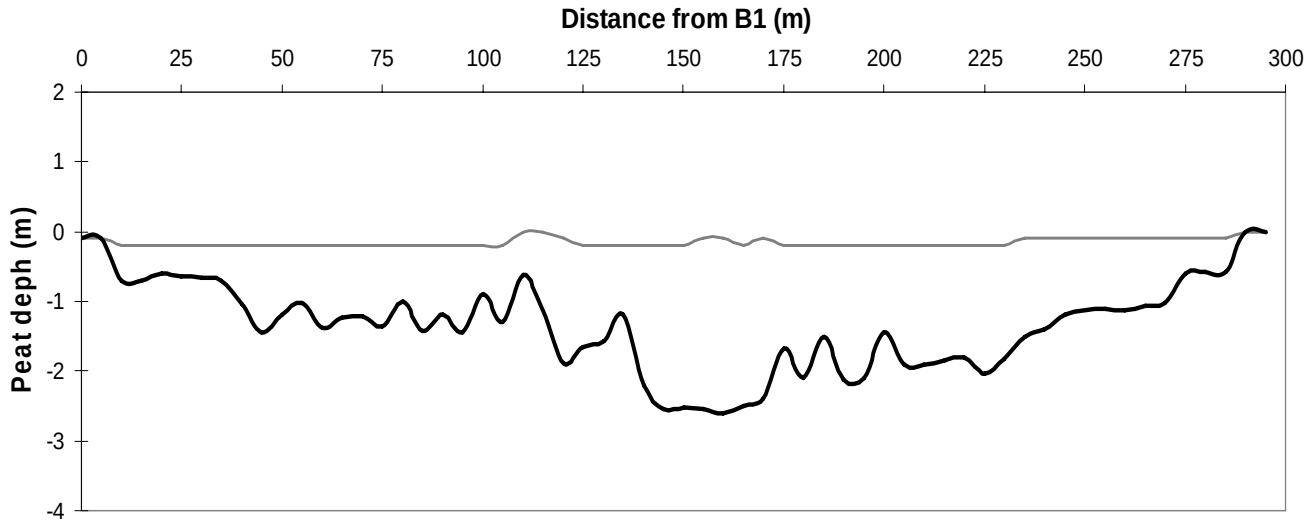

Figure 10. Peat depth profile of the Lagoa do Madruga on Transect B1 (left) – B2 (right) (see Figure 3).

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Surface hydrology

Surface water movement within the catchment of the mire is directed predominantly towards the peatland (Figure 11). The principal inflow is a small stream that enters from the east. There is one location on the western edge of the mire (B in Figure 11) where, after rainfall events, water overflows towards other peatlands located at lower altitudes.

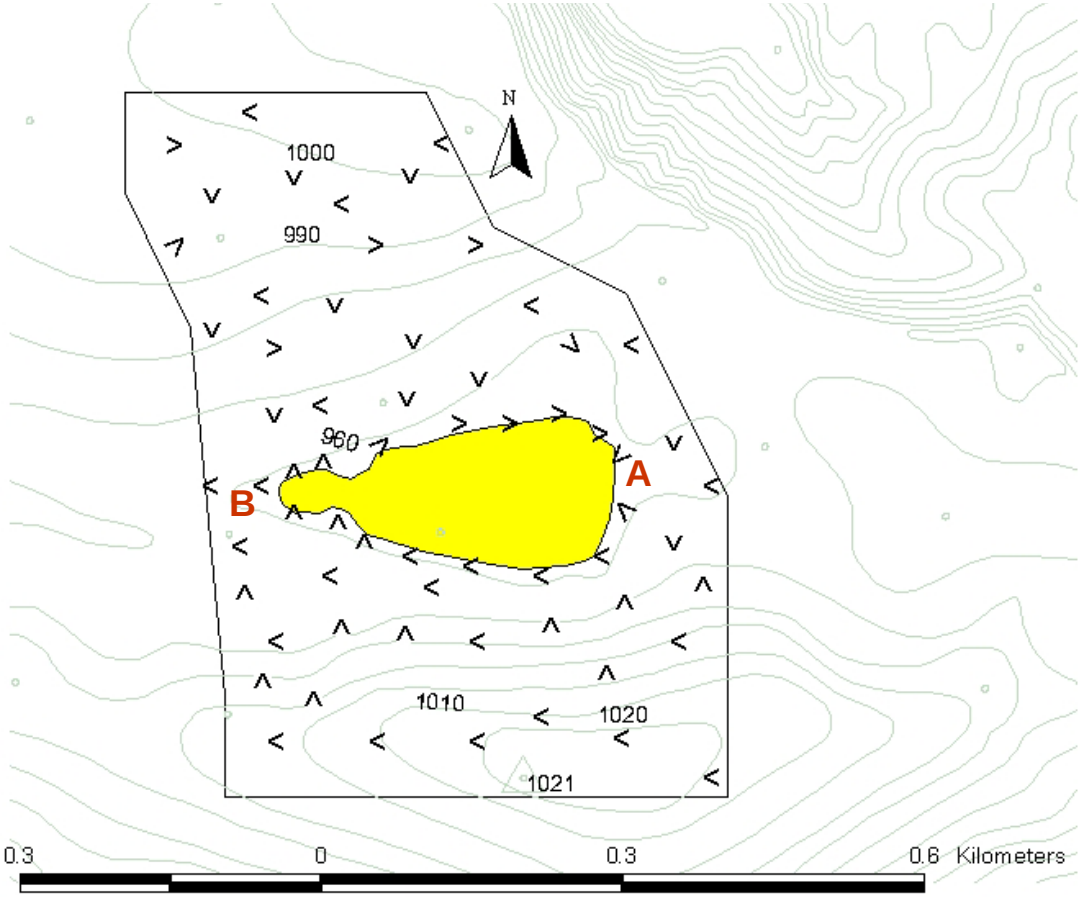

Figure 11. Surface hydrology of the catchment (black boundary) of the Lagoa do Madruga (yellow), derived from 10 m DTM (Digital Terrain Model) data using the ArcView Watershed Delineator extension and superposed on topographic contours (interval 10 m). **A** indicates the point at which the feeding stream enters the mire and **B** indicates the exit point. The direction of drainage at other points within the catchment is indicated by arrowheads generated by the "Grid Cell Flow Direction Arrows" facility with cell size set at 10 m x 10 m.

DISCUSSION

The Lagoa do Madruga is very small compared, for example, with mires in Finland, some of which cover more than 17,000 ha (Lappalainen 1996). Size must, however, be considered at regional level; and the size of the Lagoa do Madruga is typical for the climatic, topographical and edaphic setting.

Paavilainen & Päivanen (1995) adopt a very liberal definition of mire for Finland, basing it on the presence of peat-forming species without specifying a minimum peat depth. For Canada, on the other hand, Keys (1992) and Zoltai & Polet (1983) define a mire as a community in which the accumulation of organic matter is confirmed by the presence of a minimum depth of 40 cm of peat. In the present study, the view was taken that a development phase is required for peat formation to reach equilibrium, and all peat less than 70 cm deep is considered to be young. In these terms, the Lagoa do Madruga is a mature mire with up to 3 m of peat. The deepest mire on Terceira Island has 6 m of peat (Mendes 1998).

Peatlands in their natural state are inhospitable habitats for many wildlife species. This is due to a number of factors including the low nutrient status of peatland soils, the waterlogged surface conditions and the scarcity of tree cover capable of providing shelter. *Sphagnum* dominates the ground surface and is the main constituent of peat due to its ability to

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grow under such acid, low-nutrient and waterlogged conditions. The Lagoa do Madruga is rich in diversity for this genus, with records for eight of the 15 *Sphagnum* species that occur on the whole of the Azores archipelago (Sjögren 2001). Indeed, with 31 plant species, this is a peatland with high biodiversity for the vegetation as a whole, since only 76 species were identified during a survey of 58 basin mires on Terceira Island, with an average of 24 species per site (Mendes 1998). The excellent conservation status of this peatland is demonstrated by the fact that the 31 plant species recorded include nine endemics (two of which are regarded as rare) and no introduced species (Dias 2004, Table 1).

It is extremely important that all rubbish should be removed from the catchment of the mire and that measures should be taken to prevent further dumping, in order to maintain water quantity and quality not only for the Lagoa do Madruga itself but also for the other dependent wetlands downstream.

CONCLUSIONS

1. The Lagoa do Madruga (Madruga's Mire) is a typical example of the basin mires on Terceira Island in that it has a marginal community which is dominated by *Juniperus brevifolia* (Seub.) Antoine. Three additional plant communities have been identified, two dominated by *Sphagnum* (pools and lawn) and one by *Eleocharis multicaulis* (Sm.) Desv (lawn).

2. This is an extremely important Azorean Natura 2000 site because it is the largest (32,760 m^2) basin mire on Santa Bárbara Mountain, it is rich in rare species (biodiversity) and habitats, and it is almost undisturbed. The flora includes nine endemic species, two of which are regarded as rare; and the full list of 31 species contains no exotic species for the island, underlining the natural condition of the mire. The only threat to the site arises from rubbish disposal, and this should be addressed.

3. The mire is also an important landform for water retention due to the surface relief, the properties of *Sphagnum* and the depth of peat. This function is especially important on islands with limited water resources. The water supply to the mire consists predominantly of direct precipitation and intercepted fog with low concentrations of plant nutrients; but the shrub-dominated marginal community also receives drainage from the surrounding hillsides, which is richer in nutrients.

4. Given the importance of peatlands, even if viewed no more widely than at regional scale, this first detailed description of an Azorean *Sphagnum* mire is long overdue. It provides a starting-point for building an understanding of these complex habitats, but also reveals an urgent need for the acquisition of further knowledge to support measures for their conservation. However, the fact that most of the Terceira Island mires lie within Natura 2000 areas is likely to favour their conservation and study.

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