

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

Jarmo Laitinen<sup>1</sup>, Sakari Rehell<sup>2</sup> & Antti Huttunen<sup>3</sup>

<sup>1</sup> Department of Biology, Botany, P.O. Box 3000, FI-90014 University of Oulu, Finland

<sup>2</sup> Metsähallitus, Natural Heritage Services Ostrobothnia-Kainuu, Veteraanikatu 5, FI-90101 Oulu, Finland

<sup>3</sup> Oulanka Research Station, Liikasenvaarantie 134, FI-93999 Kuusamo, Finland

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

Laitinen, J., Rehell, S. & Huttunen, A. 2005: Vegetation-related hydrotopographic and hydrologic classification for aapa mires (Hirvisuo, Finland). — *Ann. Bot. Fennici* 42: 107–121.

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, *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 *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 & Hosiainluoma 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 hydromorphology (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 microtopographic 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 south-

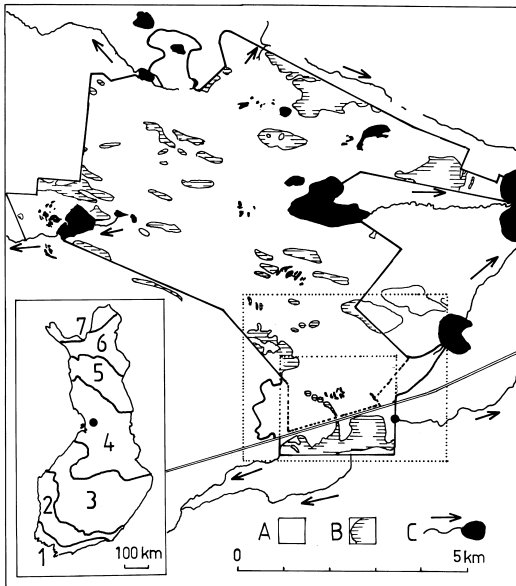
ern aapa mire zone in Finland, where peatlands cover over 50 per cent of the total land area and the peatlands form almost a uniform network, single mire complexes may be difficult to delineate from each other (cf. R. Heikkilä *et al.* 2001). Instead, certain very clearly identifiable major hydrotopographic 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

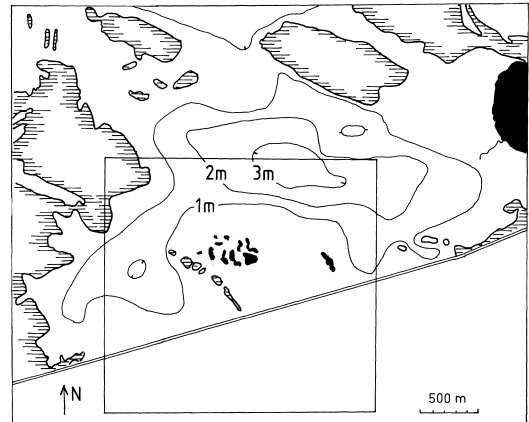
Hirvisuo is an extensive mire complex in the lowlands (about 120 m a.s.l.) bordering on the Gulf of Bothnia in northern-central Finland (Fig. 1) (Laitinen 1984). The mean annual temperature is 1–2 °C, and the annual range of monthly mean temperatures 26–27 °C. Snow depth in March is 50–60 cm, the permanent snow cover



**Fig. 1.** Location and general features of the study area. The larger map is based on published 1:20 000 mapping. The boundary of the study area is indicated with a solid line, the southern boundary of the Hirvisuo mire protection area by a dashed line, and the road by a double line. The white areas inside the study area (A) are mires and paludified forests, and the shaded areas (B) indicate mineral soil areas consisting almost exclusively of pine forests. Streams, their flow direction, and lakes are also shown (C). The larger rectangle marked with a dotted line delineates the area shown in Fig. 2, and the smaller rectangle inside this indicates the area shown in Fig. 6. The inset map shows the regional mire zones of Finland according to Ruuhijärvi and Hosiaisuus (1988); 1 = Plateau bogs; 2 = Concentric bogs; 3 = Eccentric bogs; 4 = Southern aapa mires; 5 = Main aapa mire zone; 6 = Northern aapa mires; 7 = Palsa mires. The dot indicates the location of the Hirvisuo study area.

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 & Johans-



**Fig. 2.** Contours of peat thickness in the southern part of the study area, modified from Hänninen (1988: fig. 56). Mineral soil areas, areas of open water (lake and flark pools) and the road are shown as in Fig. 1. The inset rectangle indicates the area shown in Fig. 6.

son 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.

### Conceptual framework: patterns and scales

#### Vegetation patterns and classification

The Finnish mire site type system (Eurola *et al.* 1984) was used. The following additions on

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 (Ruuhijärvi 1960: *Anmorige 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 *Rimpiartige Sphagnum balticum* *Weissmoore* (Ruuhijärvi 1960).

The Finnish hydroecologic concept of three aspects (Ruuhijärvi 1960, Eurola 1962, Ruuhijärvi 1983, Eurola et al. 1984, 1995) in mire margin vegetation was applied. (1) Groundwater influence (*Quelligkeit* by Ruuhijärvi 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 Ruuhijärvi 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 Ruuhijärvi 1960), is quite clearly differentiated by the vegetation (Ruuhijärvi 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.

Hydrotopographic pattern for aapa mires	Determinations or characteristic formations	Aario (1932): typology for Finnish raised bogs	Rydin et al. (1999): general Swedish typology based on Sjörs (1948)	Økland (1989): general typology based on material from SE Norway
Microtopographic features	Flarks, strings, hummocks, etc.	<i>Kleinformen</i>	Mire elements	Mire features
Mesotopographic mire units	Medium-sized hydromorphological entities in mire complexes that are clearly identifiable on aerial photographs	<i>Formenteile</i>	Mire units	Mire segments
Macrotopographic pattern	Aapa mire complex and its bisection to central aapa mire areas and to peripheral aapa mire areas	<i>Grossformen</i>	Mire complexes	Mire synsegments, mire complexes

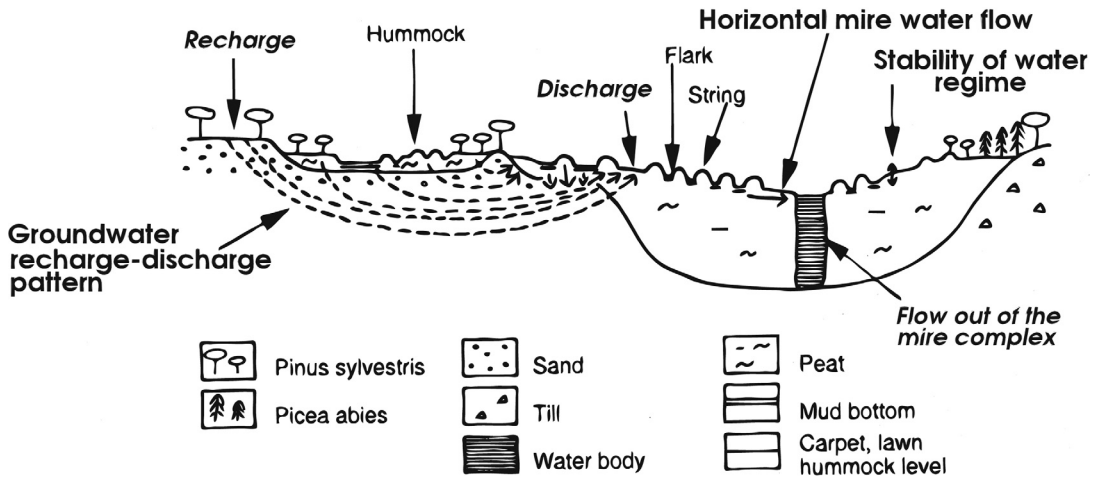


Fig. 3. Schematic profile of a large, flat aapa mire with hydrologic patterns discussed in this paper. Only the dominant groundwater recharge-discharge pattern has been denoted.

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 trophic status (mesotrophy, meso-eutrophy and eutrophy by Euroala *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 (Euroala 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

areas. Minerotrophic. Flat, wet and stringless areas. Merge without clear boundaries into parallel-patterned fens and into reticulate-patterned mires. Flark triangles and flark crosses of Sjörs (1973, 1983).

7. Reservoir-infiltration basins. Central aapa-mire areas. Minerotrophic. Flat, stringless and thin-peated mud-bottoms on sand substratum characterised by severe seasonal droughts and floods. Hummocks occur. Boundaries are clear-cut.
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.

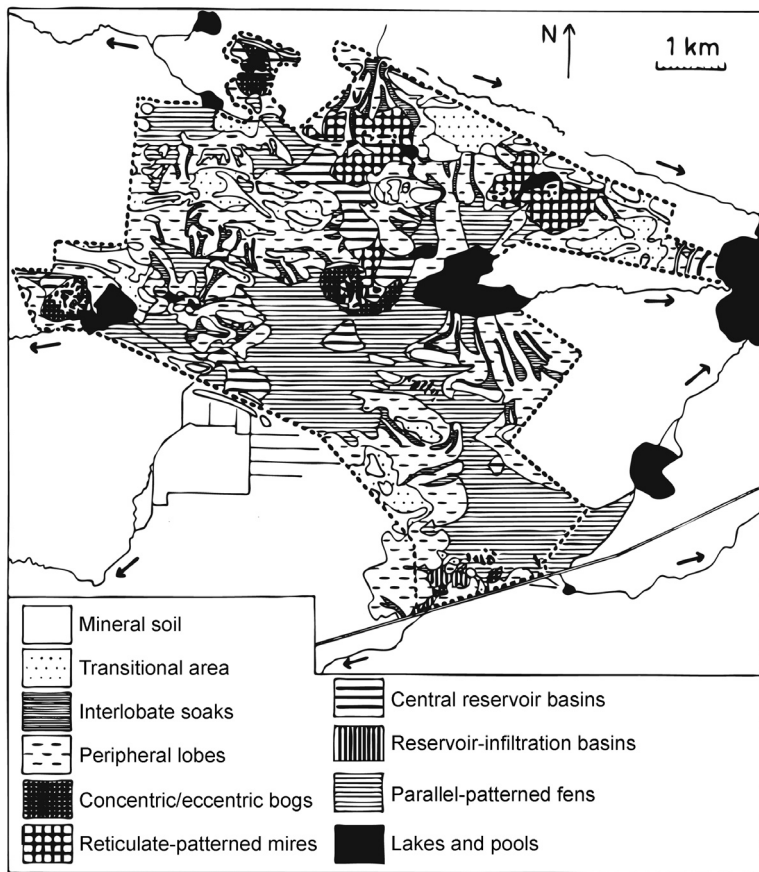
The mesotopographic pattern (Fig. 4) reflected loosely the mire site type pattern (Table 3). The macrotopographic peripheral-central pattern (Fig. 5) did not reflect the vegetational mire margin-mire expanse pattern: peripheral aapa-mire areas

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).

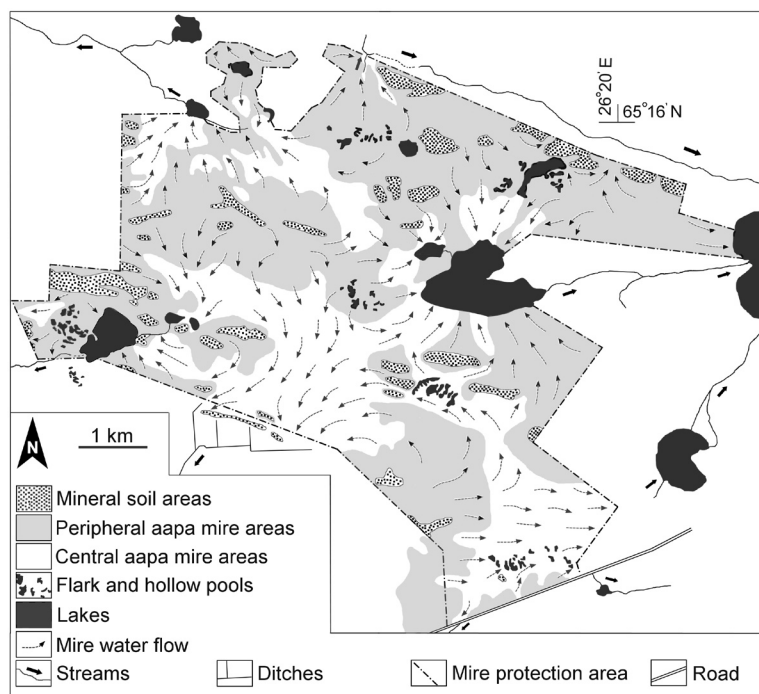
The pattern of horizontal mire water flow (Fig. 5) was closely related to the structure of the whole mire complex and to its meso- and micro-topographic patterns (Fig. 4 and Table 2). Interlobate soaks often began from islands of mineral soil within water divides. In these soaks the flow pattern was 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	Micro-topography		Pattern of horizontal mire water flow		
		Unpatterned	Patterned			
1. Areas transitional to mineral soil	Mineral + hummock	X		Parallel		Peripheral aapa mire areas Aapa mire complex
2. Interlobate soaks	Carpet	X	(X)	Convergent	Flow from watersheds to central aapa mire areas	
3. Peripheral lobes	Lawn + hummock	X	(X)	Divergent		
4. Concentric/ eccentric bogs	Hummock + lawn + carpet + 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 aapamire areas and out of the complex	Central aapa mire areas
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.



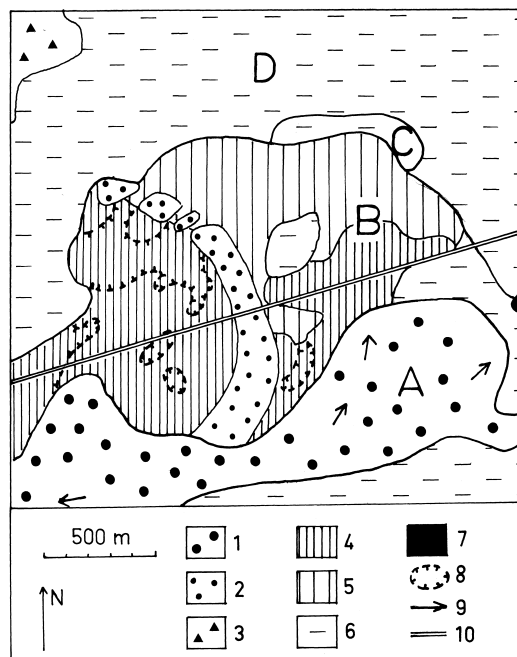
**Fig. 5.** Macrotopographic pattern and the pattern of horizontal mire water flow in the study area.



**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 Euroala *et al.* (1984) with the exception of site types 1–4 (cf. Ruuhijärvi 1983).

Mire site types*	Stability of water regime	Ground water recharge-discharge and surface layer flow	Macrotopographic pattern and mesotopographic mire units	
	Unstable	Stable	Peripheral aapa-mire areas	Central aapa-mire areas
		Occasional groundwater recharge	Areas transitional to mineral soil	
		Weak groundwater discharge	Interlobate soaks	
		Surface layer flow	Peripheral lobes	
			Concentric/eccentric bogs	
			Reticulate-patterned mires	
			Central reservoir basins	
			Reservoir-infiltration basins	
			Parallel-patterned fens	
1. Thin-peated, semi-open <i>Calluna</i> pine mires <b>KgR</b> (M)EH	x	x	(x) M	
2. Short-sedge pine fens dom. by <i>Sph. compactum</i> <b>LkNR</b> ELHCom	x	x	x	M
3. Poor <i>Sphagnum compactum</i> fens <b>OIKaN</b> EL	x	x	x	M
4. Mesotrophic <i>Sphagnum compactum</i> fens <b>MeKaN</b> EL	x	x	x	D
5. Poor mud bottom flark fens <b>OIRuRiN</b> EMu	x	x	x	M
6. Mesotrophic mud bottom flark fens <b>MeRuRiN</b> EMu	x	x	x	A A A
7. Mesotrophic <i>Drepanocladus</i> flark fens <b>MeDrepRiN</b> (M)EC	x	x	x	D D M
8. Swampy sedge fens <b>LuN</b> MEL/C	x	(x)	x	D
9. Mesotrophic tall-sedge fens <b>MeSN</b> (M)EL/C	x	(x)	x	M
10. True tall-sedge fens <b>OIVSN</b> (M)EL/C	x	(x)	x	A
11. Herb and grass birch–spruce mires <b>RhK</b> MHC	x	(x)	x	D
12. <i>Equisetum sylvaticum</i> spruce mires <b>MkK</b> MH	x	(x)	x	D
13. <i>Geranium–Oxalis–Vaccinium myrtillus</i> spruce mires <b>RhMK</b> MH	x	(x)	x	D
14. <i>Vaccinium myrtillus</i> spruce mires <b>MK</b> MH	x	x	x	D
15. Thin-peated pine forests <b>KgR</b> (M)EH	x	x	x	A
16. <i>Carex globularis</i> spruce–pine mires <b>PsKR</b> MEH	x	x	x	M
17. Swampy birch fens <b>LuNK</b> ME(H)CCom	x	x	x	D
18. Mesotrophic tall-sedge birch fens <b>MeSK</b> (M)E(H)L/CCom	x	x	x	D D
19. Mesotrophic tall-sedge pine fens <b>MeSR</b> (M)E(H)L/CCom	x	x	x	D D
20. True tall-sedge birch fens <b>OISK</b> (M)E(H)L/CCom	x	x	x	D M
21. <i>Carex globularis</i> pine mires <b>PsR</b> MEH	x	x	x	A
22. <i>Empetrum–Sphagnum fuscum</i> bogs <b>VmRaR</b> EH	x	x	x	A M M D D
23. <i>Eriophorum vaginatum</i> pine bogs <b>TR</b> EHL	x	x	x	M
24. Short-sedge pine fens <b>LkNR</b> E(H)L/CCom	x	x	x	A
25. True short-sedge fens <b>OILkN</b> EL	x	x	x	M
26. Poor <i>Sphagnum papillosum</i> fens <b>OIKaN</b> EL/(C)	x	x	x	M
27. True tall-sedge pine fens <b>OISR</b> (M)E(H)L/CCom	x	x	x	A
28. <i>Sphagnum papillosum</i> tall-sedge fens <b>KaSN</b> EL/C	x	x	x	A
29. Poor <i>Sphagnum papillosum</i> fens with small flarks <b>OIRuRiN</b> E(L)/C	x	x	x	A
30. <i>Sphagnum fuscum</i> bogs with hollows <b>KeR</b> EHCMuCom	x	x	x	A
31. Flark-level bogs <b>KuN</b> ECMu	x	x	x	M
32. Short-sedge intermediate level bogs <b>OmLkN</b> EL/C	x	x	x	M D
33. Dwarf shrub pine bogs <b>IR</b> EH	x	x	x	D
34. <i>Sphagnum</i> flark fens <b>SphRiN</b> EC	x	x	x	A
35. <i>Scorpidium</i> flark fens <b>ScoRiL</b> (M)EC/Mu	x	x	x	M M M D

\* The abbreviation for each site type according to Euroala *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).



**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*).

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 *Sphagnum* (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

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.

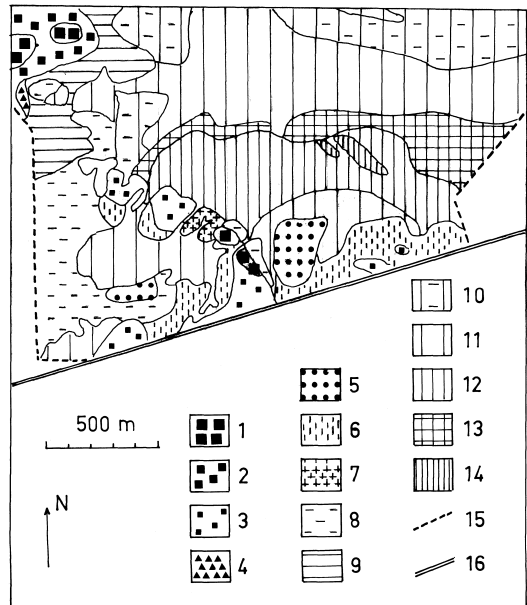
## Discussion

### 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 & Hosiainluoma 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



**Fig. 7.** Mire site type pattern in part of the study area. See index map, Fig. 1. The mire and forest site types: 1 = *Empetrum-Vaccinium* forest site type, paludified *Empetrum-Vaccinium* forest site type; 2 = thin-peated pine forest; 3 = thin-peated, semi-open *Calluna* pine mire; 4 = *Carex globularis* pine mire; 5 = *Sphagnum fuscum* bog with hollows; 6 = short-sedge pine fen dominated by *Sphagnum compactum*, poor *Sphagnum compactum* fen, small mud-bottomed patches; 7 = short-sedge pine fen dominated by *Sphagnum compactum*, mesotrophic *Sphagnum compactum* fen, small mud-bottomed areas; 8 = poor *Sphagnum papillosum* fen with small flarks (Rimpiartige *Sphagnum balticum* Weissmoore), poor *Sphagnum papillosum* fen; 9 = true tall-sedge fen, *Sphagnum papillosum* tall-sedge fen; 10 = *Sphagnum* flark fen; 11 = poor mud-bottomed flark fen; 12 = mesotrophic mud-bottomed flark fen; 13 = poor mud-bottomed flark fen, mesotrophic mud-bottomed flark fen, true tall-sedge fen, mesotrophic tall-sedge fen, mesotrophic *Drepanocladus* flark fen; 14 = *Scorpidium* flark fen as an interface against a pond, 15 = boundary of the mire protection area, 16 = road.

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 (*Waldlappland-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, Sallantausta 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 Kälvasvaara 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 Kälvasvaara 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 Kälvasvaara 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 Tönning Foundation.

## References

- Aario, L. 1932: Pflanzentopographische und paläogeographische Mooruntersuchungen in N- Satakunta. — *Fennia* 55: 1–179.
- Aario, R. & Forsström, L. 1979: Glacial stratigraphy of Koillismaa and North Kainuu, Finland. — *Fennia* 157: 1–49.
- Alalammi, P. (ed.) 1987: Climate. — In: *Atlas of Finland*, folio 131. Nat. Board Survey & Geogr. Soc. Finland, Helsinki.
- Cajander, A. K. 1913: Studien über die Moore Finnlands. — *Acta Forest. Fenn.* 2: 1–208.
- Damman, A. W. H. 1986: Hydrology, development and biochemistry of ombrogenous peat bogs with special reference to nutrient relocation in a western Newfoundland bog. — *Can. J. Bot.* 64: 384–394.
- Eurola, S. 1962: Über die regionale Einteilung der südfinnischen Moore. — *Ann. Bot. Soc. Vanamo* 33: 1–243.
- Eurola, S., Hicks, S. & Kaakinen, E. 1984: Key to Finnish mire types. — In: Moore, P. D. (ed.), *European mires*: 11–117. Academic Press, London.
- Eurola, S., Huttunen, A., Huttunen, M. & Paasovaara, P. 1982: The nature of two sloping mires in the Riisitunturi national park, northern Finland (66°15'N, 28°25'E). — *Suo* 33: 75–79. [In Finnish with English summary].
- Eurola, S., Huttunen, A. & Kukko-oja, K. 1995: Suokasvillisuusopas. — *Oulanka Reports* 14: 1–85.
- Eurola, S. & Kaakinen, E. 1978: *Suotyyppiopas*. — WSOY, Helsinki.
- Eurola, S. & Kaakinen, E. 1979: Ecological criteria of peatland zonation and the Finnish mire site type system. — In: Kivinen, E., Heikurainen, L. & Pakarinen, P. (eds.), *Classification of peat and peatlands*: 20–32. International Peat Society, Hyytiälä.
- Foster, D. & Fritz, S. 1987: Mire development, pool formation and landscape processes on patterned fens in Dalarna, central Sweden. — *J. Ecol.* 75: 409–437.
- Foster, D. & King, G. 1984: Landscape features, vegetation and developmental history of a patterned fen, south-eastern Labrador, Canada. — *J. Ecol.* 72: 115–143.
- Foster, D. R., Wright, H. E., Thelau, M. & King, G. A. 1988: Bog development and landform dynamics in central Sweden and south-eastern Labrador, Canada. — *J. Ecol.* 76: 1164–1185.
- Fransson, S. 1972: Mire vegetation in south-western Värmland, Sweden. — *Acta Phytogeogr. Suec.* 57: 1–133. [In Swedish with English summary].
- Freeze, R. A. & Cherry, J. A. 1979: *Groundwater*. — Prentice Hall, London.
- Glaser, P. H. & Janssens, J. A. 1986: Raised bogs in eastern North America: transitions in landforms and gross stratigraphy. — *Can. J. Bot.* 64: 395–415.
- Glaser, P. H., Siegel, D. I., Romanowicz, E. A. & Shen, Y. I. 1997: Regional linkages between raised bogs and the climate, groundwater, and landscape of north-west Minnesota. — *J. Ecol.* 85: 3–16.
- Hämet-Ahti, L. 1981: The boreal zone and its biotic subdivision. — *Fennia* 159: 69–75.
- Hänninen, P. 1988: Pudasjärvellä tutkitut suot ja niiden turvevarat. Osa VI. — *Turveraportti* 212. Geologian tutkimuskeskus, Maaperäosasto, Kuopio.
- Havas, P. 1961: Vegetation und Ökologie der ostfinnischen Hangmoore. — *Ann. Bot. Soc. Vanamo* 31: 1–188.
- Heikurainen, L. 1953: Die kiefernbewachsenen eutrophen Moore Nordfinlands. — *Ann. Bot. Soc. Vanamo* 26: 1–171.
- Heikkilä, H., Kukko-oja, K., Laitinen, J., Rehell, S. & Sallantausta, T. 2001: Arvio Viinivaaran pohjavedenottohankkeen vaikutuksesta Olvassuon Natura 2000 -alueen luontoon. — *Metsäntutkimuslaitoksen tiedonantoja* 799: 1–55.
- Heikkilä, R., Kuznetsov, O., Lindholm, T., Aapala, K., Antipin, V., Djatshkova, T. & Shevelin, P. 2001: Complexes, vegetation, flora and dynamics of Kauhaneva mire system, western Finland. — *Finnish Environment* 489: 1–97.
- Heikkilä, R. & Lindholm, T. 1988: Distribution and ecology of *Sphagnum molle* in Finland. — *Ann. Bot. Fennici* 25: 11–19.
- Ingram, H. A. P. 1983: Hydrology. — In: Gore, A. J. P. (ed.), *Mires: swamp, bog, fen and moor*. A. General studies: 67–158. Elsevier Sci. Publ. Co., Amsterdam.
- Karlsson, K.-P. (ed.) 1986: Water. — In: *Atlas of Finland*, folio 132. Nat. Board Survey & Geogr. Soc. Finland, Helsinki.
- Kutnar, L. & Martinčič, A. 2003: Ecological relationships between vegetation and soil-related variables along the mire margin-mire expanse gradient in the eastern Julian Alps, Slovenia. — *Ann. Bot. Fennici* 40: 177–189.
- Lahermo, P., Valovirta, V. E. & Särkioja, A. 1977: The geobotanical development of spring-fed mires in Finnish Lapland. — *Geological Survey of Finland, Bulletin* 287: 1–44.
- Laitinen, J. 1984: The protected mire area of Hirvisuo. — *Oulanka Reports* 5: 33–35.
- Malmer, N. 1985: Remarks to the classification of mires and mire vegetation — Scandinavian arguments. — *Aquilo Ser. Bot.* 21: 9–17.
- Miettunen, A. 1994: Ylikiimingin pohjavesitutkimus. — *Internal Report, North Ostrobothnia Reg. Env. Centre*. TN:o 231 Ouvy 4/3. Palokangas 6/14. Arkala, Ylikiimingi.
- Moen, A. 1985: Classification of mires for conservation purposes in Norway. — *Aquilo Ser. Bot.* 21: 95–100.
- Moen, A. 1990: The plant cover of the boreal uplands of central Norway. I. Vegetation ecology of Sølendet nature reserve; haymaking fens and birch woodlands. — *Gunnaria* 63: 1–451.
- Moen, A. 1999: Vegetation. — In: *National atlas of Norway*. Norwegian Mapping Authority, Hønefoss.
- Økland, R. H. 1989: Hydromorphology and phytogeography of mires in inner Østfold. — *Opera Bot.* 97: 1–122.
- Paasovaara, P. 1986: Riisitunturin alueen suotyypeistä. —

- Oulun yliopiston Oulangan biologisen aseman monisteita* 9: 51–85.
- Pakarinen, P. 2001: Aapa mires of northern Europe and North America: notes on ecological terminology and conservation needs. — *Bot. Electronic News* 263. Available on the web at <http://www.ou.edu/cas/botany-micro/ben/ben263.html>.
- Raitio, H. & Johansson, P. 2004: Jäätikkö sulaa. — In: Koivisto, M. (ed.), *Jääkaudet*: 69–86. WS Bookwell, Porvoo.
- Reinikainen, A., Lindholm, T. & Vasander, H. 1984: Ecological variation of mire site types in the small kettle-hole mire Heinisuo, southern Finland. — *Ann. Bot. Fennici* 21: 79–101.
- Ruuhijärvi, R. 1960: Über die regionale Einteilung der nordfinnischen Moore. — *Ann. Bot. Soc. Vanamo* 31: 1–360.
- Ruuhijärvi, R. 1962: *Drepanocladus lapponicus* (Norrl.) Z. Smirn. in Finland. — *Arch. Soc. Vanamo* 17: 218–227.
- Ruuhijärvi, R. 1963: Zur Entwicklung der nordfinnischen Hochmoore. — *Ann. Bot. Soc. Vanamo* 34(2): 1–40.
- Ruuhijärvi, R. 1983: The Finnish mire types and their regional distribution. — In: Gore, A. J. P. (ed.), *Ecosystems of the world, 4B. Mires: swamp, bog, fen and moor. Regional studies*: 47–67. Elsevier Sci. Publ. Co., Amsterdam–Oxford–New York.
- Ruuhijärvi, R. & Hosiaisuoma, V. 1988: Mires 1:1000000. — In: *Atlas of Finland*, folio 141–143. Map Appendix 2. Nat. Board Survey & Geogr. Soc. Finland, Helsinki.
- Rydin, H. 1985: Effect of water level on desiccation of *Sphagnum* in relation to surrounding *Sphagna*. — *Oikos* 45: 374–379.
- Rydin, H., Sjörs, H. & Löfroth, M. 1999: Mires. — *Acta Phytogeogr. Suec.* 84: 91–112.
- Sallantausta, T. 1988: Water quality of peatlands and man's influence on it. — In: *Symposium on the Hydrology of Wetlands in Temperate and Cold Regions, Joensuu, Finland, 6–8 June 1988*, vol. 2: 80–98. Publ. Acad. Finland 5/1988.
- Seppä, H. 1996: The morphological features of the Finnish peatlands. — In: Vasander, H. (ed.), *Peatlands in Finland*: 27–33. Finnish Peatland Soc. Helsinki.
- Seppälä, M. & Koutaniemi, L. 1985: Formation of a string and pool topography as expressed by morphology, stratigraphy and current processes on a mire in Kuusamo, Finland. — *Boreas* 14: 287–309.
- Siegel, D. I. 1983: Groundwater and the evolution of patterned mires, Glacial Slake Agassiz Wetlands, northern Minnesota. — *J. Ecol.* 71: 913–921.
- Siegel, D. I. 1988: The recharge-discharge function of wetlands near Juneau, Alaska: Part I. Hydrological investigations. — *Groundwater* 26: 427–434.
- Siegel, D. I. & Glaser, P. H. 1987: Groundwater flow in a bog-fen complex, Lost River peatland, Northern Minnesota. — *J. Ecol.* 75: 743–754.
- Simonen, A. 1987: Pre-Quaternary rocks. — In: *Atlas of Finland*, folio 123–126. Map Appendix 1. Nat. Board Survey & Geogr. Soc. Finland, Helsinki.
- Sjörs, H. 1948: Mire vegetation in Bergslagen, Sweden. — *Acta Phytogeogr. Suec.* 21: 1–299. [In Swedish with English summary].
- Sjörs, H. 1973: Mires considered for protection in Kopparberg County (prov. Dalarna), central Sweden. — *Växtekol. Stud.* 3: 1–116. [In Swedish with English summary].
- Sjörs, H. 1983: Mires of Sweden. — In: Gore, A. J. P. (ed.), *Ecosystems of the world, 4B. Mires: swamp, bog, fen and moor. Regional studies*: 64–94. Elsevier Sci. Publ. Co., Amsterdam–Oxford–New York.
- Tolonen, K. 1967: Über die Entwicklung der Moore im finnischen Nordkarelien. — *Ann. Bot. Fennici* 4: 219–416.
- Ulvinen, T., Syrjänen, K. & Anttila, S. (eds.) 2002: Bryophytes of Finland: distribution, ecology and red list status. — *Finnish Environment* 560: 1–354. [In Finnish with English documentation page].
- Vitt, D., Achuff, P. & Andrus, R. 1975: The vegetation and chemical properties of patterned fens in the Swan Hills, north central Alberta. — *Can. J. Bot.* 53: 2776–2795.