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# Classification of *Sphagnum* peatlands in Azores — cases from Terceira Island

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The aims of this study were to explore the mires (peatlands) in Terceira Island of Azores, invent their vegetation and ecology, and classify the mires to the ecological groups. In the field, totally 300 mires were identified and mapped, of which 58 were selected for the detailed analysis of this study. Physical, chemical, floristic, hydrological and geomorphologic data of the mires were collected in 1997–2004. The data were organized and analysed using ordination methods (CA). A detailed distribution map of the mires in the Island is presented. Three major mire site groups occurring in Azores were identified: (1) Basin mires; (2) Transition and raised mires and (3) Hillside and blanket mires. The profiles and the plant species of these site type groups are presented.

Keywords: Azores, mire inventory, mire vegetation, peatland, *Sphagnum*.

## Introduction

Azorean mires i.e. peatlands are an important element of the region's volcanic landscape. These peat formations are of most importance in the Macaronesian biogeographic region where peat formations are very scarce, due to inappropriate environmental conditions for peat formation and large human effect on the landscape.

Despite their recognized importance, with some types being protected by the European Habitats Directive (DL nº 49/2005, February 4th), these rare formations are still quite unknown, not only in Azores but in all of the Portuguese territory. On the Portuguese mainland, there are documented references of peatlands dating back to 1922, related to the needed exploration of these mires (Zbszewski 1979). The reconnaissance of mire habitats in the Azores islands is very recent. Only in 1975 appeared the first reference to these communities in the Lüpnitz phytosociological system. However, this description of the mires is incomplete, because certain plant associations were not recognized. Dias (1996) defined the first Azorean classification of wetland habitats and recognized these communities developed under humid conditions as extremely differentiated. He described six different types, four of which are Sphagnum dominated.

The characteristics generally used to describe the mire habitats are of varied nature. Most fall back upon characteristics, such as mire plant associations, topography and the water's chemical composition (McQueen 1990). Moore (1984) refers to characteristics like vegetation physiognomy, mire structure, hydrology, peat deposit and peat characterization. Furthermore, Clymo and Hayward (1982) suggested that the most important characteristics to classify mire habitats are nutrient availability and water supply, where different mire types support different types of vegetation. Dias (1996) used the nutrient status of the water as a classification factor. He identified the basin mire, mixed mire, and forested hillside mires as minerotrophic, and the blanket mire, forested and raised mires or bogs as ombrotrophic ecosystems.

Also taken into account is the fact that each mire has its own history with certain intra specific characteristics associated with the geography, topography and hydrology of the place and that the action of mankind directly or indirectly caused impacts on the area.

Considering that 74% of the terrestrial areas in the Azores belonging to the Nature 2000 conservation network of European Union are above 500 a.s.l., where mires are a dominant feature, it is important to know and understand the ecology and distribution of these ecosystems. Most of these studies aimed explore mires in Terceira Island and classify it by analysing the ecohydrological and geological characteristics. With this it's intended to improve the knowledge of the ecology and distribution of natural formations in Europe.

# Material and methods

### Study area

The preliminary study area for mire GIS mapping was the entire Terceira Island, one of the nine islands of the Azores archipelago. It is the northernmost Macaronesian archipelago, located about 1400 km from European continent (distance between Sta. Maria Island and Lisbon) and 1900 km (between Flores Island and USA) from the North American continent (36°56' N – 39°42' N and 25°5' W – 31°12' W). Terceira Island, has an area of about 402 km2 and its highest mountain, Santa Bárbara volcano (1023 m) is located in the western part of the island.

The mire sites selected for detailed classification are at a minimum altitude of 500 m. The climatic and topographical conditions at this altitude are very favourable for the development of wet vegetation complexes. With some exceptions, like lava domes (Dias 1996, Dias et al. 2004, Elias and Dias 2004), the majority of the plant communities is mire vegetation or directly dependent on them. The predominant types of soil on the island are andosols with *placic* (indurated subsoil horizons of cemented iron and magnesium), developed from volcanic pyroclastic material under a wet, temperate Atlantic climate (Pinheiro 1990, Madruga 1995). However in our study area, the predominant soils were histosols, formed in places where poor drainage inhibits the decomposition of plant remains, allowing the accumulation of organic material.

According to Dias (1996), the precipitation ranges between 4109 mm (at 600 m) and 13.054 mm (at 980 m) in the region. The presence of placic in soil limits its drainage and, together with high precipitation, the conditions are ideal for the occurrence of mires in the studied altitudes of the island.

### Sample collection and analysis

The first step of this study was the identification of the mire area with the use of aerial photography. In the field, totally 300 different mire basins were identified and mapped (Fig. 1). We are (Group of Ecological applied studies – GEVA) an Intergraph Registered Research Laboratory in Azores University with big experience in cartography (Dias et al. 2006). Altogether, mire occupied an area of 37.6 ha (7095 ha is the area of Terceira above 500 m a.s.l.). Of these mire areas, 58 were selected for this study. The selection of the studied mires was based in the following parameters: the location should be inside the Nature 2000 -area, Sphagnum dominated vegetation covered by more than 75% of the mire surface.

The following described parameters correspond to data collected and used in the ordination analysis.

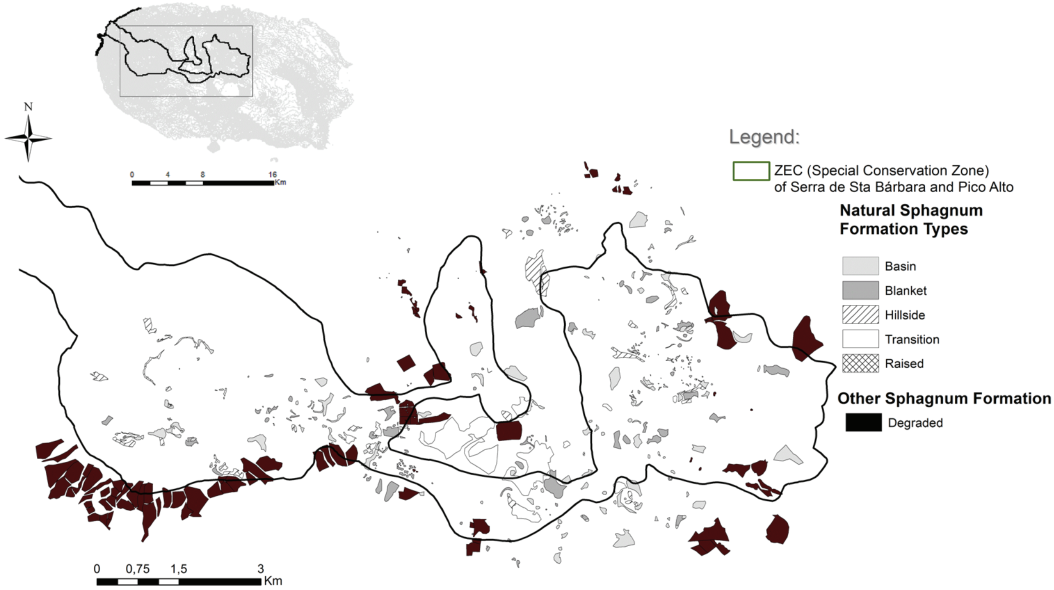


Figure 1. Peatland distribution map on Terceira Island, largely coincident with Nature 2000 special conservation zone (ZEC) of St. Bárbara/Pico Alto. This map distinguishes the types of natural mires identified in this study. The degraded formations are included in one group that not considers type. Geographic Support: Digital base File: Military Map 1:25 000. Projection System: U.T.M. Local Data: Graciosa base SW 1948 Zone 26S. Font: IGEOE.

*Kuva 1. Kartta soiden jakaantumisesta Terceira-saarella eri suotyyppiryhmien mukaan.*

### *Floristic composition*

Together 87 mire plant species were identified in the inventories of the mires in Terceira Island. In the vegetation inventories, the covering classes of Braun-Blanket (Westhoff & Maarel 1978) were used. Due to the reduced dimensions of the mire communities, and unlike traditional inventory methods, the inventory unit was considered to be the community's total area. With the objective of annulling any interpretation mistakes in terms of the floristic diversity (since the samplings were of different dimensions), an index was created that is designated as Floristic Heterogeneity (HF). This parameter compares the specific floristic wealth in function of the mire area. It is the sum of species diversity found inside each community. It considers the total area of the mire, and therefore, constitutes not only the specific richness, but the conjugation of this parameter inside the different vegetation communities of mire. The Floristic Heterogeneity index has the following form:

$$HF = \sum_{I=1}^{N} Xn / A \tag{1}$$

Where $X$ is the mire community, $n$ is the number of species inside the mire community, $A$ is the area of the mire (ha), $I$ is each studied mire area, and $N$ is the total number of studied mire areas.

The analysis of this index allowed the establishment, for classification ends, of mire groups that result in the determination of the inflection point, after which point the mire is considered to have either a high or low HF (Fig. 2). In this analysis, three different class types were found: (1) small mire with high HF; (2) small mire with low HF; and (3) large mire with low HF, for cluster analysis. Together 87 plant species were identified in the 247 inventories of this study. Vascular plant nomenclature was based on Dias (2004), and complemented with information found in Hansen & Sanding (1993) and Shäfer (2002). Moss nomenclature was based on Smith (1980),

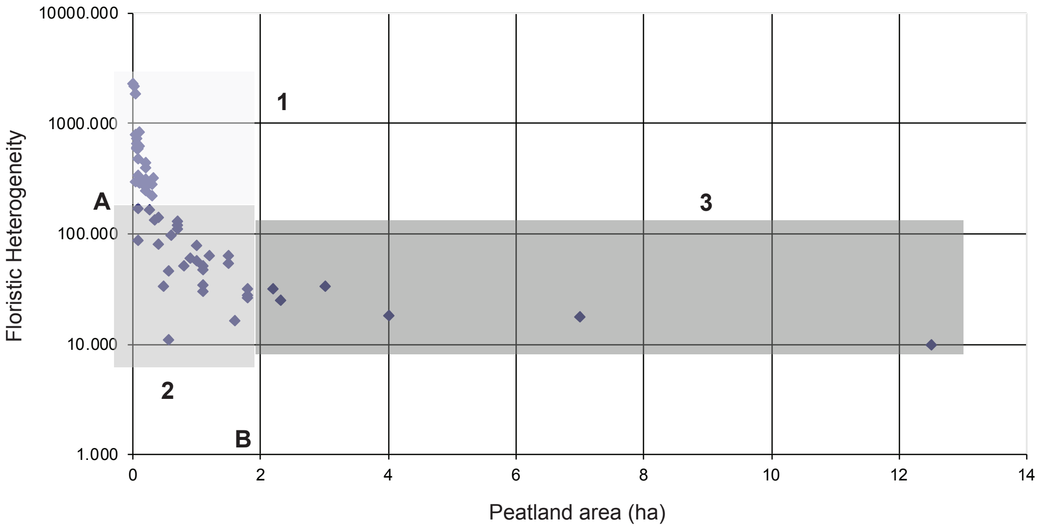


Figure 2. Studied mires Floristic Heterogeneity Index (HF) (data logarithmic transformed). Identified groups for classification: (1) small mire with high HF; (2) small mire with low HF; (3) large mire with low HF. Inflection points: A – Inflection point of HF; B – Inflection point of the area.

*Kuva 2. Tutkittujen soiden kasvillisuuden diversiteetti-indeksien arvot suon pinta-alan suhteen: 1. pieni suo, mutta suuri diversiteetti, 2. pieni suo, pieni diversiteetti ja 3. suuri suoalue, mutta pieni diversiteetti.*

Sjögren (2001) and Flatberg (2002), and lichen nomenclature was based on Hodgetts (1992) and Mason & Cole (1998).

### *Geomorphology*

Based on the geomorphological characterisation of mires, we identified the following classes (for ordination purposes) of mire formations in the field: (1) basin mires (when located in endorreic valleys); (2) hillside mires (exoreic formations, located at mountain hillsides), and (3) blanket mires (formation that differs from the hillside type, due to the fact that it develops on both sides of the mountain). The studied mires were also grouped in terms of area by performing the floristic heterogeneity analysis (see floristic characterization). Based on the analysis, a threshold value for the size of a mire area was 1.8 ha (represent with a B in Fig. 2): A mire area larger than 1.8 ha was considered "large", and otherwise "small".

The mires were also classified according to the structure of their microrelief (Seppä 1996), and the following groups of mire habitats were identified: (1) a mire dominated by lawn surface; (2) mire that possess hollows and hummocks on at least 40% of the surface; (3) mire that possess hollows and hummocks higher than 40%. This value influences given characteristics, such as flora, degree of peat decomposition, and water table level.

In our study, a mire is defined as a plant community, if the average thickness of peat was at least 40 cm (see Zoltai & Polet 1983, Keys 1992). Furthermore a formation was determined to be young, if the thickness of peat was inferior to 70 cm. The peat thickness was measured by taking 2 peat profiles with a PVC tube from each mire area (longitudinal and transversal considering the largest part of the mire, see example in Dias & Mendes 2007).

### *Hydrology*

We evaluated the origin of water reaching each mire. For classification and ordination analysis purposes we determined the origin of water to classes: (1) at least 30% of the mire surface received minerotrophic waters (runoff), and (2) all the waters entering the mire were came from rain (ombrotrophic).

The depth of the water table level is an important ecological factor in classification of the mires, since the oxygenation and the mineralization rate depend on it and this in turn, affects the nutrient quantity available for the plant species (Dias 1996). In this study, the depth of the water table level was observed in the following classes: The water can be at peat surface (Class 1), above the peat surface (Class 2), or below the soil surface of at least several centimeters (Class 3).

*Water sample analysis*

Altogether, 224 water samples were collected and analysed in year 1997. The following characteristics were analysed: electrical conductivity (µs $cm^{-1}$ with a correction for the 20 ºC temperature), total dissolved solids (TDS), expressed in mg $ml^{-1}$, and pH. The TDS consists of among others the following elements: bicarbonate ($HCO_3^-$), calcium (Ca), sulphate ($SO_4$), silica ($SiO_4$), chlorinate ($Cl^-$), magnesium (Mg), sodium (Na), potassium (K), nitrogen ($N_2$, $NH_3$, $NO^{-2}$, $NO^{-3}$) and phosphate ($PO_4$) (Resek et al. 1999). This is important for the maintenance of aquatic life controlling the water intake and outflow of the organisms (osmosis). However it's necessary to consider that the total values for TDS might not correspond to the available nutrients for organisms, because in case of low pH conditions, the solubility of many elements is low and decrease their availability for plants. The more water moves, the higher will be its value. The value of TDS are also tending to increase when human activities have impacted the ecosystem. The water samples were analysed in the field using WTW LF 320 Conductivity Meter and WTW pH 320 -*pH Meter*.

Some of the collected parameters were of a qualitative character, for which we had to establish classes (in the cases of the HF and mire areas) for subsequent quantitative analyses. These characteristics were organized in matrix form for mathematical analysis. The used methods were hierarchical clustering, Euclidian distance models and algorithm complete link. A correspondence analysis (CA) was made to evaluate the homogeneity and the degree of mire-type consistence obtained in the cluster analyses.

# Results and discussion

Three different types of mires on Terceira Island emerged from the cluster analysis: basin mire, in deep endorreic valleys; transition mire, located on less pronounced but endorreic mountain basins, raised mires, which were in a more advanced successional state than the basin mires and the hillside and blanket mires.

The results of the CA analysis (Fig. 3) show an evident coherence and homogeneity existence in the three mire groups. The group of hillside and blanket mires are more heterogeneous, which can be justified by the existent diversity in terms of relief, hydrology and vegetation: Axis 1 (eigenvalues of 0.48) represents water table depth and the regularity of it as well as the variation in the surface microrelief. Axis 2 (eigenvalues of 0.40) represents the heterogeneity of the slope. Thus, the basin mires are habitats that possess the water closest to the surface and a less accentuated slope. On the other end, hillside and blanket mires are associated with a water system quite irregular and a more accentuated relief. Hillside and blanket mires had the largest variation in the shape of their relief.

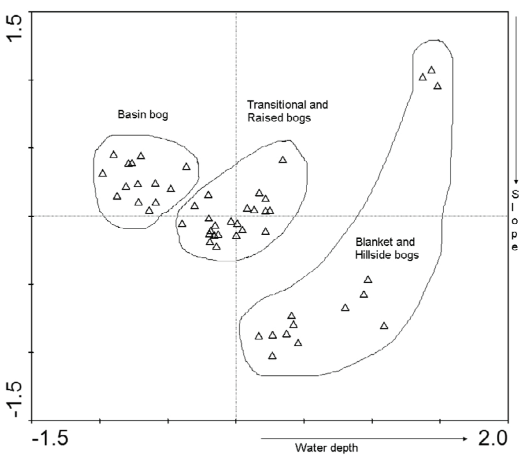


Figure 3. Ordination diagram (Correspondence Analysis) of the 58 studied mires in Terceira Island. Three ecological groups (mire type groups) can be identified.

*Kuva 3. Korrespondenssianalyysiin perustuva oordinaatiokaavio, jossa on mukana 58 suota Terceira saarelta. Kaavion perusteella voidaan erottaa kolme toisistaan poikkeavaa ekologista ryhmää.*

The following mire type groups could be characterised on Terceira Island:

### Basin Mires

This mire type develops in pronounced endorreic valleys (see Dias & Mendes 2007). Its limits are rich in hummock communities and its occurrence can be justified by the lateral movement of minerotrophic water that supplies nutrients and oxygen providing for the development of vascular species (Fig. 4 and Fig 5).

The origin of ombrotrophic water in Azores is direct precipitation and interception of thick fog. In the centre of the mire basin is the area of stagnant waters, dominated by lawn microrelief. In this habitat the water is usually at, or close to the surface.

Together, 76 different species were identified in the studied basin mires, with an average of 24 species in each mire. Only 18 species (Table 1) had a frequency higher than 20%.

The low covering degree seems to be due to the high wetness index verified in these habitats. However, at their extremities, hummock communities are richer and dominated by *Polytrichum commune* Hewd., as well as (with less frequency), *Juniperus brevifolia* (Seub.) Antoine and *Erica azorica* Hochst. The low areas (lawns) are generally dominated by *Juncus effusus* L.

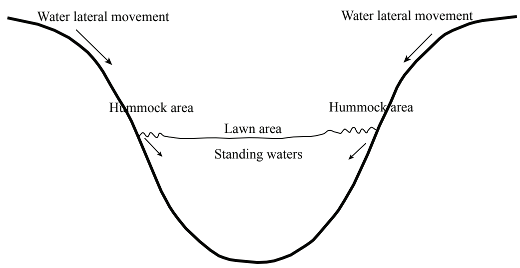


Figure 4. The profile of a basin bog.

*Kuva 4. Painannesuon profiili.*

Figure 5**.** Basin mire, located near Black Lagoon. Image from GEVA data base (Photo: Mauro Ponte).

*Kuva 5. Painannesuo Black Lagoonin lähellä (Kuva: Mauro Ponte).*

The TDS (Table 4) for this type of mire varies from 57 to 82 mg ml$^{-1}$ (the highest value was measured in the water sample collected in a hummock). For a comparison basis, Sketchell (2000) was used for a reference, where the value of 35 mg ml$^{-1}$ is given for sea water and 10 mg/l for rain water. This value proves the wealth of these habitats in nutritious terms.

The electrical conductivity values found in this kind of peat communities varied between 53.9 and 74.0 µs cm$^{-1}$, which are considerable larger than found e.g. in Canadian mires. In the study of Wind-Mulder et al. (1996) the conductivity values were between 30 and 97 µs cm$^{-1}$.

The pH (Table 4) varies between 4.5 (in hollows) and 5 (in pools). The medium pH obtained in the Azorean formation is 4.6, which is higher than the values mentioned by Wind-Mulder *et al.* (1996) for Canadian *Sphagnum* bogs, where it is around 3. However, studies of European mires by Frankard (1996), more concretely in Belgium, refers to pH values between 4 and 6.

In this basin type, the impermeable conditions are due to the formation of an iron-magnesium horizon, called placic and pomitic materials that in some cases dominate the geological substrate.

A very important aspect of this mire's characterisation is it's constitution of *Sphagnum* species. All of the species of *Sphagnum* genera inventoried in this study existed in the basin mires. This is the most diversified group of mires. The dominant species of the mentioned genera is *Sphagnum palustre* L., which was also found in all the other mire types. However, *Sphagnum cuspidatum* Ehrh. and the *Sphagnum squarrosum* Crome occur only in the basin mire formations.

## Transition and raised mires

### *Transition mires*

This type of mire is similar to the basin type, but develops in less pronounced endorreic valleys, producing a more intense lateral water movement. This supplies nutrients to the centre of the

Table 1. List of the plant species and their cover by community (dominant plant species) in the basin mires on Terceira Island in Azorean Archipelago. The cover is the average value of all sites (class scale of the Braun-Blanquet system). The species occurred in less than 20% of the inventoried mire areas are not presented.

*Taulukko 1. Kasvilajit ja niiden peittävyys inventoiduilla Azorien Terceira-saaren painannesoilla kasvillisuusluokittain, jotka on nimetty valtalajin mukaan. Lajien peittävyyden lukuarvot ovat keskimääräisiä luokkalukuarvoja viisiluokkaisessa Braun-Blanquet-järjestelmässä. Ne kasvilajit, joita esiintyy alle 20 % tutkituista soista on jätetty pois taulukosta.*

| Community<br>Plant species | *Eleocharis* | *Juncus* | *Sphagnum* | *Juniperus* | *Polytrichum* |
|---|---|---|---|---|---|
| *Sphagnum centrale* C. Jens | 2 | 3 | 1 | 4 | 4 |
| *Sphagnum palustre* L. | 4 | 3 | 1 | 2 | 2 |
| *Eleocharis multicaulis* (Sm.) Desv. | 4 | 1 | 2 | 2 | 1 |
| *Juncus effusus* L. | 2 | 4 | 2 | 1 | 1 |
| *Pteridium aquilinum* (L.) Kuhn | + | + | - | 2 | + |
| *Polytrichum commune* Hewd. | + | 2 | + | 1 | 4 |
| *Erica azorica* Hochst. | + | + | + | 2 | 1 |
| *Juniperus brevifolia* (Seub.) Antoine | + | + | - | 3 | + |
| *Calluna vulgaris* (L.) Hull | + | 1 | - | 1 | 1 |
| *Deschampsia foliosa* Hack. | + | 1 | - | 1 | 2 |
| *Holcus rigidus* Hochst. ex Seub | + | 2 | + | 1 | 1 |
| *Hydrocotyle vulgaris* L. | + | 1 | - | + | + |
| *Agrostis gracililaxa* Franco var. *gracililaxa* | + | + | - | + | 1 |
| *Blechnum spicant* (L.) Roth | + | + | - | + | + |
| *Campylopus setaceus* Card. cf. Frahm | + | + | - | + | + |
| *Leucobryum glaucum* (Hedw.) Angstr | + | + | - | + | + |
| *Luzula purpureo-splendens* Seub. | + | + | - | + | + |
| *Lysimachia azorica* Hornem. ex Hook. | + | + | - | + | + |

mire, creating a more accentuated and distributed microrelief (Fig. 6 and Fig. 7).

This mire type is also irregular in terms surface water depth. Due to its microrelief, it creates micro environments favourable to the development of a larger number of species. In relation to basin mires, this type is richer in shrubs and arboreal communities, namely dominated by *Calluna vulgaris* (L.) Hull, *Juniperus brevifolia, Erica azorica* and *Polytrichum commune*. The central area of the mire presents a less accentuated microrelief dominated by a pure *Sphagnum* community with mosaics of *Pteridium aquilinum* (L.) Kuhn and *Juncus effusus* communities.

The existence of placic and a geological substrate dominated by pomytic materials, are the reason for the low permeability of peat in transition mires.

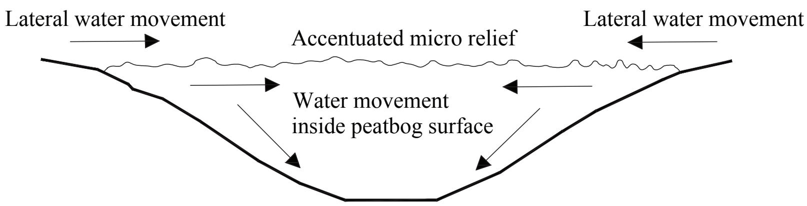


Figure 6. The profile of a transition mire.

*Kuva 6. Vaihettumasuon profiilikuva.*

Figure 7. Transition mire located in Rocha do Chambre. Image from GEVA data base (Photo: Cândida Mendes).

*Kuva 7. Vaihettumasuo lähellä Rocha do Chambrea.( Kuva: Candida Mendes.)*

*Raised mires*

Raised mire i.e. raised bog includes formations in a more advanced evolutionary state (Fig. 8 and Fig. 9). Due to the slope presented by raised mire, the ombrotrophic water that enters in the central highest part, moves to the margin of the formation, and promotes the existence of pools around them. The hummocks are less pronounced here than in transition type, occupying a smaller area.

The dominant species for pools of this type is *Eleocharis multicaulis* (Sm.) Desv. The margin hummocks are dominated by communities of *Polytrichum commune* Hewd., *Erica azorica* and *Juniperus brevifolia.* In the centre, pure *Sphagnum* carpet dominates, while in the hollows, the *Sphagnum* species, *Juncus effusus* and *Pteridium aquilinum* (L.) Kuhn occurs.

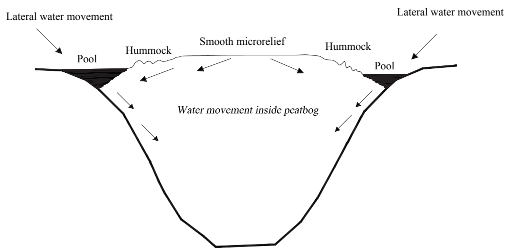


Figure 8. The profile of a raised mire.
*Kuva 8. Kohosuon profiilikuva.*

As for the floristic composition, both the transition and raised types are identical. There were 75 different species identified, with an average of 27 species for each bog unit. Twenty-four of these species presented a frequency superior to 20%, proving to be the largest covering index observed in Azorean bogs (Table 2).

The pH in transition and raised mire waters varied between 4.7 and 5.0 (Table. 4), similar to the values found in the basin type. The TDS average of this group was 60 mg ml$^{-1}$ (57–64 mg ml$^{-1}$). This was inferior to that verified in the basin mire, which can indicate a smaller water movement from its margins. The conductivity values found (between 43.6 and 60.8 µs/cm) on these two types are also inferior to those observed for basin mires.

In terms of *Sphagnum* species occurrence, the ones that dominate in transition and raised bog types are *Sphagnum palustre, Sphagnum centrale* C. Jens and *Sphagnum auriculatum* Schimp. This last mentioned species is related to the frequent existence of dystrophic pools.

Figure 9**.** Raised mire located in Pico da Bagacina. Image from GEVA data base (Photo: Cândida Mendes).
*Kuva 9. Kohosuo Pico da Bagacinan lähellä. (Kuva: Candida Mendes).*

Table 2. List of the plant species and their cover by community (dominant plant species) in the transition and raised mires on Terceira Island in Azorean Archipelago. The cover is the average value of all sites (class scale of the Braun-Blanquet system). The species occurred in less than 20% of the inventoried mire areas are not presented.

*Taulukko 2. Kasvilajit ja niiden peittävyys inventoiduilla Azorien Terceira-saaren vaihettuma- ja kohosoilla kasvillisuusluokittain, jotka on nimetty valtalajin mukaan. Lajien peittävyyden lukuarvot ovat keskimääräisiä luokkalukuarvoja viisiluokkaisessa Braun-Blanquet-järjestelmässä. Ne kasvilajit, joita esiintyy alle 20 % tutkituista soista on jätetty pois taulukosta.*

| Community<br>Plant species | *Juncus* | *Sphagnum* | *Polytrichum* | *Eleocharis* | *Calluna* | *Pteridium* | *Juniperus* | *Erica* |
|---|---|---|---|---|---|---|---|---|
| *Juncus effusus* L. | 4 | 2 | 1 | 2 | 1 | 2 | 1 | 1 |
| *Polytrichum commune* Hewd. | 1 | + | 4 | 1 | + | 2 | 1 | + |
| *Sphagnum palustre* L. | 3 | 2 | 4 | + | 3 | 3 | 3 | 4 |
| *Sphagnum centrale* C. Jens | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 3 |
| *Deschampsia foliosa* Hack. | 2 | 2 | + | + | 1 | 1 | 1 | + |
| *Holcus lanatus* (L.) Schrad | 2 | 2 | 1 | + | + | + | + | - |
| *Eleocharis multicaulis* (Sm.) Desv. | + | 2 | 1 | 3 | 1 | + | + | + |
| *Calluna vulgaris* (L.) Hull | + | 1 | + | + | 4 | + | 1 | + |
| *Juniperus brevifolia* (Seub.) Antoine | + | + | + | - | + | + | 3 | 2 |
| *Pteridium aquilinum (*L.) Kuhn | + | + | + | + | + | 4 | 1 | + |
| *Holcus rigidus* Hochst. ex Seub | 1 | 1 | 1 | + | + | 2 | + | + |
| *Erica azorica* Hochst. | + | + | + | - | + | + | + | 4 |
| *Potamogeton polygonifolius* Pourr. | - | - | - | 2 | - | - | - | - |
| *Blechnum spicant* (L.) Roth | + | + | + | + | + | + | + | + |
| *Hymenophyllum spp.* | - | + | - | + | - | + | - | - |
| *Luzula purpureo-splendens* Seub. | + | + | + | + | - | + | + | + |
| *Lysimachia azorica* Hornem. ex Hook. | + | + | + | + | + | + | + | + |
| *Potentilla anglica* Laich. | + | + | + | + | + | + | + | + |
| *Pseudoscloropodium purum* (Hedw.). | + | + | + | + | + | + | - | + |
| *Rubus inermis* Pourr. | + | + | + | + | + | + | + | + |
| *Scutellaria minor* Huds. | + | + | + | + | + | + | + | + |
| *Sibthorpia europaea* L. | + | + | - | - | + | + | + | + |
| *Thuidium tamariscinum* (Hedw.) Br. Eur. | + | + | + | + | + | + | + | + |
| *Cladonia portentosa* (Dufour). Coem | + | - | - | - | + | + | + | - |

## Hillside and blanket mires

### *Hillside mires*

This type may have several origins. It can develop from overflowing basin mire or in high places, where is a sufficient water supply to the area. Because of the slope, water retention here is difficult, and the water supply must be great for this type of mire to exist and develop.

In general this bog can be characterized by a high floristic diversity, an accentuated microrelief and an irregular water system.

### *Hillside mires resulting from high precipitation*

These mires are restricted to places, where the high precipitation levels alone enables their existence. Water entering the system (Fig. 10 and Fig. 11), is originally ombrotrophic, but it becomes rich in minerals when flowing downhill the slope.

The hummocks of margin communities of the mire are dominated by communities of *Polytrichum commune*. The small hummocks in the interior of the bog are occupied by *Sphagnum palustre* and *Juncus effusus* and in their hollows, *Sphagnum* communities are prevalent. In these mires, there are also pools, where water ponders

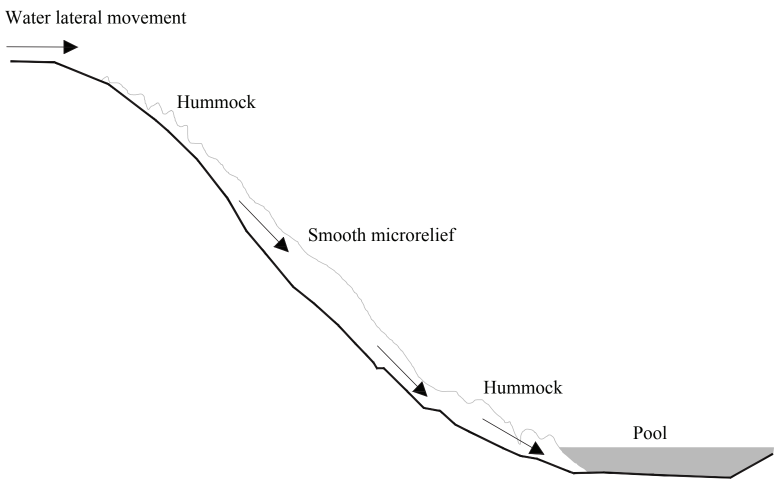


Figure 10. The profile of a hillside mire.

*Kuva 10. Rinnesuon profiilikuva.*

Figure 11. A hillside mire located in Pico do Alpanaque. Image from GEVA data base (Photo: Cândida Mendes).

*Kuva 11. Rinnesuo Pico do Alpanaquen lähellä. (Kuva: Candida Mendes).*

and they are dominated by the *Eleocharis multicaulis* (Sm.) Desv.

In the studied hillside *Sphagnum* mires, some of these resulted from the succession of a basin mire that overflowed to one of the hillsides that involve it. In these cases waters reaching the hillside mire are quite acid and poor in nutrients (water from the basin formation).The movement of the water in these habitats (Fig. 12 and Fig. 13) provokes a gradual oxygenation, increasing the decomposition, with a consequent increment of nutrients and plant cover. Just as observed in the other type of hillside mire, the dominant species and communities are obviously *Sphagnum* species, *Juncus effusus* and *Pteridium aquilinum* (L.) Kuhn.

### *Hillside mire resulting from thermal water*

In Terceira Island, three hillside thermal bogs were found. They are close to the Furnas do Enxofre (rare habitat of fumaroles with emissions of sulphur compounds), at an altitude of around 500 m. In this area, precipitation is not the only factor affecting the occurrence of the bog, but also the nature of water flowing into the bog. The hypothesis for the existence of these habitats is that this water has thermal characteristics. In one of

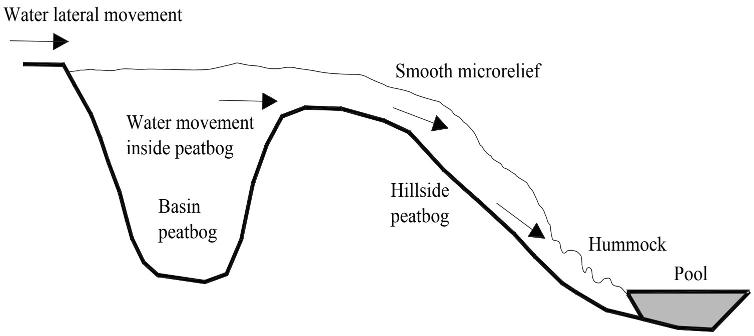


Figure 12**.** The profile of a hillside mire originated from a basin mire)**.**

*Kuva 12 Painannesuosta kehittyneen rinnesuon profiilikuva.*

Figure 13. A hillside mire originated from a basin mire located in Pico da Criação de Filipe Image from GEVA data base (Photo: Dinis Pereira).

*Kuva 13. Painannesuosta kehittynyt rinnesuo Pico da Criação de Filipessä. (Kuva. Dinis Pereira).*

these bogs, the *Sphagnum* species dominates the community over the other species, such as *Erica azorica* and the *Juniperus brevifolia*, otherwise typical to the hillside mires and this is probably resulted from fact that the mire is impacted by the poisonous gases emitted from the fumaroles restricting the occurrence of vascular plant species. The other two bogs are located at an inferior level of the Furnas do Enxofre. We suggest that these bogs are fed by underground water channels. At a certain depth, the permeable soil has an impermeable layer where water accumulates and moves down until reaching these mires.

*Blanket mires*

Blanket mires develop on both hillsides of the mountain peaks (Fig. 14 and Fig. 15).

These are characterized by an accentuated microrelief, essentially at the margins where the water reaches rich in nutrients, and where oxygenation and decomposition reach the maximum values inside of the mire. Due to the slope of the mire, water moves downhill and the formation of pools can be observed. The hummock areas are dominated by *Polytrichum commune* communities. At the centre only *Sphagnum* spp. and *Juncus effusus* communities appear.

The pH of the water collected in this type of mire had an average of 4.4. The value of TDS is 73.7 mg ml$^{-1}$ average (59–84 mg ml$^{-1}$). It is higher than all other types, because there are conditions that favour mineralization. The average electrical conductivity of mire water was 68.6 µs cm$^{-1}$ (52 µs cm$^{-1}$ in the lagoon and 74.7 µs cm$^{-1}$in the pools).

The impermeable characteristics of these bogs are also due to the presence of the placic horizon. The nature of the substrate is predominantly dominated by pomitic materials.

In the hillside and blanket bogs, 64 different species were identified. On the average, each bog had 21 species and 24 species had frequency larger than 20% (Table 3), and the most fertile sites were dominated by *Sphagnum* and *Pteridium* communities. The following *Sphagnum* species were typical for this mires: *Sphagnum palustre, Sphagnum auriculatum, Sphagnum subnitens* Russ. & Warnst. ssp. *subnitens* and *Sphagnum papillosum* H. Lindb.

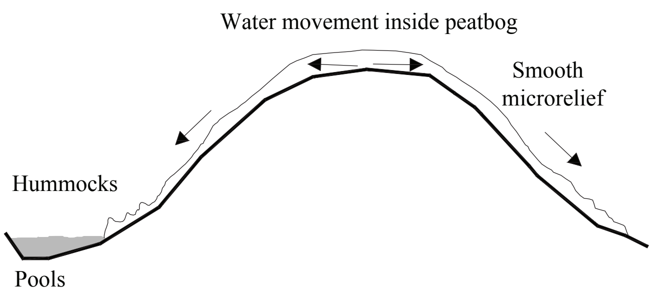


Figure 14. The profile of a blanket mire.
*Kuva 14. Peittosuon profiilikuva.*

Figure 15. A blanket mire located in Mistérios Negros. Image from GEVA data base (Photo: Cândida Mendes).
*Kuva 15. Peittosuo Mistérios Negroksella. (Kuva: Candida Mendes).*

Table 3. List of the plant species and their cover by community (dominant plant species) in the hillside and blanket mires on Terceira Island in Azorean Archipelago. The cover is the average value of all sites (class scale of the Braun-Blanquet system). The species occurred in less than 20% of the inventoried mire areas are not presented.

*Taulukko 3. Kasvilajit ja niiden peittävyys inventoiduilla Azorien Terceira-saaren rinne- ja peittosoilla kasvillisuus-luokittain, jotka on nimetty valtalajin mukaan. Lajien peittävyyden lukuarvot ovat keskimääräisiä luokkalukuarvoja viisiluokkaisessa Braun-Blanquet-järjestelmässä. Ne kasvilajit, joita esiintyy alle 20 % tutkituista soista on jätetty pois taulukosta.*

| Community<br>Plant species | *Juncus* | *Sphagnum* | *Eleocharis* | *Polytrichum* | *Pteridium* |
|---|---|---|---|---|---|
| *Juncus effusus* L. | 4 | 1 | 2 | 1 | 1 |
| *Polytrichum commune* Hewd. | 1 | 1 | + | 4 | + |
| *Pteridium aquilinum (*L.) Kuhn | + | 1 | + | 1 | 4 |
| *Sphagnum centrale* C. Jens | 3 | 3 | 1 | 4 | 4 |
| *Sphagnum palustre* L. | 2 | 2 | + | 3 | 2 |
| *Calluna vulgaris* (L.) Hull | + | 1 | 1 | + | + |
| *Deschampsia foliosa* Hack. | 2 | 2 | + | + | 2 |
| *Eleocharis multicaulis* (Sm.) Desv. | 1 | 2 | 3 | + | + |
| *Holcus lanatus* (L.) Schrad | 2 | 1 | + | 1 | 1 |
| *Holcus rigidus* Hochst. ex Seub | 1 | 1 | + | 2 | 2 |
| *Erica azorica* Hochst. | + | 1 | + | - | + |
| *Rubus inermis* Pourr. | + | 1 | - | - | + |
| *Blechnum spicant* (L.) Roth | + | + | + | + | + |
| *Cladonia portentosa* (Dufour). Coem | + | + | - | + | + |
| *Duchesnea indica* (Andr.) Focke | + | + | - | - | + |
| *Leucobryum glaucum* (Hedw.) Angstr | + | + | + | + | + |
| *Lotus uliginosus* Schkuhr | + | + | + | + | + |
| *Luzula purpureo-splendens* Seub. | + | + | + | + | + |
| *Lysimachia azorica* Hornem. ex Hook. | + | + | + | + | + |
| *Potentilla anglica* Laich. | + | + | + | + | + |
| *Pseudoscloropodium purum* (Hedw.) Fleisch. | + | + | + | + | + |
| *Scutellaria minor* Huds. | + | + | + | - | + |
| *Sibthorpia europaea* L. | + | + | + | + | + |
| *Thuidium tamariscinum* (Hedw.) Br. Eur. | + | + | - | + | + |

# Conclusions

In this study, the Azorean mires were explored and classified by utilising field mapping, a GIS data base, and the introduction of a new integrated system for the classification of these habitats. As a result, three major groups of mires, corresponding to five different types i.e. basin, transition, raised, hillside and blanket mires could be identified.

The analyses demonstrated that the geomorphologic, hydrological and floristic parameters demonstrated to be the most important factors controlling the establishment of the mire types. The geomorphology of the area was a very important parameter for the classification being the location of the mire and its slope the starting for classification, which was supported by this study.

The knowledge of the hydrological characteristics of the Azorean mires has been very rudimentary. In this study we found, that at an altitude of around 650 m rain water (ombrotrophic) can be a decisive element for the mire development. In terms of the flora, the difference between the mire (bog) types is essentially marked by the *Sphagnum* species.

One problem of this study was that the selected chemical parameters might not have been the most appropriate. The observed differences between the mire types were very small. For example, the pH values varied more with given environmental conditions than with the mire type. The relatively high total values for the dissolved

Table 4. Physical-chemical characteristics (average values of 224 analysis) of water sample analysis from 58 mires on Terceira Island according to the type and the microsite (pool, hollow, hummock or lawn and lagoon) where the water samples were collected.

*Taulukko 4. Suoveden fysikaalis-kemiallisia tunnuksia perustuen 58 suolta Terceira-saarelta kerättyihin vesinäytteisiin. Analyysitulokset on esitetty suotyyppiryhmittäin ja suon pinnan pienmuotojen (allikko, painannepinta, mätäs, tasapinta ja kulju) sisällä.*

| Type | pH | Cond.(µs/cm) | TDS (mg/ml) | Water Depth (cm) | Microsite |
|---|---|---|---|---|---|
| Basin mire | 5.0 | 59.6 | 65 | 10 | |
| Transition and Raised mire | 4.9 | 58.3 | 64 | 10 | Pool |
| Hillside and Blanket mire | 4.6 | 74.7 | 84 | 10 | |
| Basin mire | 4.5 | 53.9 | 57 | –6 | |
| Transition and Raised mire | 4.7 | 55.4 | 61 | –23 | Hollow |
| Hillside and Blanket mire | 4.4 | 73.5 | 77 | –13 | |
| Basin mire | 4.6 | 74.0 | 82 | –9 | |
| Transition and Raised mire | 4.7 | 60.8 | 63 | –25 | Hummock |
| Hillside and Blanket mire | 4.3 | 70.5 | 76 | –8 | |
| Basin mire | 4.8 | 65.1 | 69 | –4 | |
| Transition and Raised mire | 4.7 | 50.4 | 57 | –1 | Lawn |
| Hillside and Blanket mire | 4.3 | 72.4 | 76 | –8 | |
| Basin mire | - | - | - | - | |
| Transition and Raised mire | 5.0 | 43.6 | 57 | 10 | Lagoon |
| Hillside and Blanket mire | 4.6 | 52.0 | 59 | 10 | |

solids and conductivity, mainly in the hillsides and blanket types, were inversely related with degree of naturalness of the mire.

Assuming that mires are an important habitat, even if just seen at a regional scale, this study can represent a starting point for the understanding of these complex habitats in Azorean archipelago. The knowledge obtained in this study can be utilised in taking measures for conservation and restoration of these rare habitats. According to this study material, about 70% of the mires in Terceira Island had signs of human impacts. More information is still needed on e.g. the nature, amounts and movements of the water entering the mires, and how is the water interception capacity of the plant communities on the mires.

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**Tiivistelmä: Azorien rahkasuot – esimerkkinä Terceira-saaren suot**

Tutkimuksessa inventoitiin ja luokitettiin Azorien saaristoon kuuluvan Terceira-saaren suot, niiden kasvillisuus sekä analysoitiin niiden geologisia ja ekohydrologisia tunnuksia yhdistämällä erilaisia menetelmiä. Saarelta löydettiin yhteensä 300 suoaluetta, joista 58 suota valittiin tarkempaan tutkimukseen. Näiltä soilta inventoitiin erilaisia geomorfologisia ja vesikemiallisia tunnuksia ja kasvillisuutta vuosina 1997–2004. Aineiston käsittelyssä ja soiden luokituksen pohjana hyödynnettiin oordinaatioanalyysimenetelmää (CA). Tulosten perusteella voitiin erottaa kolme suotyyppiryhmää, jotka kuvaavat hyvin Azorien soita. Nämä ryhmät olivat painannesuot (basin mires), vaihettuma- ja kohosuot (Transition and raised mires) sekä rinne- ja peittosuot (Hillside and blanket mires). Rinnesuot jakautuvat edelleen neljään alatyyppiin. Suotyyppiryhmille ominaiset muotoprofiilit esitetään kuvina sekä niiltä inventoitu kasvilajisto selostetaan yksityiskohtaisesti taulukoissa.

Asiasanat: Azorit, *Sphagnum*, suotyyppi, suo, suokasvillisuus

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