Vegetation-related hydrotopographic and hydrologic classification for aapa mires (Hirvisuo, Finland)

Jarmo Laitinen\(^1\), Sakari Rehell\(^2\) & Antti Huttunen\(^3\)

\(^1\) Department of Biology, Botany, P.O. Box 3000, FI-90014 University of Oulu, Finland
\(^2\) Metsähallitus, Natural Heritage Services Ostrobothnia-Kainuu, Veteraanikatu 5, FI-90101 Oulu, Finland
\(^3\) Oulanka Research Station, Liikasenvaarantie 134, FI-93999 Kuusamo, Finland

Received 17 June 2004, revised version received 10 Dec. 2004, accepted 4 Mar. 2005


We used a case study (Hirvisuo mire complex, southern aapa mire zone, Finland) to describe a new morphological classification for aapa mires and used as a basis the broad, vegetation-based ecological aapa-mire concept. It deviates from the narrow morphological aapa-mire concept referring solely to patterned fens. Three scales (micro, meso and macro) were applied for the morphology. The important meso scale included eight different units. Units were delineated on aerial photographs. Macro scale included the whole complex and its bisection to central and peripheral aapa-mire areas according to the horizontal water flow pattern within the whole complex. Stability of water regime was mainly inferred from vegetation on the basis of previous literature about the ecology of mire site types and other vegetation units described in Finland and Sweden. Groundwater recharge-discharge pattern was also mainly inferred from mire vegetation supported by previous, sporadic groundwater level measurements in the mineral soil formation south of the study area. For the importance of understanding the whole geo-hydro-ecologic system as a unit, the landscape level is stressed.

Key words: boreal, groundwater, \textit{Hamatocaulis lapponicus}, hydromorphology, landscape ecology, mire site type, mire vegetation, patterned fen, peatland, seasonal drought, vegetation ecology

Introduction

Aapa mire is the most important mire complex type (Cajander 1913, Ruuhijärvi 1960, 1983) in northernmost Europe and occurs also in northern America. In spite of this the concept has not been understood uniformly. In fact there are nowadays two different concepts of aapa mire, a morphological and a vegetation-based ecological concept. According to the morphological aapa mire concept aapa mires are about the same as patterned fens or northern ribbed fens (e.g. Vitt \textit{et al.} 1975). Patterned fens are fens in which narrow, drier strings and larger, wet flarks follow each other. This narrow morphological aapa mire concept was originally outlined by Cajander (1913) in Finland and it was followed especially by several Canadian authors (see Pakarinen 2001). The broad, vegetation-based ecological aapa mire concept, which was originally created by
Ruuhijärvi (1960) on the basis of comprehensive regional studies in Finland, was further developed by Eurola and Kaakinen (1979) and Eurola et al. (1995) in accordance with the general Fennoscandian vegetation-ecological concepts originally created by Sjörs (1948) in Sweden. Eurola and Kaakinen (1979) also delineated the “ecological boundaries” of the aapa mire complex type towards other zonal mire complex types: aapa mires and raised bogs, which are the zonal mire complex types of boreal regions, carry mire expanse vegetation in their central parts, while (more northern) arctic mires, alpine mires (in mountains) and the (more southern) limnogenic complex type (swamp, marsh or carr types) carry mire margin vegetation. According to the broad concept aapa mires thus carry minerotrophic mire expanse vegetation in their central parts, regardless of morphology: it is a question of patterned fens or of lawn fens without any or without a clear patterning. Individual aapa mire complexes, especially in the southern aapa mire zone (Ruuhijärvi 1983, Ruuhijärvi & Hosiaisluoma 1988) include often both the patterned fens (‘flark aapa mires’) and fen lawns (‘lawn aapa mires’) and additionally small bogs (cf. concept ‘combination complex of aapa mires and raised bogs’; Tolonen 1967). There is an evident need for a new aapa mire classification that takes into consideration the broad, vegetation-based ecological aapa mire concept and the morphology of this whole “large aapa mire”.

Morphological features of mire complexes are visible on aerial photographs as elements of very various sizes. These elements are relative to water level and hence terms hydromor-
phology (Moen 1985, 1990, Økland 1989) and hydrotopography (Sjörs 1948, Malmer 1985) have also been used. Sjörs (1948) uses the concept hydrotopography relative to the whole mire complex. Malmer (1985) uses the term microtopography for hummocks, hollows, flarks and strings and macrotopography for the whole mire complex. In aapa mires the research has mainly concentrated on microporphographic features and their development (e.g. Foster & King 1984, Seppälä & Koutaniemi 1985, Foster & Fritz 1987) but the macrotopography and its relation to spatial vegetation patterns are less studied (Seppä 1996). In the coastal half of the southern aapa mire zone in Finland, where peatlands cover over 50 per cent of the total land area and the peatlands form almost a uniform network, single mire complexes may be difficult to delineate from each other (cf. R. Heikkilä et al. 2001). Instead, certain very clearly identifiable major hydrotopographic features occur repeatedly throughout the mire network. The large Hirvisuo mire complex provides a case study for classifying the hydrotopography of the mire network of the southern aapa mire zone. It has features typical of aapa mires of all the regional aapa mire subzones of Ruuhijärvi (1960, 1983).

Hydrology and especially the relation of hydrology to vegetation are even less studied than the morphology of aapa mires. The pattern of horizontal mire water flow that is a hydrologic pattern related to hydrotopography, is crucial for broad scale spatial vegetation patterns (e.g. ombrotrophy vs. minerotrophy). Only the main features of it have been described for aapa mires because of the lack of detailed hydrotopographic classification. Stability of water regime is a relevant environmental factor for mire vegetation as suggested by Havas (1961), Reinikainen et al. (1984) and Heikkilä and Lindholm (1988). However, the problem has been treated very little for flat aapa mires (e.g. Ruuhijärvi 1960) and spatial presentations are lacking. The same concerns the groundwater recharge-discharge pattern in aapa mires. The aim of this study is (i) to suggest a practical hydrotopographic classification (typology) for aapa mires and (ii) to relate the hydrotopographic pattern of the Hirvisuo case study to vegetation, mire water flow, the stability of the water regime and to groundwater recharge-discharge conditions.

Material and methods

The study area

Hirvisuo is an extensive mire complex in the lowlands (about 120 m a.s.l.) bordering on the Gulf of Bothnia in northern-central Finland (Fig. 1) (Laitinen 1984). The mean annual temperature is 1–2 °C, and the annual range of monthly mean temperatures 26–27 °C. Snow depth in March is 50–60 cm, the permanent snow cover
appears on 15–25 November and disappears from open ground by 5 May (Alalammi 1987). The climate is humid: annual precipitation is 600 mm, annual evapotranspiration 250–300 mm and annual runoff 300–350 mm (Karlsson 1986). The difference between precipitation and evaporation (in cultivated areas) from the disappearance of snow to the end of July is about 0 mm (Alalammi 1987), indicating moderate dryness of the climate during that period. The area belongs to the middle-boreal zone (Hämet-Ahti 1981).

The bedrock consists of granitic veins in basement gneiss (Simonen 1987). Ice retreated slightly over 10 000 years ago (Raitio & Johansson 2004). The lowland area by the Gulf of Bothnia was deeply submerged during the Holocene in the Baltic Sea. Rapid isostatic uplift gave rise to a series of ancient sandy shorelines at levelled glaciofluvial eskers (Aario & Forström 1979). The largest aapa-mire complexes and the most uniform peatland network are situated in the more elevated, plain-like part of the coastal lowland. Hirvisuo is located in the western part of this area.

A glacial cover moraine with some drumlins dominates the landscape. The southern part of the studied aapa mire, however, lies on a sandy terrace combined with the glaciofluvial formation south of the study area. Peat thickness is small in this area (Fig. 2). The age of the bottom peat in the deeper parts is 7600 C-14 years (Hänninen 1988). The area is nearly in an undisturbed state, but there are some traces of previous forestry. Large areas outside the study area are drained by several deep ditches. The growth of pines near the road has increased.
edaphic grounds were made: (1) poor *Sphagnum compactum* fens and mesotrophic *Sphagnum compactum* fens were treated as separate mire site types which were unrelated to corresponding *Sphagnum papillosum* fens, (2) short-sedge pine fens dominated by *Sphagnum compactum* were differentiated from other short-sedge pine fens, (3) along with thin-peated pine forests typical for this region (Ruuhiärv 1960: *Anmotorige Heidewälder*), an edaphic type, heath-like ‘thin-peated, semi-open *Calluna* pine mires’ was differentiated. These specifications were evident and easily detectable on physiognomic grounds by the dominating species. ‘Poor *Sphagnum papillosum* fens with small flarks’ refer to Rimpiar*-tige Sphagnum balticum Weissmoore* (Ruuhiärv 1960).

The Finnish hydroecologic concept of three aspects (Ruuhiärv 1960, Eurola 1962, Ruuhiärv 1983, Eurola et al. 1984, 1995) in mire margin vegetation was applied. (1) Groundwater influence (*Quelligkeit* by Ruuhiärv 1960) is a mire vegetation pattern distinguished by strong and continuous flow of water derived from mineral soil. It appears in vegetation as the occurrence of spring species, species of spring fens, certain species of meso-eutrophic fens or species of certain rich fens of mire margin character. (2) Surface water influence (*Sumpfigkeit* by Ruuhiärv 1960) is defined by us in terms of hydrology as a mire vegetation pattern distinguished by strong, horizontal and quite continuous flow of water. Its effect on vegetation is shown by the occurrence of littoral species (see Eurola et al. 1984). (3) Mineral soil influence as indicated by hummock level spruce mire vegetation (*Bruchmoorigkeit* by Ruuhiärv 1960), is quite clearly differentiated by the vegetation (Ruuhiärv 1960, Eurola 1962, but see Kutnar & Martinčič 2003) and by the magnitude of tree stands (Heikurainen 1953), but the hydrological causes are not as clear as for the two former aspects of mire margin vegetation.

### Hydrotopographic and hydrologic patterns and classification

Hydrotopographic pattern is a pattern that is clearly visible in aerial photographs, arising from spatial differences in water level relative to certain elements of the mire surface. Some Fennoscandian hydrotopographic (hydromorphological) typologies are related to the present typology for aapa mires (Table 1). The term ‘patterned’ refers to a mire with a ribbed or reticulate (network) pattern, but not to a pattern with just hummocks. ‘Unpatterned’ refers to bogs or fens with hummocks or no pattern.

Hydrologic patterns discussed here are patterns concerning water movement in mires and in mineral soil beneath the peat and in the surroundings of the mire complexes (Fig. 3). The stability of water regime also belongs to these. We define the central–peripheral pattern of aapa mires as a hydrotopographic and hydrologic macro-scale

### Table 1. Hydrotopographic typology for aapa mires in relation to some other Fennoscandian typologies.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Microtopographic features</td>
<td>Flarks, strings, hummocks, etc.</td>
<td><em>Kleintarmen</em></td>
<td><em>Mire elements</em></td>
<td><em>Mire features</em></td>
</tr>
<tr>
<td>Mesotopographic mire units</td>
<td>Medium-sized hydromorphological entities in mire complexes that are clearly identifiable on aerial photographs</td>
<td><em>Formenteile</em></td>
<td><em>Mire units</em></td>
<td><em>Mire segments</em></td>
</tr>
<tr>
<td>Macrotopographic pattern</td>
<td>Aapa mire complex and its bisection to central aapa mire areas and to peripheral aapa mire areas</td>
<td><em>Grosformen</em></td>
<td><em>Mire complexes</em></td>
<td><em>Mire synsegments, mire complexes</em></td>
</tr>
</tbody>
</table>
pattern: peripheral aapa mire areas are areas in which mire water flows towards central aapa mire, while central aapa mire areas are areas that receive water from the periphery of the complex, and transport the water out of the mire complex. Within the stability pattern of water regime, areas with unstable water regime are characterised by variation between pronounced seasonal drought and wet conditions. The seasonal drought (Havas 1961, Heikkilä & Lindholm 1988), complete drying-out of the mire surface during dry periods, is the most important characteristic. Flood, on the other hand, may occur. In areas with stable water regime, the dried-out state is neither so frequent nor so evident. Flood may occur or not. We use here the concept “groundwater” in a narrow sense to refer to subsurface water in completely saturated mineral soil and to water that flows from mineral soil onto the ground (peatland or mineral soil) surface (cf. Freeze & Cherry 1979).

Aapa mire

We adopt the broad vegetation-based aapa mire concept of Ruuhijärvi (1960, 1983) and Eurola et al. (1984, 1995) and define aapa mires as a mire complex type with minerotrophic mire expanse vegetation in the central parts. A weak tendency towards surface water influence (Sumpfigkeit) and, even less frequently, towards a groundwater influence (Quelligkeit) may be present in the central parts. Sloping fens (slope mires) of the same character belong to aapa mires (Ruuhijärvi 1960, Havas 1961, Eurola et al. 1984, 1995). As such the definition makes a valid difference from raised bogs (mire complex type with ombrotrophic mire expanse vegetation in the central parts).

Methods of investigation

Mapping of vegetation and hydrotopography, delineating the stability pattern of water regime

The vegetation pattern was delineated on black and white aerial photographs (1:10 000), and the dominating mire site types (Eurola et al. 1984) for each pattern were determined in the field. Mesotopographic mire units within a hydrotopographic pattern were delineated on 1:20 000 colour air photographs as the pattern of horizontal mire water flow. The division of the mire complex into mire areas with stable and unstable water regime was based primarily on vegetation mapping and literature: both the Finnish and Swedish literature describe the considerable temporal variation in moisture conditions of certain communities (Trichophorum cespitosum–Sphagnum compactum fens, oligotrophic mud bottom flark fens dominated by Eriophorum angustifolium) (Ruuhijärvi 1960, Havas 1961, Fransson...
1976, Paasovaara 1986, Heikkilä & Lindholm 1988). This was the basis for the interpretation of stable vs. unstable conditions in different parts of the mire complex. In addition, ocular observations of the floods and seasonal drought were made to evaluate the position of other mire site types. Ocular evaluation was made at different times in the snow-free period in 1984 and 1985, most intensively in the southern part of the study area, at the extremely to moderately thin-peated sand flat. Occasional ocular observations were made during 18 years up to 2003.

Delineating the groundwater recharge-discharge pattern

The groundwater recharge-discharge pattern in the southern part of the study area was compiled mainly on the basis of the vegetation and prevailing direction of groundwater flow in the glaciofluvial formation south of the Hirvisuo mire complex. The topography of the bottom of the mire basin was also taken into consideration. The determination of the gradient of the groundwater table (the direction of groundwater flow) was based on groundwater level measurements at several points of the glaciofluvial formation (Miettunen 1994): the gradient of the groundwater table showed that the direction of the groundwater flow was from the glaciofluvial formation toward the Hirvisuo mire complex. The topography of the bottom of the mire basin was estimated with the help of a peat thickness map (Hänninen 1988).

The interpretation of the occasional infiltration of water from very shallow peat (about 20 cm) into permeable, sandy mineral soil (groundwater recharge) was made on the basis of the occurrence of a seasonal shallow water layer on the surface and the relatively rapid disappearance of this layer followed by severe drought in the surface during dry seasons. This phenomenon was concentrated on flat, thin-peated areas with permeable sand bottom, not on areas with a corresponding shallow peat layer on (less permeable) till substratum. Evaporation evidently causes at least a small part of the water loss from the surface.

The groundwater discharge area in the mire was determined on floristic grounds by the occurrence of species and sites indicative of groundwater influence or otherwise more moving water (surface water influence) and higher trophy status (mesotrophy, meso-eutrophy and eutrophy by Eurola et al. 1984) in comparison with the surroundings.

Results

Hydrotopographic classification

Characteristics of the mesotopographic mire units described for the Hirvisuo mire complex and for aapa mires in general are shown in Table 2. Additional features, which cannot be directly interpreted from the air photos (e.g. ombrotrophy and minerotrophy) are listed below.

1. Areas transitional to mineral soil. Peripheral aapa mire areas. Minerotrophic. Thin-peated forests, etc., around mineral soil. Merge without any boundary to peripheral lobes.
2. Interlobate soaks. Peripheral aapa mire areas. Minerotrophic. Long, narrow, moister areas between peripheral lobes. The longitudinal axis coincides with the direction of horizontal mire water flow. Soaks of Sjörs (1948).
3. Peripheral lobes. Occupy the largest part of the peripheral aapa mire areas. Minerotrophic to ombrotrophic. Broad, drier areas between soaks, adjacent to areas transitional to mineral soil.
4. Concentric/eccentric bogs. Peripheral aapa-mire areas. Ombrotrophic. Patterned bogs with a definite pattern of hummock surfaces (Kermis) and hollows (Schlenken). The boundaries of the unit seem clear-cut in air photographs. Corresponds to the central area (Hochfläche) and the marginal slope (Randgehänge) of the raised bogs of southern Finland (Eurola 1962), although the marginal slope is in practice almost entirely absent.
5. Reticulate-patterned mires. (Central)-peripheral aapa mire areas. Ombro-minerotrophic. Definite reticulate pattern with elevated Sphagnum fuscum strings and mainly mud-bottom hollows or flarks.
6. Central reservoir basins. Central aapa-mire


8. Parallel-patterned fens. Occupy the largest area of all in the central aapa-mire areas. Minerotrophic. Wet flark-string patterns. Strings (Stränge) are lawn strings or Sphagnum fuscum strings (string mixed mires; Moen 1985, 1999). Flarks (Rimpis) are largely poor in mosses.

The mesotopographic pattern (Fig. 4) reflected loosely the mire site type pattern (Table 3). The macrotopographic peripheral-central pattern (Fig. 5) did not reflect the vegetational mire margin–mire expanse pattern: peripheral aapa-mire areas carried mainly mire expanse vegetation similarly to central aapa-mire areas. The vegetation of soaks represented also principally the mire expanse vegetation. Particularly the vegetation of peripheral lobes was of the mire expanse character, with the exception of Carex globularis pine mires at the proximity of areas transitional to mineral soil. Within the treeless central and outer parts of the lobes, the vegetation ranged from evident minerotrophy (tall sedge fens) to ombrotrophy (Empetrum–Sphagnum fuscum bogs).

The pattern of horizontal mire water flow (Fig. 5) was closely related to the structure of the whole mire complex and to its meso- and microtopographic patterns (Fig. 4 and Table 2). Interlobate soaks often began from islands of mineral soil within water divides. In these soaks the flow pattern was convergent: they appeared to gather water from the neighbouring peripheral lobes before merging into central aapa-mire areas. The flow pattern in the mainly slightly minerotrophic peripheral lobes was similar to that seen in eccentric bogs. Central aapa-mire areas (Table 2) served as intermediary water reservoirs or as

| Table 2. Central characteristics of mesotopographic mire units described for Hirvisuo mire complex and for aapa mires in general. |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Mesotopographic mire units | Water level, surface texture | Microtopography | Pattern of horizontal mire water flow |
|                          |                          | Unpatterned | Patterned |                          |                          |                          |                          |
| 1. Areas transitional to mineral soil | Mineral + hummock Carpet Lawn + hummock | X | Parallel |                          |                          |                          |                          |
| 2. Interlobate soaks | Carpet Lawn + hummock | X (X) | Convergent | Flow from watersheds to central aapa mire areas |                          |                          |                          |
| 3. Peripheral lobes | Hummock + lawn + carpet + mud bottom Hummock + mud bottom | X | Divergent |                          |                          |                          |                          |
| 4. Concentric/ eccentric bogs | Hummock + mud bottom | X | Divergent |                          |                          |                          |                          |
| 5. Reticulate-patterned mires | Hummock + mud bottom | X | Divergent |                          |                          |                          |                          |
| 6. Central reservoir basins | Hummock + mud bottom | X | Divergent | Flow from peripheral aapa mire areas and out of the complex |                          |                          |                          |
| 7. Reservoir-infiltration basins | Hummock + mud bottom | X | Convergent |                          |                          |                          |                          |
| 8. Parallel-patterned fens | Lawn + mud bottom | X | Parallel |                          |                          |                          |                          |
Fig. 4. Mesotopographic pattern of the study area. The distribution of mesotopographic mire units (Table 2) within the study area is shown by different shadings as indicated in the key. The boundary of the mire protection area is indicated by a dashed line. Streams and the road are shown as in Figs. 1 and 2. Ditches are shown as straight lines connecting with the stream system.

Fig. 5. Macrotopographic pattern and the pattern of horizontal mire water flow in the study area.
Table 3. Mire site types in relation to hydrologic and hydrotopographic patterns in the study area. Typology and nomenclature of mire site types mainly according to Eurola et al. (1984) with the exception of site types 1–4 (cf. Ruuhijärvi 1983).

<table>
<thead>
<tr>
<th>Mire site types*</th>
<th>Stability of water regime</th>
<th>Ground water recharge and surface layer flow</th>
<th>Macrotopographic pattern and mesotopographic mire units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unstable</td>
<td>Stable</td>
<td>Weak</td>
</tr>
<tr>
<td>1. Thin-peated, semi-open Calluna pine mires KgR (M)EH</td>
<td>x x (x)</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>2. Short-sedge pine fens dom. by Sph. compactum LkNR ELHCom</td>
<td>x x x</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>3. Poor Sphagnum compactum fens OIkAN EL</td>
<td>x x x</td>
<td>M D</td>
<td></td>
</tr>
<tr>
<td>4. Mesotrophic Sphagnum compactum fens MeKaN EL</td>
<td>x x x</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>5. Poor mud bottom flark fens OIrRuRIN EMu</td>
<td>x x x</td>
<td>M A A A</td>
<td></td>
</tr>
<tr>
<td>6. Mesotrophic Drepanocladus flark fens MeDrepRiN (M)EC</td>
<td>x x x</td>
<td>D D M</td>
<td></td>
</tr>
<tr>
<td>7. Swampy sedge fens LuN MEL/C</td>
<td>x (x)</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>8. True tall-sedge fens OiSN (M)EL/C</td>
<td>x (x) x</td>
<td>M D</td>
<td></td>
</tr>
<tr>
<td>9. True tall-sedge fens OiSK (M)E(H)L/CCom</td>
<td>x x</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>10. True tall-sedge fens LuNK ME(H)CCom</td>
<td>x x</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>11. Herb and grass birch–spruce mires RhK MHC</td>
<td>x (x)</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>12. Equisetum sylvaticum spruce mires MkK MH</td>
<td>x (x)</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>13. Geranium–Oxalis–Vaccinium myrtillus spruce mires RhMK MH</td>
<td>x (x)</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>14. Vaccinium myrtillus spruce mires MK MH</td>
<td>x x</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>15. Thin-peated pine forests KgR (M)EH</td>
<td>x x A</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>16. Carex globularis spruce–pine mires PsR MEH</td>
<td>x x M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Swampy birch fens LuNK ME(H)CCom</td>
<td>x x</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>18. Mesotrophic tall-sedge birch fens MeSK (M)E(H)L/CCom</td>
<td>x x</td>
<td>D D</td>
<td></td>
</tr>
<tr>
<td>19. Mesotrophic tall-sedge pine fens MeSR (M)E(H)L/CCom</td>
<td>x x</td>
<td>D D</td>
<td></td>
</tr>
<tr>
<td>20. True tall-sedge birch fens OiSK (M)E(H)L/CCom</td>
<td>x x</td>
<td>D M</td>
<td></td>
</tr>
<tr>
<td>21. Carex globularis pine mires PsR MEH</td>
<td>x x A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22. Empetrum–Sphagnum fuscum bogs VmRaR EH</td>
<td>x x</td>
<td>A M M D D</td>
<td></td>
</tr>
<tr>
<td>23. Eriophorum vaginatum pine bogs TR EHL</td>
<td>x x</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>24. Short-sedge pine fens LkNR E(H)L/CCom</td>
<td>x x</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>25. True short-sedge fens OIkN EL</td>
<td>x x</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>26. Poor Sphagnum papillosum fens OIkAN EL/(C)</td>
<td>x x</td>
<td>M D D</td>
<td></td>
</tr>
<tr>
<td>27. True tall-sedge pine fens OiSR (M)E(H)L/CCom</td>
<td>x x</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>28. Sphagnum papillosum tall-sedge fens KaSN EL/C</td>
<td>x x</td>
<td>A D</td>
<td></td>
</tr>
<tr>
<td>29. Poor Sphagnum papillosum fens with small flarks OIrRuRIN E(L)/C</td>
<td>x x</td>
<td>A D D</td>
<td></td>
</tr>
<tr>
<td>30. Sphagnum fuscum bogs with hollows KeR EHCMuCom</td>
<td>x x</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>31. Flark-level bogs KuN ECMu</td>
<td>x x</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>32. Short-sedge intermediate level bogs OmLkN EL/C</td>
<td>x x</td>
<td>M D</td>
<td></td>
</tr>
<tr>
<td>33. Dwarf shrub pine bogs IR EH</td>
<td>x x</td>
<td>D D</td>
<td></td>
</tr>
<tr>
<td>34. Sphagnum flark fens SphRiN EC</td>
<td>x x</td>
<td>A M M M</td>
<td></td>
</tr>
<tr>
<td>35. Scorpidium flark fens ScoRiL (M)EC/Mu</td>
<td>x x</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

* The abbreviation for each site type according to Eurola et al. (1995) is shown in bold type immediately after the site type name. This is followed by an indication of its characteristics, as follows: — M = mire margin vegetation; E = mire expanse vegetation; parentheses refer to an affinity to mire margin or mire expanse vegetation. — H = hummock level; L = lawn; C = carpet; Mu = mudbottom; L/C = transitional case between lawn and carpet; parentheses refer to minor affinity to the specific level. — Com = combination site type. Estimated abundance of mire site types in mesotopographic mire units: A = abundant, M = moderate, D = diminutive (only as patches).
routes of water flow within and out of the mire complex.

**Hydrologic classifications**

Most of the mire complex could, in our view, be roughly characterised by surface flow. However, there appeared to be a groundwater recharge-discharge area in its southern part. This interpretation was based on the groundwater flow direction (Miettunen 1994), the topography of the mire floor, the presence of permeable sand beneath the shallow peat, and the vegetation. The vegetation of a transitional zone 400–1200 m wide within this area (B in Fig. 6) showed practically no signs of groundwater influence, but unstable water regime was typical (4 and most of 5 in Fig. 6). This area could also be delineated from the spatial vegetation pattern (Fig. 7). It was outlined by the sand flat beneath the peat, and the maximum peat thickness was 60 cm. Characteristics included mire expanse vegetation, a diminished proportion of *Sphagna* (with the exception of *Sphagnum compactum*), a close-textured, dark brown mud bottom, lawn or hummock level of the same type, a lack of soaks, occurrence of steep-edged hummocks and a lack or scantiness of strings (some broad, firm *Molinia* strings occurred). Two very small concentric/eccentric bogs were also found on the sand flat.

One hummock level site type, one combination site type and two lawn site types (Table 3: 1–4) were found in fen areas with unstable water regime, reflecting in our view the occasional infiltration of mire water into mineral soil (groundwater recharge). Twenty-nine site types were found within the whole complex in mire areas with stable water regime, reflecting weak groundwater discharge or surface layer flow (Table 3: 7–35). Poor mud bottom flark fens and mesotrophic mud bottom flark fens (Table 3: 5–6) represented vegetation occurring in areas with both stable and unstable water regime.

Small, diffuse patches (in area C in Fig. 6) with greenish appearance and vegetation different from the surrounding mud bottoms were found in the middle of the mire in a parallel-patterned fen with a sparse string pattern. The patches included vegetation of four mire site types (explanation of C in Fig. 6), some of them with a special affinity to groundwater influence. An endangered moss species, *Hamatocaulis lapponicus* (*Drepanocladus lapponicus*), that belongs to international responsibility species of Finland (Ulvinen et al. 2002), was found in one patch. The area outlined by patches was interpreted as representing the groundwater discharge.

---

**Fig. 6.** The stability of water regime and the groundwater recharge-discharge pattern interpreted for part of the study area. See index map, Fig. 1. The 1–6 pattern of mineral soil formations and the stability of water regime in mire areas: 1 = glaciofluvial interlobate complex (gravel, sand), 2 = raised beach ridge (sand), 3 = till areas, 4 = mire areas with unstable water regime, 5 = mire area in which areas with unstable water regime and areas with stable water regime occur, 6 = mire areas with stable water regime. Other code numbers: 7 = lake, 8 = reservoir–infiltration basin, 9 = direction of groundwater flow, 10 = road. The ABC pattern, the groundwater recharge-discharge pattern: A = groundwater recharge area, B = transitional area, C = groundwater discharge area, D = surface layer flow area. Area C includes patches of (1) true tall-sedge fens dominated by *Carex rostrata*, (2) mesotrophic tall-sedge fens (including *Helodium blandowii*), (3) mesotrophic *Drepanocladus* flark fens (including *Hamatocaulis lapponicus*) and (4) mesotrophic fens with surface water influence (including *Cinclidium subrotundum*, *Sphagnum squarrosum*, *Sphagnum teres*, *S. fimbriatum*).
area of the glaciofluvial mineral soil formation (A in Fig. 6) in a zone where peat thickness increases abruptly from an approximate maximum of 60 cm on the sand flat to over 3 m in the central deep part of the mire (Fig. 2).

Minimal groundwater discharge was also seen in till areas. It was manifested as the extremely weak groundwater influence at tiny sites of spruce mire vegetation (Table 3: 11–13) in areas transitional to mineral soil. No springs or seeps were found.

Discussion

Hydrotopographic classification in aapa mires

We found especially the meso and macro scales of hydrotopographic classification very useful when characterising the morphology and some features of the hydrological functioning of large mire complexes. Meso- and macrotopography are easy to delineate from air photographs, whereas the very detailed vegetation pattern (e.g. the mire site type pattern by the Finnish system), is not possible to delineate on the basis of air photos alone, but requires field determinations.

The proportion of central vs. peripheral aapa-mire areas in single mire complexes varies regionally according to the regional description of Ruuhijärvi (1960, 1983). In southern aapa mires the peripheral aapa-mire areas (mainly peripheral lobes) are large or even occupy the entire complex as described by Ruuhijärvi (1960) for aapa mires of Suomenselkä area. In more northern parts of the southern aapa-mire zone the peripheral and central aapa-mire areas occupy almost equal areas in single aapa-mire complexes. In the main aapa-mire zone (Ruuhijärvi 1983, Ruuhijärvi & Hosiaisluoma 1988) the wet central aapa-mire areas typically occupy the bulk of the aapa complex, and both parallel-patterned fens and central reservoir basins are commonly found. Parallel-patterned fens, however, cover considerably larger parts of the mire complexes.

The hydrotopographic pattern in mire complexes is for the most part climatically induced (e.g. Tolonen 1967). However, the reservoir-infiltration basins, in which the unstable water regime and the stagnant state of peat growth are evident, represent partly edaphic formations (see Malmer 1985) in the climatically induced hydrotopographic pattern of aapa mires. They occur sporadically in aapa-mire complexes next to glaciofluvial formations, at least in the southern aapa-mire zone of Finland.

Reticulate-patterned mire is a concept that has been used for one hydrotopographic mire unit in connection with the Hirvisuo mire com-
plex. There the unit represents a transitional form between central reservoir basins (belonging clearly to central aapa-mire areas) and concentric/eccentric bogs (belonging clearly to peripheral aapa-mire areas). In concentric/eccentric bogs, the flow pattern of mire water is divergent with no inflow from the surroundings. In central reservoir basins, instead, the flow from the surroundings typically disperses into two directions as described by Sjörs (1973, 1983) for flark crosses and flark triangles. The flow pattern associated with the reticulate-patterned mires of Hirvisuo mire complex evidently represents a transition between the other two types. The existence of this unit type suggests that considerable areas in the wet parts of mire complexes of the southern aapa-mire zone may at present be in a developmental stage, in which it is nearly impossible to classify them either into central aapa-mire areas (that gather water from their surroundings) or into peripheral aapa-mire areas (that yield water to their surroundings). Incomplete reticulate patterns with strings that are not totally connected to each other are typical of northern aapa mires (Waldläppland-Aapamoore, Ruuhijärvi 1960). The network-pattern of especially the northernmost unit of this kind in the Hirvisuo mire complex is more uniform and the strings form an unbroken network.

Classification of the stability of water regime in aapa mires

Areas with unstable water regime are not restricted to reservoir-infiltration basins in the Hirvisuo mire complex but also occur in lawn and hummock level areas (peripheral aapa-mire areas) and to a smaller degree also in a (thin-peated) parallel-patterned fen. In fact, the stability of water regime may be characterized as a macro-scale pattern in aapa mires, the areas with unstable water regime being largely separate from those with stable water regime. In raised bog centres in non-oceanic (boreonemoral–southern boreal) areas (Rydin 1985), the same pattern has been reported to occur as a micro-scale pattern: *Sphagnum fuscum* hummocks have stable water regime, while hollows have unstable water regime.

The vegetation (mire site types) of aapa mires belongs mainly to the stable group. The major points regarding the mire site types with unstable water regime should be emphasised: (1) Lawn vegetation with dominance of *Trichophorum cespitosum* and *Sphagnum compactum* is the principal site type in poor fens of that type in flat aapa mires, and it occurs also in sloping fens (Ruuhijärvi 1960, Havas 1961, Fransson 1972, Eurola *et al.* 1982, Paasovaara 1986, Heikkilä & Lindholm 1988). (2) The unstable water regime of certain mud bottoms is a well-known feature (Ruuhijärvi 1960), but further testing is required for different communities. (3) The occurrence of thin-peated, semi-open *Calluna* pine mires, partly in combination with *Trichophorum cespitosum–Sphagnum compactum* lawns, is a common feature for the lowland sites of the study area and elsewhere (not on the coastal area of the Bothnian Bay) and for upland site Riisitunturi in northeastern Finland (Paasovaara 1986). It is proposed here that one reason for the dominance of *Calluna vulgaris* at these sites is their stagnant state in terms of peat growth. The same pattern occurs in old, concentric raised bogs of western Finland, where lichens, in addition to *Calluna vulgaris*, are notable in the vegetation (Aario 1932, Eurola 1962, Ruuhijärvi 1983).

The stability of water regime, which has here been interpreted primarily on edaphic grounds, has been suggested earlier from the middle and northern boreal uplands of northeastern Finland — partly on topographic grounds (Havas 1961). According to Havas (1961), sloping fens generally have slightly less stable water levels than flat fens. In a sloping fen, the situation may roughly be comparable to that in a shallow peat layer on a level sand substratum: on sand the occasional infiltration of water takes place vertically downwards, leading (in conjunction with evapotranspiration) to seasonal desiccation. In a sloping fen with high inclination, the water moves obliquely downwards, evidently leading to the same phenomenon. There is a paradox concerning the oceanic climate (Eurola *et al.* 1982, Moen 1990) and seasonal drought in sloping fens: the climate enables the occurrence of mire in a site, where even desiccation is possible. We conclude here that the stability of water regime evidently has two patterns in fens of boreal aapa
mires, an edaphic one and a topographic one. In the sloping fens of middle and northern boreal uplands, the stability pattern is mainly controlled by inclination (topographic pattern), whereas in flat lowland aapa mires, it is mainly controlled by the permeability of the mineral soil underlying the peat (edaphic pattern). This hypothesis, however, requires further testing.

Groundwater recharge-discharge pattern in aapa mires

The bulk of any aapa-mire complex comprises a groundwater discharge area in the (geological) sense of e.g. Siegel (1983, 1988), and groundwater recharge should be very exceptional. Infiltration of water from mires into mineral soil (groundwater recharge) is usually considered to be minimal, especially in bogs (Ingram 1983, Damman 1986, Sallantaus 1988; but see e.g. Siegel & Glaser 1987 and Glaser et al. 1997). In the study area, however, we suggested that it may occasionally occur in certain fen site types and maybe in a thin-peated small raised bog on sand substratum, too. We further suggest that the situation is not exceptional in mire complexes in the southern aapa-mire zone of Finland, because the Hirvisuo mire complex is not the only mire complex situated on sandy, glaciofluvial formations in this area.

We call here groundwater discharge areas only those very limited areas or patches of mire surface, in which the groundwater discharge is evident according to the vegetational indication by Eurola et al. (1984). Definite groundwater influence in the vegetation occurred in diffuse patches in the middle of the parallel-patterned fen in the southern part of the study area. We interpret the groundwater flow to take place in the deep soil layers from the recharge area (glaciofluvial mineral soil formation) to the discharge area (patches in the middle of the parallel-patterned fen). So the water seems to flow a considerable distance in the mineral soil beneath the peat.

Groundwater discharge with similar vegetation as presented from the study area is known to occur at the nearby Kälväsvaara esker complex (H. Heikkilä et al. 2001). Lahermo et al. (1977) describe examples in northern boreal central Finnish Lapland, which deviate from those described above in that the groundwater discharge in the middle of the mire takes place through volcano-like hummocks. In the Hirvisuo study area, instead, the discharge of groundwater onto the mire is not specifically reflected in the topography.

It is remarkable that in the abovementioned cases the special vegetation influenced by groundwater does not occur as springs next to the esker but as diffuse areas of higher nutrient status far out in the wet aapa-mire centre. In middle boreal localities of this type in northern-central Finland — in the Kälväsvaara area (H. Heikkilä et al. 2001) and in the Hirvisuo mire complex — these sites are characterised by patches of Hamatocaulis lapponicus. The sites of Hamatocaulis lapponicus are characterised by meso-eutrophy, and ground and surface water influence by Ruuhijärvi (1962) and H. Heikkilä et al. (2001). It can be assumed that the preservation of the species at these sites relies on the supply of groundwater derived from the glaciofluvial mineral soil formation outside the mire complex, as proposed by H. Heikkilä et al. (2001) for the Kälväsvaara area. The supply of groundwater from this source is dependent on the preservation of the groundwater table in the mineral-soil formation, because lowering will affect the hydraulic gradient and so may hinder the flow of groundwater towards the centre of the mire complex. Thus, we assume that a hydrologic pattern of landscape scale provides an explanation for the existence of these habitats. This case underlines the importance of understanding the whole geo-hydro-ecologic system of the mire complex and its surroundings as a unit, which must be taken into consideration when planning nature conservation areas.

Acknowledgements

We thank Prof. Seppo Eurola for ideas and comments on the manuscript, Pekka Pakarinen, Ph.D., for comments on the manuscript, Prof. Håkan Rydin for comments on an early version of the manuscript and Tauno Ulvinen, Dr. h.c., for determining some moss species. Raimo Heikkilä, Ph.D. and Teemu Tahvanainen, Ph.D., kindly commented on an early version of the manuscript. Prof. Jari Oksanen made constructive comments on the later versions. Three anonymous referees are also thanked. The study material was mainly collected in the 1980s during the vegetation mapping, which
was supported financially by the Finnish National Board of Forestry. Later financial support was provided by the Tauno Töning Foundation.

References


Oulun yliopiston Oulangan biologisen aseman monisteita 9: 51–85.


