CHARACTERISATION OF A BASIN MIRE IN TERCEIRA ISLAND: TAMUJAL CASE STUDY

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With 11 figures and 1 table

ABSTRACT: The Azores archipelago in the North Atlantic is an extremely important area for biodiversity because it is rich in rare species and habitats distributed in vast and almost undisturbed areas. The Tamujal peatland is a small basin mire located on the central plateau of Terceira island, and it's a good example of a peatland type that was first discovered in 1998 and is now being described in the international literature. This paper intends to provide baseline information on Azorean mire flora, vegetation communities, structure and hydrology. Thirty-two plant species including four *Sphagnum* species and nine endemic vascular plants have been recorded, and eight plant communities are distinguished. The maximum peat depth is 3, 2 metres. The mire receives flowing water from small streams entering at its eastern and southern end and from its margins, 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 still good, but it is under several pressures: cattle pasture in and around the mire, inordinately implementation of infrastructure (roads and walking trails) and surrounding soil transformation for *Eucalyptus* forest implantation. This mire, under the responsibility of the Regional Environmental Services, should be target of an active conservation plan.

Key words: European Habitats Directive, North Atlantic, peatland vegetation, Terceira Island, surface hydrology.

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RESUMO: O arquipélago dos Açores, no Atlântico Norte, é uma área extremamente importante em biodiversidade pois é rica em espécies e habitats raros, distribuídos numa vasta e quase imperturbável área. A turfeira do Tamujal é uma pequena formação de base localizada no Planalto Central da ilha Terceira e um bom exemplo de uma tipologia de turfeira identificada pela primeira vez em 1998 e descrita agora na literatura internacional. Este estudo pretende disponibilizar informação base na flora, vegetação, estrutura e hidrologia das turfeiras açorianas. Trinta e duas plantas, incluindo quatro espécies de *Sphagnum* e nove vasculares endémicas foram identificadas, bem como oito comunidades vegetais distintas. O máximo de profundidade de turfa encontrada é de 3,2 metros. A turfeira recebe água de pequenas linhas de água existentes no extremo Este e Sul, das suas margens, para além da água da precipitação e nevoeiros directos. A água acumulada forma pequenos charcos que alimentam zonas húmidas existentes a um nível inferior. O estado de conservação desta turfeira é ainda elevado, mas encontra-se sobre diversas ameaças: pastoreio marginal por gado bravo, implantação desordenada de caminhos e trilhos e alteração da cobertura dos solos na zona adjacente para implantação de uma mata de *Eucalyptus*. Esta turfeira, localizada numa área da propriedade dos Serviços de Ambiente, deveria ser alvo de um plano de gestão activa.

INTRODUCTION

The Azores (Portugal) is the most northerly Macaronesian archipelago, comprising nine volcanic islands scattered over area of approximately 1000 km^2 in the North Atlantic between latitudes 36º 56' N – 39º 42' N and longitudes 25º 5' W – 31º 12' W. The east-most island, Santa Maria, is located approximately 1400 km from mainland Europe and the west-most island, Flores, lies 1900 km from the North American continent.

These islands host the most westerly mires in Europe. The first reference of these rare landforms for Portuguese mainland is about its exploration and it was first proposed in 1922 (Zbyszewski, 1979). For Azores, some of mire plant associations were included in the phytosociological system of Lüpnitz (1975). Otherwise, almost nothing was known about them until the mid-1990's, and they have not previously been described with detail in the international literature.

The European Union (EU) Habitats Directive provides, for 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 required, 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 valleys. 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 description of the vegetation and surface hydrology of an Azorean basin mire, as a foundation for further research and publications and a temporal reference for future assessment against ongoing disturbances.

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 (1023 m), hosts the largest concentration of 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 Tamujal Mire (Fig. 1) is a basin mire located at an altitude of 570 metres above sea level within the SCI (Fig. 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 26076 m^2, and its surface catchment extends to 263000 m^2. 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.

Fig. 1 - View across the Tamujal Mire from the north-east. Image from the AZU (Azorean Herbarium) photo database.

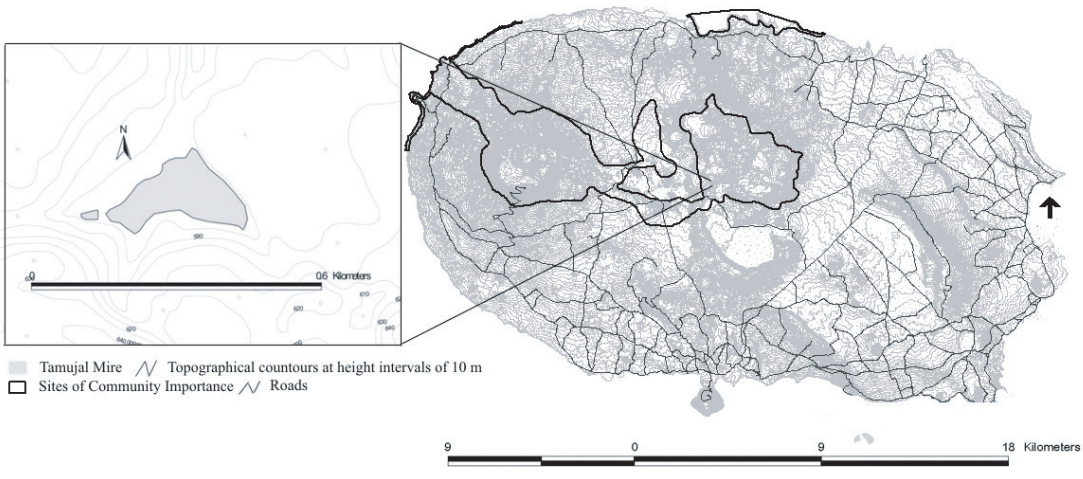

Fig. 2 - Map of Terceira Island showing the location of the Tamujal Mire in relation to the boundary of the Santa Bárbara Mountain and Pico Alto SCI.

Precipitation at 600 m is 4109 mm yr^{-1} (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 a production forest on one of the hillsides overlooking the mire. An increasing cattle pasture and the existence of roads and walking trails that pass throw the mire may be responsible for serious hydrological changes.

Sample collection and analysis

A map of the mire was made from aerial photographs based on colour gradient and subsequently adjusted using data collected in the field. Floristic composition was recorded 16 (5 m x 5 m) relevés 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, three profiles were laid out with PVC tubes, along the major and the two minor axes of the mire respectively (Fig. 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 a Watershed Delineator extension to GIS package (see *e. g*. Romanek, 1998).

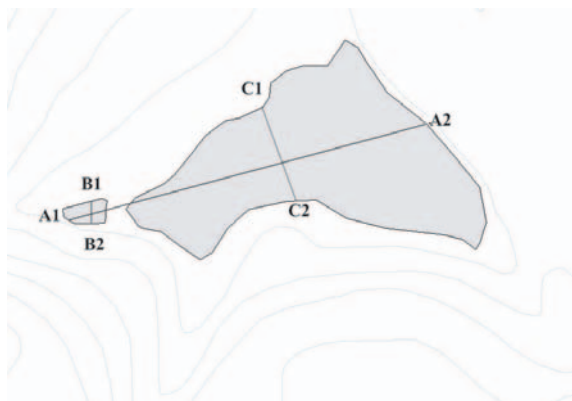

Fig. 3 - Positions of the peat depth profiles on the Tamujal Mire.

RESULTS

Vegetation

The vegetation survey of the Tamujal Mire recorded 32 species, including four species of *Sphagnum*. Three species, *Erica azorica* Hochst, *Culcita macrocarpa* C. Presl and *Frangula azorica* V. Grubow are listed in Annex II of the EU Habitats Directive and another four are listed in Annex V of the same Directive. Eight plant communities were distinguished (Fig. 4, Table 1).

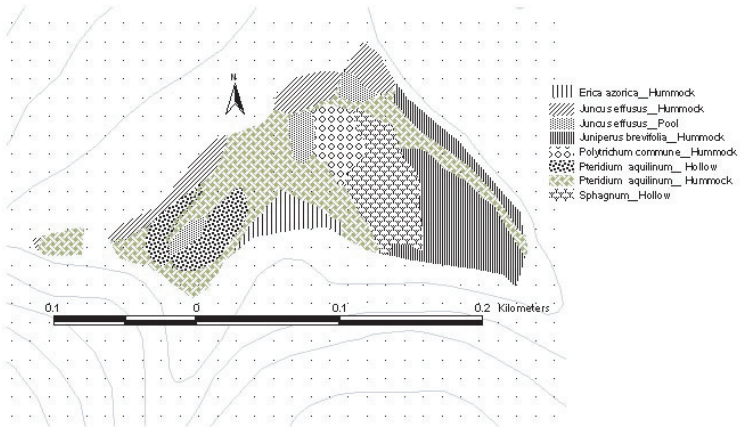

Fig. 4 - Vegetation map of the Tamujal Mire.

The *Pteridium* community (Fig. 5) has the highest biodiversity of the mire with 21 species and it is also the dominant community, covering 41% of the mire, predominantly in hummock area. This plant (*Pteridium aquilinum* (L.) Kuhn) is indicative of soil nitrous conditions showing that organic decomposition is occurring in the mire, probably due to hydrological changes derived of the implantation of the *Eucalyptus* forest and existence of walking trails that deviate water outside this peat formation.

The *Juniperus* community occurs at the margins of the mire and covers 20% 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 19 species, including the indicator moss *Campylopus setaceus* Card. Cf. Frahm.

The *Erica* community (Fig. 6), occupying 4.6% of the mire area, is also cover dominated by vascular species. Although this is an atypical community because this endemic

specie is adapted to more dry conditions, it is located near (its south and east limits) the walking trail responsible of significant water deviate. Diminishing water entrance, this shrub found more dry and nutrient rich conditions to develop.

Fig. 5 - *Pteridium* community on the Tamujal Mire. Source: AZU photo database.

Fig. 6 - Marginal *Erica* community on the Tamujal Mire. Source: AZU photo database.

TABLE 1 - Plant species and vegetation communities of the Tamujal Mire. 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 of Azores; E* - endemic of Azores and Madeira; I - indigenous; N - naturalised) and frequency for the Azores (F - frequent; R - rare). Data based of SJÖGREN (2001); SHAFER (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: plant species of Community interest whose taking in the wild and exploitation may be subject to management measures (EU, 1992).

	vegetation communities										
	Sphagnum hollow	*Pteridium* hummock	*Pteridium* hollow	*Polytrichum* hummock	*Erica* hummock	*Juncus* hummock	*Juncus* pool	*Juniperus* hummock	Azores status	Azores frequency	Habitats Directive
Eleocharis multicaulis (Sm.) Desv.	2	.	.	.	.	+	1	.	I	F	
Juniperus brevifolia (Seub.) Antoine	1	.	.	.	1	.	.	4	E	F	
Blechnum spicant (L.) Roth	+	1	.	+	+	+	.	+	I	F	
Juncus effusus L.	+	+	+	.	.	4	1	+	I	F	
Luzula purpureo splendens Seub.	+	+	.	.	+	.	.	+	E	F	
Vaccinium cylindraceum J. E. Sm.	+	+	.	1	.	.	.	1	E	F	
Holcus lanatus L.	+	.	.	.	.	+	+	.	N	F	
Holcus rigidus Hochst. ex Seub.	+	.	.	.	.	+	.	.	I	F	
Pteridium aquilinum (L.) Kuhn	.	5	5	4	+	+	.	3	N	F	
Sibthorpia europaea L.	.	+	+	.	.	+	.	+	I	F	
Erica azorica Hochst.	.	1	.	.	3	.	.	+	E	F	Annex II(b)
Culcita macrocarpa C. Presl	.	+	.	.	.	.	.		I	F	Annex II(b)
Dryopteris azorica (Christ) Alston	.	+	.	.	.	.	.	+	E	F	
Frangula azorica V. Grubow	.	+	.	.	.	.	.	.	E*	R	Annex II(b)
Hypericum foliosum Ait.	.	+	.	.	.	.	.	+	E	R	
Calluna vulgaris (L.) Hull	.	+	.	.	.	+	.	.	I	F	
Laurus azorica (Seub.) Franco	.	+	.	.	.	.	.	.	E	R	
Lysimachia azorica Hornem. ex Hook.	.	+	.	.	.	+	.	+	E	F	
Rubus inermis Pourr	.	+	.	.	.	1	.	+	N	F	
Scirpus fluitans L.	.	.	+	.	.	+	1	.	I	F	
Hydrocotyle vulgaris L.	.	.	+	.	.	.	1	+	I	F	
Potentilla anglica Laich.	.	.	.	.	+	.	.	.	N	F	
Scutellaria minor Huds.	.	.	.	.	.	.	.	+	N	F	
Sphagnum auriculatum Schimp.	+	.	.	.	.	.	5	.	I	F	Annex V(b)
Sphagnum rubellum Wils.	+	.	.	.	.	.	.	.	I	F	Annex V(b)
Sphagnum centrale C. Jens	2	3	2	3	3	2	+	3	I	F	Annex V(b)
Sphagnum palustre L.	3	2	4	2	3	1	+	3	I	F	Annex V(b)
Thuidium tamariscinum (Hedw.) Br. Eur	+	.	.	+	+	+	.	.	I	F	
Pseudoscloropodium purum (Hedw.) Fleisch.	+	+	.	.	.	.	.	.	I	F	
Campylopus setaceus Card. cf. Frahm	+	.	.	+	+	+	.	2	I	F	
Polytrichum commune Hewd.	.	2	2	5	.	.	+	3	I	F	
Cladonia portentosa (Dufour) Coem.	.	.	.	+	+	.	.	+	I	F	

The poorest biodiversity community is the *Polytrichum* dominated, with 9 species. It is a hummock dominated community that occupies 5% of the mire surface.

The *Sphagnum* community, occupying 13% of its mire area, forms remarkably homogeneous hollows (Fig. 7) 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 bryophyte species (8) of the communities identified.

Fig. 7 - *Sphagnum* hollow community on the Tamujal Mire. Source: AZU photo database.

The other two communities are *Juncus*-dominated. Small pools which occur in the extremely waterlogged portion of the site cover 4.7% of the mire area. The remaining 11% of the mire is covered by a *Juncus*-dominated hummock community with 15 species including 4 bryophytes.

Peat

The data collected indicate that the maximum peat depth is 3,2 m (Figs. 8, 9 and 10), the average depth is 2,17 m on the longer axis of the mire (Transect A), 0,54 m on the shorter axis (Transect B) and 1,13 m on the third transect (Transect C) (Fig. 3). The volume of peat accumulated is about 30325 m^3, underlining the importance of the basin for water storage.

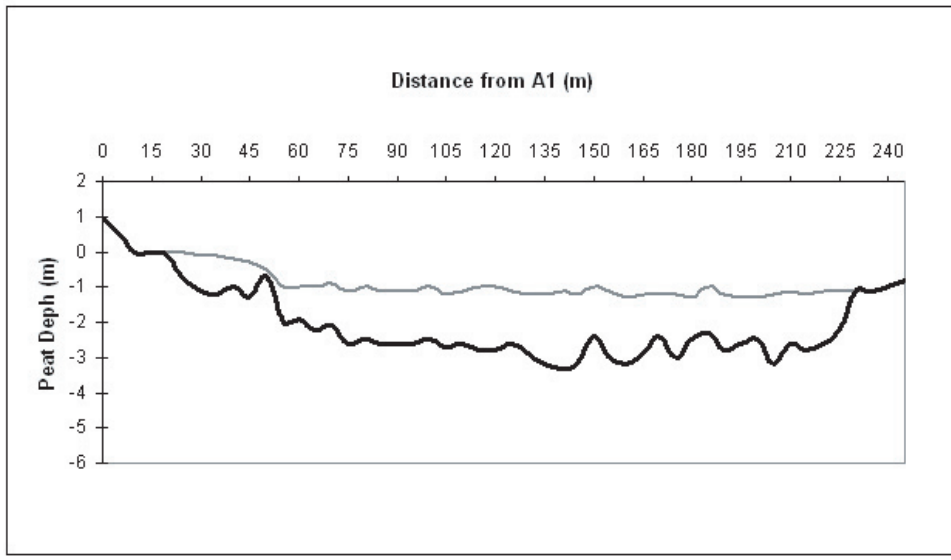

Fig. 8 - Peat depth profile of the Tamujal Mire on Transect A1 (left), A2 (right) (see Fig. 3).

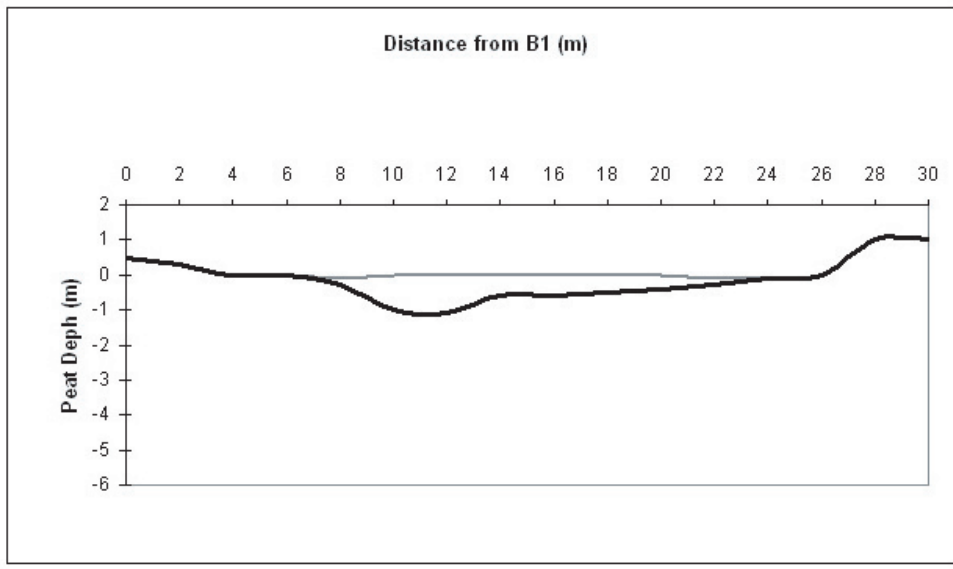

Fig. 9 - Peat depth profile of the Tamujal Mire on Transect B1 (left), B2 (right) (see Fig. 3).

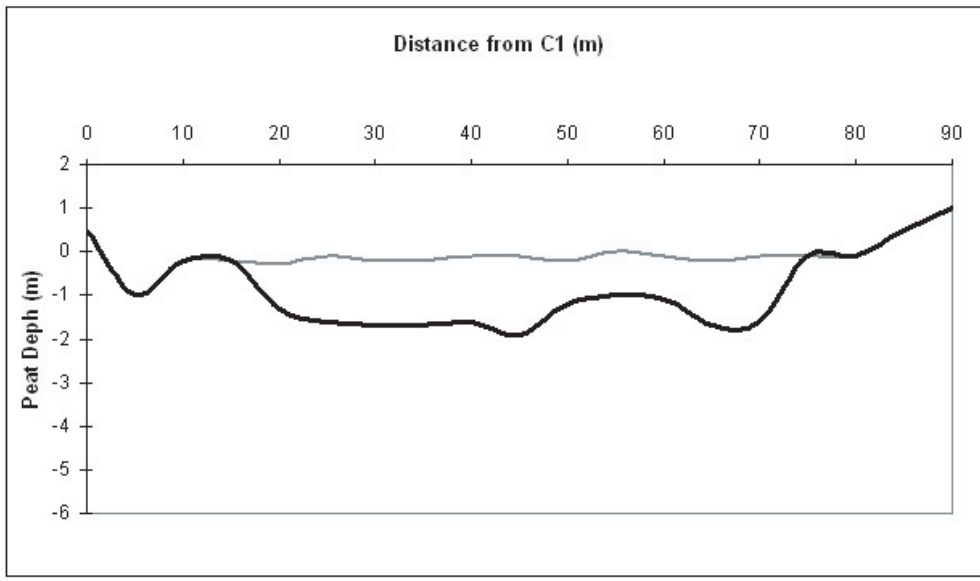

Fig. 10 - Peat depth profile of the Tamujal Mire on Transect C1 (left), C2 (right) (see Fig. 3).

Surface hydrology

Surface water movement within the catchment of the mire is directed predominantly towards the peatland (Fig. 11). However in the south and east limits the water movement was altered due to roads / walking trails. The principal inflows are small streams that enter from the east and south (Fig. 11A). There is one location on the north edge of the mire (Fig. 11B) where, after rainfall events, water overflows towards other peatlands located at lower altitudes.

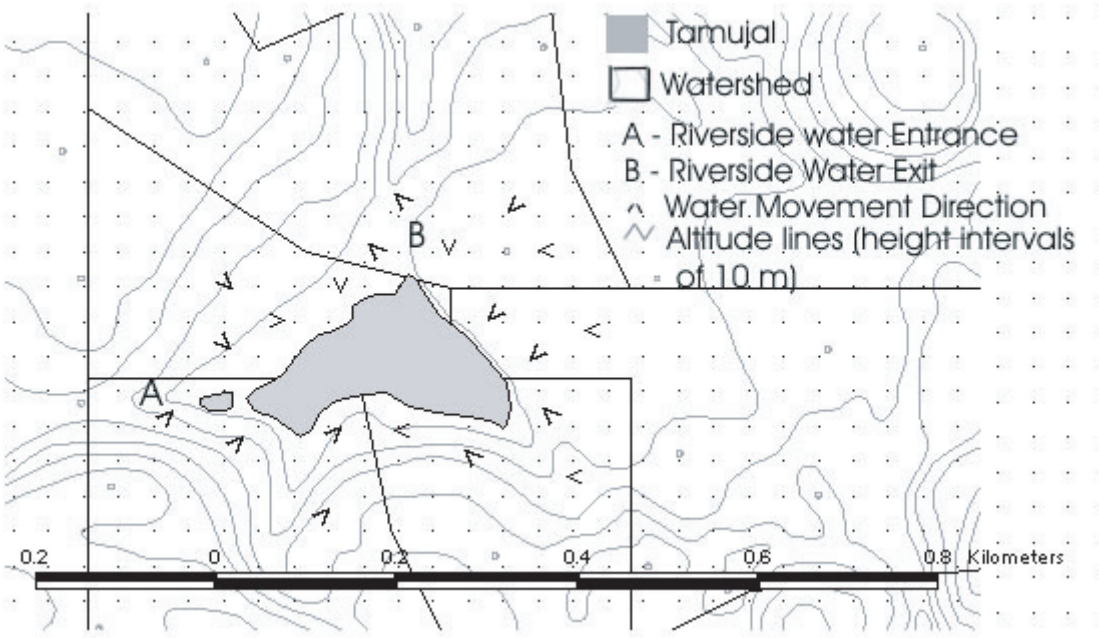

Fig. 11 - Surface hydrology of the Tamujal Mire catchment, modelled by GIS. **B** - indicates the point at which the feeding stream enters the mire and **A** - indicates the exit point. The direction of drainage at other points within the catchment is indicated by arrows generated by the model using the "Grid Cell Flow Direction Arrows" facility with cell size set at 10 m x 10 m.

DISCUSSION

The Tamujal peatland is very small compared, for example, with mires in Finland, some of which cover more than 17000 ha (Lappalainen, 1996). Size must, however, be considered at regional level.

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 Tamujal is a mature mire with up to 3 m of peat; however, 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 grow under such acid, low-nutrient and waterlogged conditions. The Tamujal peatland is rich in diversity for this genus, with records for four of the 15 *Sphagnum* species that occur on the whole of the Azores archipelago (Sjögren, 2001). Indeed, with 32 plant species, this is a peatland with high biodiversity levels 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 good conservation status of this peatland is demonstrated by the fact that the 32 plant species recorded include nine endemics (two of which are regarded as rare) and no exotic species (Dias, 2004; Table 1).

It is extremely important that all cattle pasture should be removed from the mire and it's the water catchments area and measures should be taken to diminish the effects of the roads and walking rails presence, in order to maintain water quantity and quality not only for the Tamujal Mire itself but also for the other dependent wetlands downstream. This area, under the management responsibility of Regional Environmental Services, should be object of an active conservation/restoration plan.

CONCLUSIONS

The Tamujal'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 and *Juncus effusus* L. (both in hummock area). Additional plant communities have been identified: another *Juncus* community, two dominated by *Pteridium* (hollow and hummock), one by *Erica azorica* Hochst., one by *Polytrichum commune* Hewd. and a hollow *Sphagnum* community.

This is an extremely important Azorean Natura 2000 site because it is one of the largest (26076 m^2) basin mire on Central Island plateau, it is rich in rare species (biodiversity) and habitats, but is under some aggressive conditions. The flora includes nine endemic species, three of which are regarded as rare; and the full list of 32 species contains no exotic species for the island, underlining the (still) natural condition of the mire. The threats to the site arise from cattle pasture, Eucalyptus forest implantation and the presence of roads and walking trails, that should be addressed.

The mire is also an important landform for water retention due to the surface relief and the properties of *Sphagnum*, with a maximum peat depth of 3,2 m. Its water supply 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. This water reservoir is extremely important, especially in islands with limited water resources.

Given the importance of peatlands, even if viewed no more widely than at regional scale, the detailed description of 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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