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Mire systems in Finland — special view to aapa mires and their water-flow pattern

Suomen suosysteemit — erityistarkastelussa aapasuot ja niiden vedenvirtauskuviointi

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An attempt is made in this paper to create two consistent mire typologies, i.e. 1) the Combined Finnish Mire Typology covering all possible mire areas in Finland and 2) the Mire Water Flow Typology for boreal, zonal mire systems, i.e. aapa mires and raised bogs. Furthermore, larger groundwater recharge-discharge patterns concerning mires and the biological significance of morphologic and hydrologic mire classifications are discussed. Zonal mire systems from raised bogs to aapa mires are described as a dominance-based continuum. Local mire systems are subdivided according to factors that impede the formation of mire massifs, which are the essential morphological units of zonal mire systems. Smaller-scale mire units for aapa mires and the acrotelmic flow pattern are presented on the basis of a typical mid-boreal aapa mire system with a raised bog, based on the aerial photograph interpretation. The discussion of the groundwater recharge-discharge pattern and the biological significance of morphologic and hydrologic mire classifications is based on literature.

Key words: aapa mire, raised bog, groundwater, mire classification, mire hydrology, aerial photograph interpretation, peatland morphology, slope fen

Introduction

The idea of classifying mire areas, alongside with vegetation, was initially introduced in Finland by A.K. Cajander (1913), who described three mire complex types: the raised bog (*Typus des Hochmoorkomplexes*), the Carelian mire complex type (*Die Moorkomplexe des Karelischen Typus*) and the aapa mire (*Typus des Aapamoor-Komplexes*). In addition, he referred to still another mire complex type, the palsa mire (*Torfhügelmoor, Hügelmoor*), but he was not absolutely sure about its position among the mire complex types. Auer (1923) regarded the slope fen as the fifth mire complex type. Later such typologically oriented research strongly concentrated on the largest, climatic mire complexes according to the concept of Ruuhijärvi (1960), Havas (1961), Eurola (1962) and Tolonen (1967). They regarded the slope fen as a topographic variant of aapa mires, and the Carelian mire complex type was no longer considered a mire complex type, as the concept was exclusively reserved for zonal, climatic mire complexes. The opinions of the authors slightly differed in that Ruuhijärvi (1960) regarded the palsa mire as a separate mire complex type, while Eurola et al. (1984, 1995) combined it with aapa mires on vegetation-ecological grounds. Thus, the number of the main mire complex types referred to by the Finnish concept was reduced to two ones (the aapa mire and raised bog). Later, Tolonen (1967) additionally proposed that the combination of raised bogs and aapa mires (*Mischkomplex)* is still another mire complex type.

Research on mire complex types has been very closely linked with phytogeography and vegetation ecology in Finland (Ruuhijärvi 1960, Eurola 1962). The subtypes of raised bogs and aapa mires have been described on the basis of the morphology of their central parts (originally Ruuhijärvi 1960, Eurola 1962). The regionality of those subtypes essentially reflects the general vegetation zonality (see Eurola & Vorren 1980 and Vorren et al. 1999 for the treatment of Northern Fennoscandia). Eurola & Huttunen (1984), instead, consider that certain characteristic vegetational features of some slope fens in Northeastern Finland (Riisitunturi area) more have to do with sectional variation than corresponding zonal variation. The zonal subtypes of raised bogs (Eurola 1962) and aapa mires (Ruuhijärvi 1960) are poorly known outside Finland and the Finnish aapa mire concept as described by Ruuhijärvi (1960) is not established there (see Pakarinen 2001).

There is some deficiency in the present Finnish mire complex classification, however, in that narrow, treed mire chains and networks of the inland, e.g., the Carelian mire complex type of Cajander (1913) etc., are not included in the current typology (see Kokko et al. 2005). The same concerns some minor swamp wetland entities, minor spring and spring fen entities and young mire entities of the land uplift coast in Finland (Rehell 2006ab). Morphologic typology including total mire systems and not only the central parts is lacking for aapa mires (Seppä 1996, Laitinen et al. 2005a). Large mire entities with varying proportions of raised bog and aapa mire parts have proved to be more common in Western and Northern Finland than was previously commonly thought (Heikkilä et al. 2006). Their systematic classification deserves more attention (see Tolonen 1967, Heikkilä et al. 2001). The position of slope fens should be re-evaluated by taking into consideration that they often occur in connection with flat, valley-bottom aapa mires. Earlier, the water flow patterns of mires have been classified in Russia (Ivanov 1981), but in Finland any general terminology and typology has not yet been established. Furthermore, groundwater flow patterns in deeper soil layers, which occur as a part of the total flow pattern within large mire entities and their surroundings, have been discussed only little in Finland (but see Lahermo 1973, Lahermo et al. 1984, Heikkilä et al. 2001).

The aim of this article is to supplement and revise the current Finnish mire complex classification. Two concurrent typologies are proposed: (1) the Combined Finnish Mire Typology (CFMT), which is a rough division for all kinds of mire areas in Finland, and (2) the Mire Water Flow Typology (MWFT) of boreal, zonal mire systems, based on the ideas of Ivanov (1981). Thirdly, the hydrogeologic flow patterns within and between mire systems, and the biological significance of morphologic and hydrologic mire classifications, are discussed. The discussion of the morphology and water flow pattern of zonal mire systems is based on a case study of a typical mid-boreal mire system (Hoikkasuo).

Material and methods

The aerial photograph interpretation was the main research method in this investigation. The Combined Finnish Mire Typology was drawn up as a combination of a literature survey and our own research. For testing the typology, we carried out an aerial photo interpretation on the morphology of the Hoikkasuo mire system in Simo (Figs. 1 and 2). The mire system is situated in the central to northern part of a southern aapa mire zone (Ruuhijärvi 1983), where the morphological diversity of larger mire systems is often high, as the mire systems have characteristics from both the aapa mires and raised bogs. For this reason, such mire systems can serve as a case study for a more general typology of zonal mire systems. The morphology of the Hoikkasuo mire system was compared with the morphology of the Hirvisuo mire system situated a little more south in the same mire zone (Laitinen et al. 2005a).

The Mire Water Flow Typology for boreal, zonal mire systems was compiled on the basis of the interpretation of an aerial photograph (the Hoikkasuo mire system, Fig. 3) and Ivanov's (1981) flow line model. Flow lines were drawn on the basis of the morphological pattern visible in the aerial photograph. The starting points of the flow lines were placed at even intervals and accordingly each flow line shows the annual runoff from a certain area, which in the case of Hoikkasuo was of size 250 m x 250 m. The closer each other the flow lines are situated, the higher the flow rate through the surface layer is, provided that the structure of the surficial peat layer is similar in all parts of the mire and the water flows entirely in the acrotelm.

Hydrogeological flow patterns within and between mire systems were described on the basis of previous studies, especially the inventories made in the Kälväsvaara – Olvassuo area in North-Central Finland (Heikkilä, H. et al. 2001). The biological significance of morphological and hydrological mire classifications, i.e. the dependency of species richness and its maintenance over time on environmental heterogeneity, was discussed on the basis of some recently published, repeated mire system inventories made in Sweden (e.g. Gunnarsson et al. 2000). The results of our investigation and the previous classification basis for Finnish mires and water-flow patterns will be presented as a synthetic description in the next main chapter.

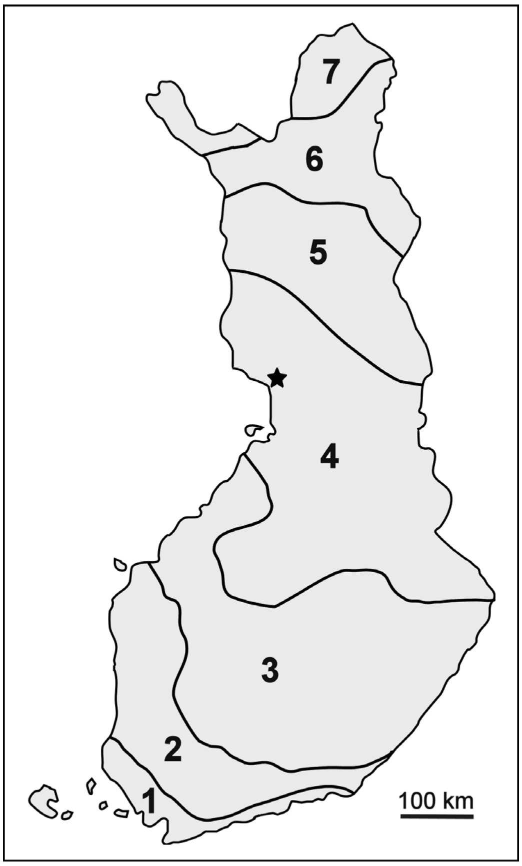

Fig. 1. Mire zones of Finland and the location of the Hoikkasuo mire system presented in Figs. 2 and 3. Mire zones according to Ruuhijärvi & Hosiaisluoma (1988): 1: plateau bogs, 2: concentric bogs, 3: eccentric bogs, 4: southern aapa mires, 5: main aapa mire zone, 6: northern aapa mires, 7: palsa mires.

Kuva 1. Suomen suovyöhykkeet ja kuvissa 2 ja 3 esitetyn suosysteemin (Hoikkasuo) sijainti. Suovyöhykkeet Ruuhijärven & Hosiaisluoman (1988) mukaan: 1: laakiokeitaat, 2: konsentriset kermikeitaat, 3: eksentriset keitaat, 4: eteläiset aapasuot, 5: aapasoiden päävyöhyke, 6: pohjoiset aapasuot, 7: palsasuot.

Synthesis of Finnish mire and water flow classifications

Basic concepts

In this article, *mire morphology* means forms of any size of the mire surface, beginning from hummocks and hollows and continuing up to large mire units detectable from aerial photos. It mainly appears as various *mire surface levels*, which occur as patterns of various forms and sizes. We use three mire surface levels, the *hummock level*, the *lawn* and the *flark level*. Of these, the lawn corresponds to the intermediate level by Eurola et al. (1984, 1995) and the flark level to mud bottom (*Moosarme Rimpigesellschaften*, Ruuhijärvi 1960) and the bulk of carpet (*Moosreiche Rimpigesellschaften*, Ruuhijärvi 1960) by Sjörs (1948). For spruce mires (*Bruchmoore*) of mosaic type (e.g. for herb and grass birch-spruce mires, Eurola et al. 1995) the term *mosaic level* is used. It refers to a mire surface level in which all the three levels or some of them are mixed in a very small (ca 1 m^2) scale.

Threshold is a morphologic micro-scale or meso-scale mire part, in which the gradient of the water table is steeper than in the part situated in the upflow direction from it. The water conductivity of the surface parts of the threshold is lower than in the reservoir. Narrow, sandy raised beach ridges may exceptionally act as similar thresholds in certain mire systems. *Reservoir* is a morphological micro-scale or meso-scale mire part with a plain or relatively plain water table. The water body in the peat of the reservoir is dammed by a threshold.

Surface water (limnogenic water) refers to water in lakes, rivers and brooks (Eurola et al. 1984, 1995). *Geological groundwater* (general groundwater) in this article means the water beneath the groundwater table in any soil (see Freeze & Cherry 1979). *Mire water* is the part of the geological groundwater in peat soil, also including the floodwater on the mire surface. *Mire groundwater* (specific groundwater) is water that flows directly from the mineral soil to peat soil or onto the mire (see Eurola et al. 1984, 1995). *Groundwater flow pattern* (hydrogeologic flow pattern) is the flow pattern formed by the recharge and discharge of geological groundwater (e.g. Freeze & Cherry 1979). *Groundwater recharge area* is an area in which the water table in deep piezometers is below the water table of shallow wells, and the saturated flow takes place downwards. *Groundwater discharge area* is an area in which the saturated flow takes place upwards, towards the water table in shallow wells (e.g. Freeze & Cherry 1979).

Mire water flow is any water flow in the peat layers or above the peat surface in mire systems or in parts of mire systems. The flow may categorically take place either

(a) laterally in the porous surface peat (acrotelm) in diplotelmic mires (Ingram 1978, Ivanov 1981)

(b) laterally through the whole peat column in percolation mires (Succow & Joosten 2001) or

(c) vertically from the mire surface through the peat to deeper layers, mainly within habitats with considerable water level fluctuations (Laitinen et al., in press).

Water flow rate through the mire surface layer is a function of water input and hence can be evaluated with the help of the catchment area, surface flow pattern (flow lines, see Fig. 3), groundwater recharge-discharge pattern and regional climatic data. The flow rate at each point can be quantified as a specific discharge of the surface layer ($m^3\ m^{-2}\ a^{-1}$). This discharge is dependent on water supply and is regulated by the gradient of the slope and the hydraulic conductivity of the surface layer at each point of the mire.

Supplementary vs. *inherent nutrient effect* (Eurola et al. 1984, 1995, Eurola & Huttunen 2006) is a vegetation-ecological concept used in Finland. It is originally derived and revised from the concept mire margin vs. mire expanse by Sjörs (1948). The latter terms were also used e.g. by Ruuhijärvi & Lindholm (2006). It is question here of vegetation gradients defined in accordance with whether the surface peat is constantly being supplied with additional nutrients other than those already present in the peat or supplied by rainwater (Eurola et al. 1984). Mire vegetation exhibiting a supplementary nutrient effect is constantly receiving additional nutrients from various sources, and mire vegetation exhibiting an inherent nutrient effect relies entirely on nutrients already present in the peat or supplied by rainwater. A supplementary nutrient effect appears in three forms, which are briefly listed below (for comprehensive descriptions, see Eurola et al. 1984, 1995).

1. Surface water influence. Additional nutrients are received from moving surface water, especially from river and lake water (limnogenic water) or they occur as the "remnants" of nutrients derived directly from the sea flooding in young mire systems close to the Bothnian Bay.

2. Groudwater influence. Additional nutrients to the mire system are received from moving groundwater derived from mineral soil (specific ground water).

3. Mineral soil influence (spruce mire influence, Eurola et al. 1984, 1995). Additional nutrients are received mainly from the mineral soil through a relatively thin peat layer.

Mire site type (*mire type*) is a basic vegetation unit used in the Finnish mire site type classification (Cajander 1913, Ruuhijärvi 1960, Eurola 1962, Eurola et al. 1984, 1995). It falls between the micro scale (small features) and the meso scale (form parts and small meso units) as compared with the scales of the Combined Finnish Mire Typology. "Mire site" (myrelement) of Sjörs (1948), instead, is a "geographical unit" and corresponds to the meso-scale mire units of the Combined Finnish Mire Typology. Main mire vegetation units (six units) and the mire site types (about 80) in the mire site type classification have been related to the major mire gradients by Eurola et al. (1984, 1995)(cf. Økland et al. 2001), i.e. to the trophic status (poor-rich gradient, Tahvanainen 2004), to water level (water level categories, Laitinen et al. (in press), mire surface levels (in this article)) and to the supplementary vs. inherent nutrient influence.

Aapa mire is defined by Eurola et al. (1995) as a mire complex (system) type whose central parts are characterised by minerotrophy and near-to mire inherent influence and which may receive supplementary nutrients to its central parts — besides marginal parts and brooksides — also through snow-melt water from the surroundings (Eurola et al. 1995). The definition is vegetation-ecological and largely accepted and used in Finland, but poorly known elsewhere (see Pakarinen 2000). Aapa mires are morphologically variable, which is schematically shown in table 1 (including a comparison with a Swedish and a Norwegian system).

Combined Finnish Mire Typology (CFMT)

The Combined Finnish Mire Typology (CFMT) presented here attempts to classify all the mires (within a certain area) in Finland. The treatment of large, zonal mires systems (mire complexes by Ruuhijärvi 1960 etc.) is based on the principles of Ruuhijärvi (1960), Eurola (1962), Tolonen (1967), Eurola & Vorren (1980) and Vorren et al. (1999). The idea of local systems, instead, stems from Cajander (1913). "*Zonal*" refers here to latitudinal mire zones, which were defined in Finland on the basis of the main distribution areas of different mire complex types (Ruuhijärvi 1960, Eurola 1962, Ruuhijärvi 1983, Ruuhijärvi & Hosiaisluoma 1988). Zonal mire systems are climatic formations composed of mire massifs and marginal areas. Of these, the marginal areas are mostly treed while the massifs are usually treeless. "*Local*" refers here to morphologic features other than those formed by latitudinal zonality in large mire systems. Mire massifs are lacking or cover very small areas in the local mire system, and a transition from mires to other wetlands occurs within them.

The CFMT prevalently operates with mire surface levels visible in aerial photographs and the system is mainly morphological. Especially the mire massif types typical of zonal mire systems and the subunits of mire massifs are identified with mire surface levels. In addition, the developmental stage of the mire system must be taken into consideration. The identification of local mire systems presupposes further scrutiny with certain topographic, climatic and hydrologic features of those mire systems.

Mire units of three scales (macro, meso, micro) are included in CFMT (Table 2). The macro and meso scales are additionally divided into corresponding upper and lower subscales. The upper macro scale is represented by mire systems and the lower macro scale by mire massifs and their marginal areas. The mire massifs (the lower macro scale) do not occur in all mire systems, and in such cases the subdivision into the upper and lower subscale is not applied. The meso scale calls for a corresponding scrutiny: the upper meso scale (form parts of mire massifs) only occurs in mire systems with mire massifs (zonal mire systems) and even then not in all of them. The small features of mires represent the micro scale.

Mire systems

Mire systems form the largest scale units within the CFMT (Table 3). By our definition, a mire system is any uniform mire area surrounded by mineral soil areas or watercourses. In the case of uniform, large branching network-like mire areas, one system can be practically separated, if necessary, by the narrowest points of the mire branches. Accordingly, the mire systems range from large mire entities with several mire massifs to small mire patches surrounded by mineral soil and without any mire massifs. In Russian typologies, however, the mire system means a complex structure always consisting of mire massifs (e.g. Yurkovskaya 1995). Mire massif, by our definition, is a uniform peatland block with a convex, concave or sloping gross profile. In Finland, where there are no extremely oceanic areas, mire massifs only include various raised bog massifs and various aapa mire massifs.

Mire basin is a primary, concave topographic form on which the mire system is forming or has formed. The form of mire basins, i.e. the original topography of the ground surface, affects the type of forming mire systems while the geological age of the mire system affects their succession stage. Mire systems may even cover larger areas than the primary mire basins in geologically older areas in Finland, if the topography is not very dissected and the valley sides are not too steep and high. In geologically young areas, e.g. in the land uplift coast of the Gulf of Bothnia, mires just cover the bottoms of mire basins (Rehell 2006a, 2006b).

Young mire systems (Table 3) denoted here are mire systems in the immediate vicinity of the coast, where the land uplift phenomenon affects the succession of all the vegetation. Parts of these

Table 1. Zonal, eco-climatic mire complex types by Eurola & Kaakinen (1979). Mire type classifications of Malmer (1985) and Moen (1985) elucidate the differing concepts in Scandinavian typologies as compared with the Finnish typology.

Taulukko 1. Vyöhykkeelliset, ekoklimaattiset suokompleksityypit Eurolan & Kaakisen (1979) mukaan. Vertailuna Malmerin (1985) ja Moenin (1985) skandinaaviset luokitusjärjestelmät.

I. Zonal, eco-climatic mire complex types[1] – from about subtropic to arctic zones	II. Hydrotopographic mire types (Malmer 1985)	III. Hydromorphological mire types in Norway (Moen 1985)
1. Limnogenic mire complex type	1. Bog mire complexes	1. Typical raised bogs
2. Raised bogs (of various types)	– Blanket bog complexes	2. Atlantic raised bogs
3. Aapa mires	– Raised bog complexes (eccentric or concentric)	3. Plane bogs
– flark-string aapa mires	– Flat bog complexes	4. Blanket bogs
– lawn (intermediate level) aapa mires	2. Fen mire complexes	5. Mixed mires
– slope mires	– Aapa fen complexes (string mires, patterned mires)	– string mixed mires
– palsa mires	– Topogenous fen complexes (horizontal)	– island mixed mires
4. Arctic mires	– Soligenous fen complexes (sloping, incl. spring fens)	– palsa mires
	– Palsa mires	6. Minerotrophic mires
		– flat fen
		– sloping fen
		– flark fen

[1](Eurola & Kaakinen 1979)

mire systems are developing into zonal, climatic mire systems (B in Table 3). Mire systems of this kind are typically wet and lack a flark-string pattern but differentiation into various parts is taking place in them (Rehell 2006a, 2006b).

Zonal mire systems (Table 3) are here named according to their mire massifs and they form a continuum (1–5), which is more in response to a climatic gradient and less to local conditions (e.g. Tolonen & Seppä 1994). The zonal, climatic mire system continuum ranges from raised bog systems to aapa mire systems on the basis of the dominance of the main mire massif types as follows.

1. Ordinary raised bog systems (ordinary raised bog complexes) are mire systems, in which raised bog massifs dominate and no other mire massif types (aapa mire) occur. These mire systems are probably common in raised bog zones in Southern Finland.

2. Raised bog systems with aapa mires (raised bog complexes with aapa mires) are mire systems, in which there is at least one aapa mire massif along with dominating raised bog massifs. The abundance of mire systems of this kind in Finland is not well known. A large “classic” mire locality, the Skattlösbergs Stormosse in Central Sweden, seems to fall in this category. Sjörs (1948), who described the site, of course did not use this concept.

3. Raised bog-aapa mire systems (raised bog-aapa mire complexes) are mire systems, in which raised bog and aapa mire massifs dominate and both of the main massif types cover almost equal areas (*Mischkomplexe,* Tolonen 1967). They have been originally described from Eastern Finland (Northern Karelia) where they occurred in a transitional area between raised bog and aapa mire zones (Tolonen 1967). Such large mire systems, however, are found in North-Central Finland (Revonneva-Ruonneva, Rehell 2006c) and in Western Finland (Kauhanneva, Heikkilä et al. 2001, Heikkilä et al. 2006) and even in Southern Finland (Tolonen & Seppä 1994).

4. Aapa mire systems with raised bogs (aapa mire complexes with raised bogs) are mire systems, in which there is at least one raised bog massif along with dominating aapa mire massifs. This is a common mire system type in the southern aapa mire zone. Hoikkasuo (Fig. 2), and Hirvisuo mire systems (Laitinen et al. 2005a, Huttunen & Laitinen 2006) belong to this type. Larger raised bog massifs occur especially in lake or river shores with good drainage conditions while smaller massifs are found near esker formations with a sandy mineral soil beneath the peat (e.g. Laitinen et al. 2005a).

5. Ordinary aapa mire systems (ordinary aapa

Table 2. Scales and mire units in the Combined Finnish Mire Typology (CFMT) as compared with the geographic system of Sjörs (1948) and the general system proposed by the International Mire Conservation Group.

Taulukko 2. Yhdistetyn suomalaisen soiden tyypittelyn (CFMT) tasot ja suoyksiköt rinnastettuna Sjörsin (1948) maantieteellisen suotyypittelyn ja IMCG:n tyypittelyn yksikköihin.

CFMT			Sjörs (1948)	IMCG
Scale		Mire units (formerly used terms in parenthesis)		
Macro	Upper macro	Mire systems (mire complexes etc.)	Myrkomplex	Mire system
	Lower macro	Mire massifs & marginal areas (mire complex types)		Mire massif
Meso	Upper meso	Form parts of mire massifs (form parts)		
	Lower meso	Lower meso units	Myrelement, mire site	Mire site
Micro		Small features (small features)	Myrstruktur, mire feature	Mire feature

mire complexes) are mire systems, in which aapa mire massifs dominate and no raised bog massifs occur. Ordinary aapa mire systems probably occur in the southern aapa mire zone mainly as relatively small, unbranched mire systems but may occur in more northern aapa mire zones also as large, branched mire systems. *Sphagnum fuscum* bogs of aapa mire margins (Tolonen 1967, Tolonen & Seppä 1994, Laitinen et al. 2005a) commonly occur in connection with peripheral lobes (see chapter Lower meso units). They are not regarded as raised bog massifs.

Local mire systems (C inTable 3) are mire (to mire-like wetland) systems in which mire mas-

Table 3. Mire systems and mire massifs in the Combined Finnish Mire Typology (CFMT). Upper macro scale refers to mire systems and lower macro scale to mire massifs and the marginal areas of mire massifs. For the meso-scales and micro-scales of zonal mire systems, see Table 4.

Taulukko 3. Suosystemit ja suomassiivit yhdistetyn suomalaisen soiden tyypittelyn (CFMT) mukaan. Yläsuurtaso tarkoittaa suosysteemejä ja alasuurtaso suomassiiveja ja suomassiivien marginaalialueita. Vyöhykkeellisten suosysteemien keski- ja pientason tyypittely on esitetty taulukossa 4.

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1. Mire systems – Upper macroscale

A Young mire systems: mire massifs (raised bog massifs, aapa mire massifs) are not yet formed

B Zonal mire systems (*mire complexes*): climatic mire systems in which raised bog and/ or aapa mire massifs occur

- ordinary raised bog systems: only raised bog massifs occur
- raised bog systems with aapa mires: raised bog massifs dominate, aapa mire massifs occur
- raised bog-aapa mire systems: raised bog massifs and aapa mire massifs with about equal proportions
- aapa mire systems with raised bogs: aapa mire massifs dominate, raised bog massifs occur
- ordinary aapa mire systems: only aapa mire massifs occur

C Local mire systems: mire systems strongly affected by local climatic, local topographic or local hydrologic conditions and thus raised bog or aapa mire massifs do not occur or only minor and poorly delimited mire massifs may occur; transition appears from mire systems to other wetland systems

a. Local, topographic-climatic mire systems: local climate caused by high elevations and hilly topography suppress the occurrence of raised bog and aapa mire massifs

- ordinary slope fen systems and aapa mire-slope fen systems

b. Local, topographic mire systems: local topography in itself does not allow the formation of mire massifs

- paludified areas on rock surfaces
- small depression mires (incl. e.g. such mires in morainic topography and kettle hole mires)
- depression-network mire systems

c. Local, hydrogenetic wetland systems: local hydrology does not allow the formation of mire massifs; transition appears from mire systems to other wetlands

- spring & spring fen systems: abundant groundwater discharge prevents the formation of mire massifs
- swamp wetland systems: abundant surface water influence prevents the formation of mire massifs
- aro wetland systems and mire-aro wetland systems: large fluctuations in water table level in aro wetlands prevent the formation of mire massifs and the peat layer proper

2. Mire massifs and marginal areas (*Mire complex types*) – Lower macroscale

Mire massif types

- raised bog massif
- aapa mire massif: lawn aapa mire massif, lawn-flark aapa mire massif, flark aapa mire massifs

Marginal areas of zonal mire systems

- laggs (in raised bog systems)
- various forest mires (in aapa mire systems)

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sifs (lower macro scale) are lacking or are very small-sized and only cover a small proportion of the whole mire system. They are divided here into three groups. (a) In local, topographic-climatic mire systems the formation of raised bog or aapa mire massifs is prevented by a hilly topography and the oceanic local climate caused by high altitudes. (b) In local, topographic mire systems, local topography (narrow and steep-sided mire basins etc.) prevents the formation of mire massifs and (c) in local, hydrogenetic wetland systems, the formation of mire massifs is prevented by local hydrology.

a. Local, topographic-climatic mire systems include o*rdinary slope fen systems.* These are separate slope fen systems, which do not directly combine with more flat aapa mires. Instead, *aapa mire-slope fen systems* are combinations of slope fens and more flat aapa mires. In Finland, slope fens may be regarded "local" and they occur here and there in mid-boreal and north-boreal zones in the eastern (Havas 1961) and northern parts of the country. When the whole Fennoscandia is considered, their specific zonal and especially sectional distribution becomes more evident (Eurola & Vorren 1980, Vorren et al. 1999, Moen 1999). Slope fens are very rare in Finland, but more common and abundant in those parts in mountaneous Scandinavia where climatic conditions are suitable. Slope fens have been mainly regarded as a topographic variant of aapa mires in Finland (Ruuhijärvi 1960, Havas 1961, Eurola & Kaakinen 1979, Eurola et al. 1984, 1995). In this connection slope fen merely denotes middle or northern boreal (see e.g. Havas 1961, Dierssen 1996, Moen 1999) slope fens (slope angle more than 3 degrees), which are essentially lawn fens with no or very scattered strings and flarks. Thus the principal morphological features of the slope fens denoted here are the considerable slope and the occurrence of lawn (for peat characteristics, see Auer 1923, for climatic presupposes, see Eurola & Vorren 1980 and Eurola & Huttunen 1984). Spruce mire (*Bruchmoor*) chains on slopes with no lawn fen do not belong to the slope fens denoted here. Most slope fens in Finland probably occur as combination mire systems with aapa mires, while ordinary slope fen systems may be very rare.

b. Local, topographic mire systems denoted here form a collective, heterogeneous group for all those mire systems, in which the local topography of bedrock or mineral soil has prevented the formation of zonal mire systems, but which are not bound to specific, local climatic conditions. These mire systems are mainly composed of pine mires (*Reisermoore,* Ruuhijärvi 1960) and spruce mires (*Bruchmoore,* Tuomikoski 1942, Ruuhijärvi 1960) like the marginal areas of climatic mire systems, but may include treeless or sparsely treed mire parts (*Weissmoore* or *Braunmoore,* Ruuhijärvi 1960 etc.).

1. Paludified areas on rock surfaces are typically small-sized and broken mire systems in areas where outcrops occur abundantly, but are lacking in areas where outcrops do not occur. Outcrops as a whole are convex or sloping formations. Paludified patches and areas on them most often occur in small depressions but also on an even or sloping rock-substratum.

2. Small depression mires occur in a separate depression whose breadth reaches from some meters or some tens of meters to some hundreds of meters. Such small mires may occur everywhere, e.g. in monrainic or glaciofluvial topography. In the latter case more or less round kettle hole mires are typical. In some cases even small kettle hole mires may have features of mire massifs, e.g. features of raised bog massifs (Reinikainen et al. 1984).

3. Depression-network mire systems are a mire system type typical of large areas in Fennoscandia with highly broken bedrock and small-scaled topography. In those regions the mire basins are branching and form networks. They are, however, so narrow and steep-sided that pronounced raised bog or aapa mire massifs cannot be formed. Minor mire massifs or massif-like sites, instead, may occur especially at the crossing points of the mire networks (see Cajander 1913). It may be difficult to identify a mire massif from the rest of the mire area in these mire systems. The Carelian mire complex type of Cajander (1913) roughly corresponds to this type. According to Cajander (1913), that type is the most common mire complex type of all in large areas in Southern and Eastern Finland.

c. Local, hydrogenetic wetland systems denoted here form a collective group of mires and wetlands, in which the conditions in water flow or in fluctuations of the water table level are such that raised bogs or aapa mire massifs cannot be formed. Three subgroups of this group also represent the extreme ends of three mire ecological gradients i.e. the gradient of groundwater influence (Eurola et. al. 1984, 1995), the gradient of surface water influence (Eurola et al. 1984, 1995) and the gradient in fluctuations of water table level (Laitinen et al., in press).

1. Spring & spring fen systems are aquatic, wetland or mire systems, in which the discharge of specific groundwater and the small size of the topograhic basin prevent the formation of mire massifs. They are very rare as individual wetland systems in Finland (Repo 1955, Ulvinen 1961), because most springs and spring fens occur in connection with zonal mire systems etc.

2. Swamp wetland systems are wetland or mire systems in which surface water influence (Eurola et al. 1984, 1995), i.e. the influence of limnogenic water (river water, lake water etc.) or otherwise very moving water in the mire, continuously keeps the wetland system devoid of typical mire massif features. These systems occur in the climatic area typical of Finland usually in connection with other mire system types, but may form exceptionally distinct small swamp wetland systems (Mäkinen 1978, 1979). Zonal swamps (limnmogenic mire complex type, Table 1), according to Eurola & Kaakinen (1979) and Eurola et al. (1984), occur south of the zones of various bogs far south from Finland in an area where the formation of mire-like vegetation is restricted to near watercourses.

3. Aro wetland systems are temporary wetlands (Gopal et al. 1990), in which large fluctuations in water table level and seasonal drought prevent the formation of a peat layer proper, and hence also mire massifs do not occur (Laitinen et al. 2005b). They occur outside permanent watercourses in sites where flood water can penetrate into the mineral ground or evaporate during dry seasons in summer. Aro wetlands occur either as separate wetland systems or as combinations with mires. Individual aro wetland systems are very small, ranging from some acres to some hectares in size. In North Central Finland, where the aro wetlands are most abundant and largest, they are usually combined with zonal mire systems (*mire-aro wetland systems*).

Mire massifs and marginal areas

Mire massif is a large, morphologic mire unit with a convex, plain, sloping or concave gross profile and with one to several microtopographically uniform sub-areas (meso units) usually situated regularly in relation to each other (Table 3). Mire massifs are always real peatlands and form the “main peatland blocks” of mire systems. Mire massifs at first attract attention when large mire areas are viewed in aerial photographs. The formation of a mire massif always takes a certain time; in quite young mire systems, typical mire massifs are not yet formed. Yurkovskaya (1995) uses the mire massif as a synonym for the mire complex type used by Cajander (1913). We apply it for raised bogs so that the lagg is left out of the massif to the marginal area. This is due to simple morphologic reasons: uniform, convex to plain to sloping raised bog massif formation essentially makes up the central plain and the marginal slope only, the lagg is evidently “something else” in the morphological sense.

Main mire massif types include the raised bog and the aapa mire massif. Micro-scale and meso-scale morphological patterning in mire massifs is typical of climatic mire zones in Finland (Ruuhijärvi 1960, Eurola 1962, Ruuhijärvi 1983, Ruuhijärvi & Hosiaisluoma 1986). The main mire massif types are briefly characterised below.

1. Raised bog massif is a zonal (climatic) mire massif type of boreal and temperate zones. Its vegetation is ombrotrophic and the gross profile is convex to plain to slightly sloping.

2. Aapa mire massif is a zonal mire massif type of the boreal zone. Its central parts have minerotrophic vegetation of a mire expanse character. The gross profile is typically concave. The most characteristic feature of aapa mire massifs in aerial photos is the definite patterning of wet areas (flark level) in relation to lawn and hummock-level areas. This shows as a transversal, micro-scale flark-string pattern or as a longitudinal, meso-scale soak-lobe pattern. Aapa mires are practically flat or considerably sloping either partly or totally, which can even be seen by the eye, as is sometimes the case in a hilly terrain in North-Eastern and Northern Finland and e.g. in northern Dalarna in Central Sweden (see e.g. Sjörs 1973, Rydin et al.1999).

Subtypes of raised bog and aapa mire massifs correspond to the climatic mire zones in the lowland-dominated Finland (Fig. 1). According to Ruuhijärvi & Hosiaisluoma (1984), the subtypes of raised bog massifs, with small additions, include (1) the plateau bog (Hummock plateau bog & Hummock-hollow plateau bog), (2) Concentric domed bog, (3) patterned eccentric bog and (4) unpatterned eccentric bog (Fuscum bog & Forest bog). In aapa mires we separate three subtypes of massifs, which include (1) lawn aapa mire (predominantly in the southern part of the southern aapa mire zone), (2) lawn-flark aapa mire (predominantly in the northern part of the southern aapa mire zone) and (3) flark aapa mire (predominantly in the main aapa mire zone and north of it). In addition to those mentioned above, there are at least two intermediate massif types of aapa mires and raised bogs: 1) an aapa mire - raised bog intermediate type with the morphology of hummock-ridged raised bogs but with minerotrophic vegetation in the hollows/flarks (Laitinen et al. 2005a) and 2) an aapa mire - raised bog intermediate type with the morphology resembling that of lawn aapa mires but having totally ombrotrophic vegetation within lawns (Sallinen 2005). Brief descriptions of aapa mire massif types are given below.

1. Lawn aapa mire massif is an aapa mire massif, in which lawn dominates but flark level (mostly carpet) often occurs in the form of longitudinal soaks. Soaks may lack in some cases or the longitudinal lobe-soak pattern is visible in aerial photos but hardly detectable in the field.

2. *Lawn-flark aapa mire massif* is an aapa mire massif, in which peripheral lobes and various flark fens (string flark fens, unoriented flark fens, flark outlets) dominate. It seems to be a very widely spread mire massif type but has not been specifically termed before in Finland. The main distribution is in the southern aapa mire zone, especially in the northern half of it (Ruuhijärvi 1983).

3. Flark aapa mire massif is an aapa mire massif overwhelmingly dominated by the flark level. Flark aapa mires dominate in the central and northern parts of the whole aapa mire zone.

Marginal areas of zonal mire systems include the laggs of raised bogs and various forest mires of aapa mires. Marginal areas are not divided here into meso-scale units as are the mire massifs.

1. Laggs are narrow, minerotrophic formations at the boundary between the raised bog massif and the mineral soil. They are minerotrophic and do no belong to raised bog massifs morphologically but rather form an entity of their own (cf. concept raised bog complex, e.g. Eurola 1962). Laggs may be treeless fens, treed fens or forest mires (densily treed mires, which are not treed fens).

2. Various forest mires are typical of the marginal areas of aapa mire systems. They include many kinds of densely forested mires, which do not belong to the peripheral parts of aapa mire massifs. There is no natural boundary between the peripheral parts of the aapa mire massifs and the forest mires in the marginal areas of aapa mire systems: the boundary is in most cases fully conventional.

Form parts of mire massifs

The gross profiles of aapa mires are typically concave, whereas those of raised bogs are typically convex (e.g. Seppä 1996). Accordingly, one may expect that in both the main mire massif types some kind of a morphological centre vs. periphery differentiation can be found. These parts have been called form parts (*Formenteile*) in the case of raised bogs (Aario 1932 etc.) and they include the central plain and the marginal slope (Table 4). In connection with aapa mires such morphology has not been discussed, but corresponding “dual morphology” has been found in the aapa mire massifs of the Hoikkasuo (Fig. 2) and the Hirvisuo mire systems (Laitinen et al. 2005a). In those cases the *central basin* is formed by different flark fens, which are surrounded by the *peripheral parts* of aapa mire massifs. These are composed of various treeless or treed lawn fens or hummock-level areas. The same dual form-part-pattern evidently reappears in most but not in all aapa mire massifs, e.g. in typical flark aapa mire massifs of the main aapa mire zone. There the difference in wetness and morphology between the large central basin and the narrow peripheral part (peripheral fringe) may be even more evident than the corresponding difference in the southern aapa mire zone (see the transitional border between the central basin and the peripheral part of the aapa mire massif in the eastern part of the Hoikkasuo mire system, Fig. 2).

Lower meso units

Lower meso units are mire parts in which two or more mire surface levels alternate regularly, or mire parts in which either the flark level or the lawn and hummock level or hummock level dominates. Units have a typical flow pattern. Lower meso units for aapa mire massifs with well-developed form parts (Fig. 2, Table 4) will be briefly described below.

The central basins of aapa mire massifs may include the following lower meso units.

1. String flark fens have a parallel-oriented flark-string pattern (Fig. 2: pattern 4). Strings are either lawn strings or *Sphagnum fuscum* strings. The latter refers to string-mixed mires as known in the Scandinavian classifications. Flarks are mainly composed of a mud bottom, in marginal parts also of carpet. This is the most important mire unit in the aapa mires of the main aapa mire zone (Ruuhijärvi 1983) but it is also abundant in the southern aapa mire zone of Finland. The type corresponds to parallel-patterned fens of Laitinen et al. 2005a. Parallel flow (Cajander 1913) is a characteristic feature (Fig. 3).

2. Unoriented flark fens are plain flark level areas with or without scattered strings and with a divergent flow pattern. They include stringless central flark fens and reservoir-infiltration basins of Laitinen et al. (2005a). (a) *Stringless central flark fens* (Fig. 2: pattern 5) are wet flarks surrounded by string flark fens and occasionally by a small raised bog massif from one side (Laitinen et al. 2005a). The occurrence of this unit together with small raised bog massifs suggests the complexity of the morphological response to a divergent flow pattern in the central basins of aapa mire massifs in the southern aapa mire zone. The transition from this unit to string flark fens is gradual. The unit corresponds to flark crosses and flark triangles of Sjörs (1973, 1983) and is very common in flark and lawn-flark aapa mires throughout Finland. In the classic Finnish aapa mire site, the Heikinjärvenneva mire, for instance, there is a stringless central flark fen of considerable size as compared with the size of the mire massif (Cajander 1913, Tahvanainen 2006). (b) *Reservoir-infiltration basins* in flark fens have only been described from the Hirvisuo mire system (Laitinen et al. 2005a) in the southern aapa mire zone. There they only occur in mire areas with a very thin peat layer and sand beneath it. In mire-aro wetland systems they are more numerous in Northern Ostrobothnia.

3. Outlet fens are typically narrower places bordered by mineral soil from two sides in the middle of chain-like mire systems (Fig. 2: pattern 6). The sites are characterised by a conver-

Table 4. Form parts (upper meso scale) in raised bog and aapa mire massifs, lower meso units in aapa mire massifs and the most important micro-scale units in raised bogs and aapa mires. For the macro scale of CFMT, see table 3.

Taulukko 4. Keidas- ja aapasuomassiivien muoto-osat (yläkeskitaso), aapasuomassiivien alakeskitason yksiköt sekä keidas- ja aapasuomassiivien tärkeimmät pientason yksiköt. CFMT:n suurtason yksiköt esitetään taulukossa 3.

1. Form parts in mire massifs – Upper mesoscale
   - a. Centre
     - central plain (in raised bog massifs)
     - central basin (in aapa mire massifs)
   - b. Periphery
     - peripheral (marginal) slope (in raised bog massifs)
     - peripheral part (in aapa mire massifs)
2. Lower meso units in aapa mire massifs – Lower mesoscale
   - a. In central basins:
     - string flark fens
     - unoriented flark fens: stringless central flark fens, reservoir-infiltration basins
     - outlet fens
   - b. In peripheral parts
     - peripheral lobes and fringes
     - interlobate soaks
3. Small features – Microscale
   - a. In raised bog massifs: hummock ridges, hollows etc.
   - b. In aapa mire massifs: strings, flarks (rimpis) etc.

gent flow pattern (Fig. 3) and abundant flow. They may be accompanied by weak groundwater discharge from the underlying mineral soil. The concept outlet fen denoted here does not refer to e.g. densely treed birch-spruce mires at the outlet brooks of mire systems, but exclusively to fen sites visible as fen units of their own in aerial photos, either dominated by flark level or lawn. Flark level outlet fens mostly occur at narrower places in the middle of flark-level entities in aapa mires (see Fig. 2). They are only slightly sloping but more sloping than the string flark fens on their proximal and distal sides. The form of the pattern (area) may be slightly funnel-shaped. In flark level outlets the transversal flark-string pattern typical of aapa mires turns into a pattern in which the strings are situated very close to each other and can only be separated with difficulty from each other in aerial photos, or even into almost a longitudinal pattern. Exceptionally, the outlet fens of this kind almost completely occupy the central parts of certain aapa mire massifs. This type of aapa mire has some similarities in peat structure and in water permeability to the "percolation mire" described in Central Europe (Succov & Joosten 2001). The morphology, hydrology and vegetation of mires of this type were studied by Rehell (1985) in Pilpasuo, although the concepts outlet fen or percolation mire were not used or referred to. Olvassuo mire system has a very large outlet fen (see Heikkilä et al. 2001, Rehell & Tahvanainen 2006). Lindholm & Heikkilä (2006) call those mire parts percolation mires, stating that percolation mires differ from true aapa mires in terms of their structure and vegetation. Lawn level outlet fens are more sloping than flark level outlet fens. Small mud-bottom like water tracks (small seasonal rivulets) may occur. Seasonal drought and partly seasonal flood are typical and transitions from lawn level outlet fens to small slope fens may occur. These outlet fens deviate abruptly from percolation-fen-like outlet fens in terms of their peat structure (see Auer 1922) and hydraulic conductivity of the peat.

The peripheral parts of aapa mire massifs may include the following lower meso units.

1. Peripheral lobes and fringes form a clearly visible zone between marginal areas and various flark fens in aapa mires. Peripheral lobes (Fig. 2: pattern 3) are broad, include large lawn fen and treed lawn fen (even small *Sphagnum fuscum* bog) areas and constitute essential parts in the lawn-flark aapa mire massifs of the southern aapa mire zone (Ruuhijärvi 1983). Peripheral fringes are narrow and typically occur in flark aapa mire massifs in the main aapa mire zone in Finland (Ruuhijärvi 1983). This unit is characterised by a divergent (to parallel) flow pattern (Fig. 3).

2. Interlobate soaks are long, narrow and band-like moister areas between peripheral lobes in aapa mire massifs (Laitinen et al. 2005a) (Fig. 2: narrow patterns within patterns 3). Interlobate soaks in the aapa mire massifs combine with central basins at their distal ends. In raised bog systems or in raised bog-aapa mire systems, as in the Revonneva-Ruonneva mire system south of Oulu, there are soaks that do not combine with the central basins of aapa mire massifs but fade into the bog (Rehell 2006c). There may further be soaks between various raised bog massifs in raised bog-aapa mire systems or in raised bog systems with aapa mires, e.g. as in the case of the Skattlösbergs Stormosse in Central Sweden (see Sjörs 1948). Although the soaks in all cases represent sites with a more pronounced possibility of water movement in comparison with their surroundings (more wet surface than in their surroundings), there is, however, considerable variation within the ecohydrology of soaks between different mire systems in that soaks range from poor *Sphagnum*-dominated carpet soaks (e.g. in Hirvisuo, Laitinen et al. 2005a) to soaks originating from springs at mineral-soil edges and hence representing routes through which groundwater discharges to mire systems. This is the case e.g. in the Skattlösbergs Stormosse (Sjörs 1948, Gunnarsson et al. 2000).

Small features

Small features (small parts, small forms) or the microtopography of mires includes the hummock banks and hollows of raised bogs and flarks, strings, pounus and palsas of aapa mires (Table 4). These features are out of the scope of this article; they have been much discussed in mire literature (e.g. Foster & King 1984, Seppälä & Koutaniemi 1985, Foster & Fritz 1987, Seppä 1994, Oksanen 2005, Seppälä 2005).

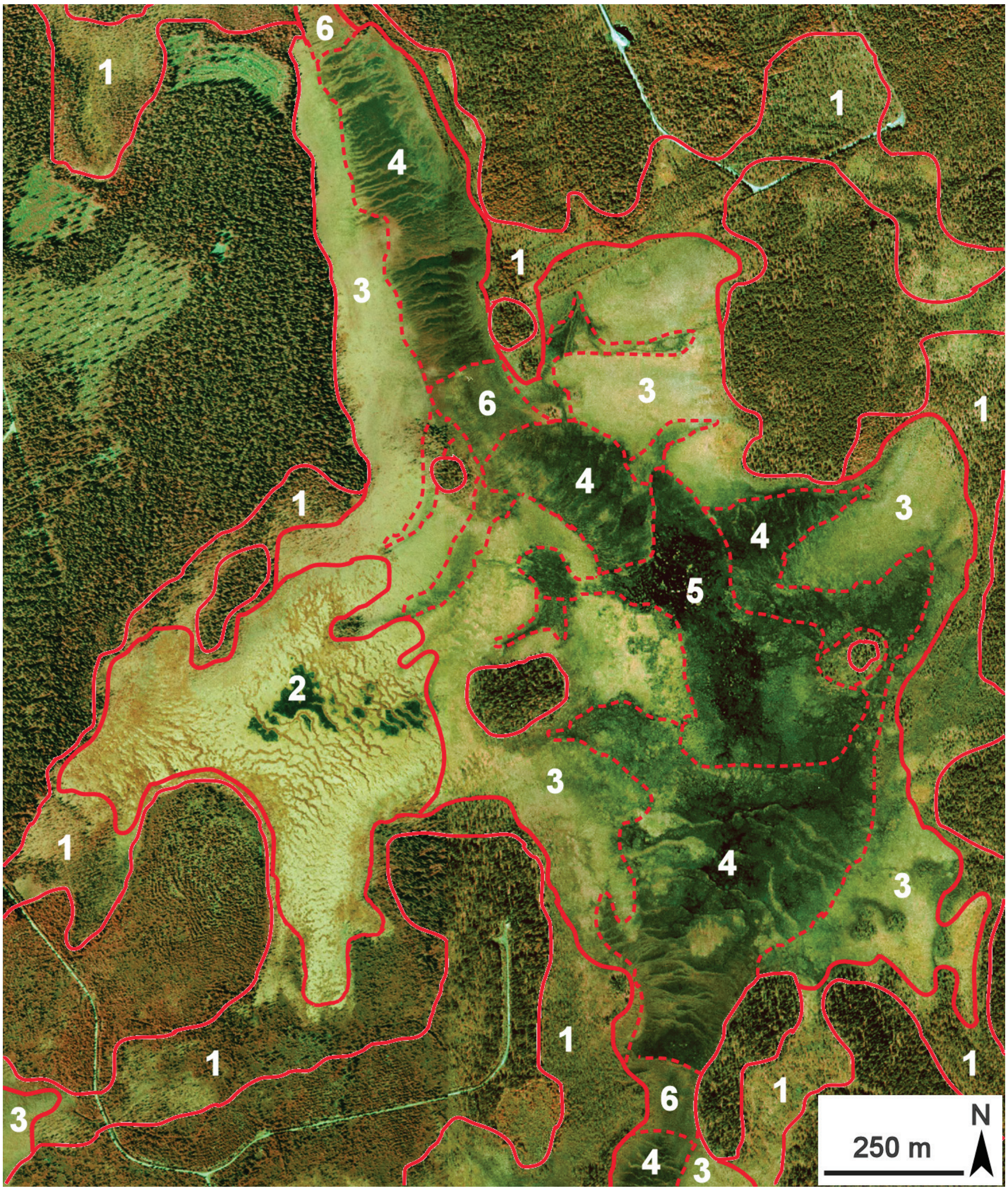

Fig. 2. The CFMT applied for the Hoikkasuo mire (65º 42' N, 25º 1' E, c. 70 m a.s.l., see Fig. 1), an aapa mire system with a raised bog. The mire system has marginal areas (1) around mire massifs, a patterned eccentric bog massif (2) and a lawn-flark aapa mire massif in the N-S direction. In the aapa mire massif, there are peripheral lobes (3) interrupted by soaks, string flark fens (4), stringless central flark fens (5) and outlet fens (6). Unit 3 (with soaks) forms the peripheral part and units 4–6 the central basin of the aapa mire massif. The patterns have been drawn on the basis of aerial photograph interpretation.

Kuva 2. CFMT sovellettuna Simon Hoikkasuon (65º 42' N, 25º 18' E, c. 70 m a.s.l., ks. kuva 1) muodostamaan keidasaapasuosysteemiin. Suosysteemissä on massiiveja ympäröivien marginaalialueiden (1) lisäksi kermikeidassuomassiivi (2) ja etelä-pohjoissuuntainen väli-rimpipinta-aapasuomassiivi, jossa syrjälohkot (3) osittain juottien katkomina, jännerimpinevat (4), jänteettömät keskusrimpinevat (5) ja purkusuot (6). Syrjälohkot juottien kera muodostavat aapasuomassiivin syrjäosan ja yksiköt 4–6 sen keskusaltaan. Kuviot on piirretty ilmakuvatulkinnan avulla.

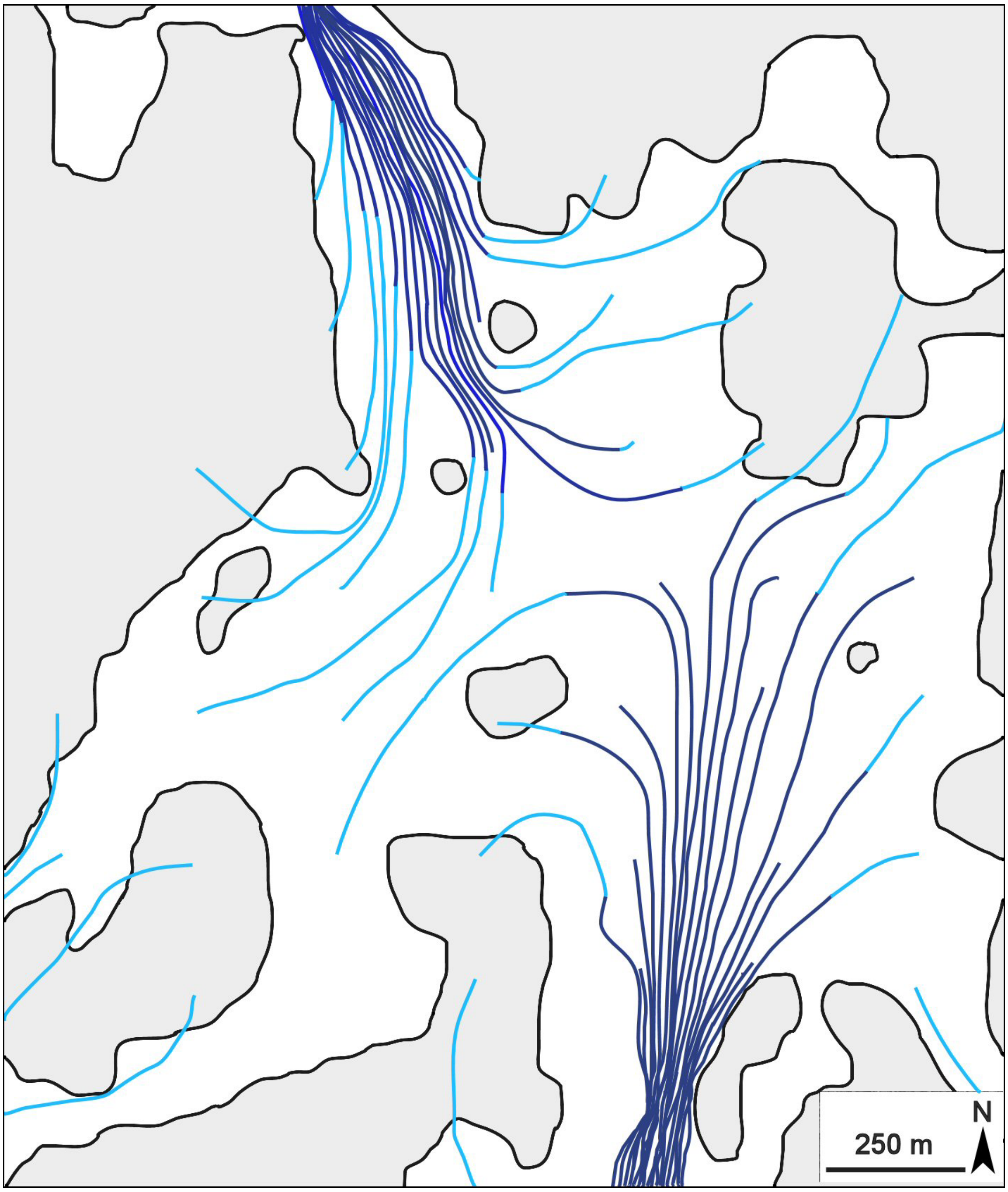

Fig. 3. Mire water flow pattern according to the MWFT applied for the mire system presented in Fig. 2. The flow lines of Ivanov (1981) with a donor-receiver pattern are presented: the light blue parts of the lines refer to waterflow within donor segments and dark blue lines to flow within receiver segments. The dark continuous line shows the border of the mineral soil areas.

Kuva 3. Kuvassa 2 esitetyn suosysteemin suoveden virtauskuviointi MWFT:n mukaan. Ivanovin (1981) virtausviivojen avulla esitetty myös luovuttaja-vastaanottajakuviointi: vaaleansiniset viivanosat tarkoittavat virtausta luovuttajaosan alueella, tummansiniset virtausta vastaanottajaosan alueella. Tumma kokoviiva on mineraalimaa-alueiden raja.

Mire Water Flow Typology (MWFT) for boreal, zonal mire systems

The mire systems in Finland mostly and for much of their area fall into the category of acrotelm mires, and the mire water flow pattern can be presented by the flow-line model of Ivanov (1981). The model presupposes the flow of mire water to take place laterally in the porous surficial peat layer (acrotelm), with the flow in deeper parts and the groundwater discharge from mineral soil to peat being of minor importance in the degree that they must not be taken into consideration (e.g. Cowenberg & Joosten 2005). The Hoikkasuo mire system, which was already discussed in connection with the CFMT (Fig. 2), involves a case study for the mire water flow pattern in a typical mid-boreal, zonal mire system (Fig. 3).

Flow segments of the mire system

The aerial view of the Hoikkasuo mire system (Fig. 2) shows a somewhat (weakly) dual pattern visible in the morphology: the peripheral parts of the aapa mire massif (together with marginal areas) and the eccentric bog massif can be seen as lighter patterns in relation to the darker central basin of the aapa mire massif. This morphologically dual total pattern (hydrotopographic pattern by Laitinen et al. 2005a) is a response to the water flow pattern (Fig. 3). Lighter i.e. drier peripheral parts of the mire system (Fig. 2: patterns 1, 2 and 3) form the donor segments and the darker i.e. more wet central parts the receiver segments of the mire system (Fig. 2: patterns 4, 5 and 6). The *donor segments* yield water to the receiver segments and the *receiver segments* receive water from the donor segments and convey it out of the mire system. This differentiation of the mire system into two flow segments refers to different water flow rates in the segments according to the diplotelmic model: the more wet receiver segments have higher water flow rates than do the drier donor segments, provided that the gradient of the water table is the same in both the segment types. Brinson (1993) originally used a three-division (donor, receptor, conveyor) model for wetlands on the basis of the principal water source (precipitation, groundwater, overland flow). For boreal mire systems the concepts receptor and conveyer of Brinson (1993) have been partly combined (receiver segment). The receiver segments correspond to central aapa mire areas in a case study of Hirvisuo in the southern aapa mire zone in Finland (Laitinen et al. 2005a), and the donor segments correspond to peripheral aapa mire areas in that study.

Flow subsegments

The donor and receiver segments in zonal mire systems can be mechanically further subdivided into flow subsegments according to a divergent, parallel or convergent flow pattern, which for each aapa mire unit was already touched upon in connection with the CFMT. A concluding list is given below.

1. Subsegment *donor-divergent flow* is typical of the central parts of raised bogs and partly peripheral lobes of aapa mires. This subsegment is characterised by a stepwise gradient of the water table with a micro-scale threshold-reservoir pattern or an evenly sloping water table.

2. Subsegment *donor-parallel flow* is typical of the peripheral (marginal) slopes of raised bogs and narrow peripheral fringes of aapa mires. The peripheral slopes of raised bog massifs form a meso-scale threshold in raised bog massifs.

3. Subsegment *donor-convergent flow* occurs in soaks. The gradient of the water table is typically evenly sloping, especially in very narrow soaks. In broader soaks, a weak micro-scale threshold-reservoir pattern, i.e. flark-string pattern, has been encountered. This is the case e.g. with the Hirvisuo mire system (Laitinen et al. 2005a).

4. Subsegment *receiver-divergent flow* is especially characteristic of stringless central flark fens (Figs. 2 and 3). Aro wetlands are a special case in which seasonal flood occurs (seasonal flow from peatlands to aro wetlands), but the flood water disappears relatively rapidly through evapotranspiration and infiltration (Laitinen et al. 2005b).

5. Subsegment *receiver-parallel flow* is significant in aapa mires (Cajander 1913), because it includes string flark fens (Figs. 2 and 3). They are characterised by a stepwise gradient of the

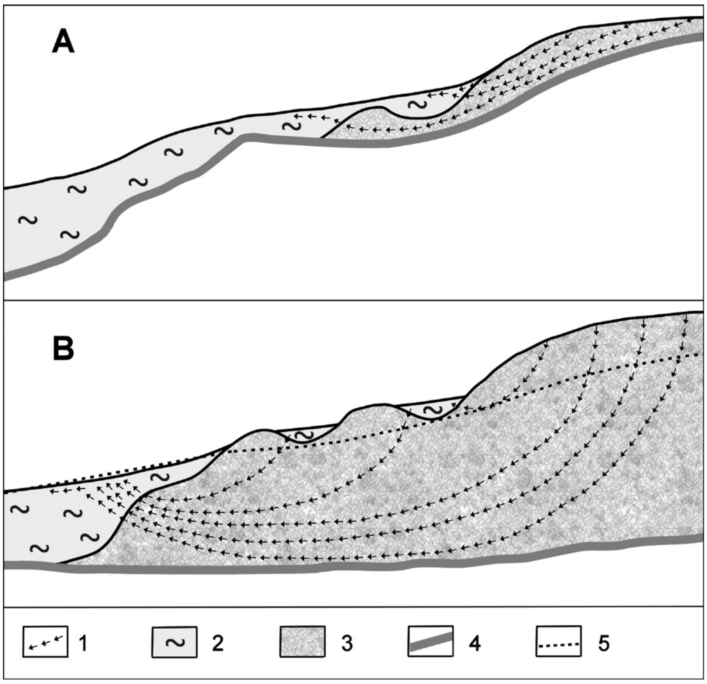

Fig. 4. Schematic presentation of groundwater recharge-discharge patterns within mire systems and aquifer-connected mire groups. Model A represents a common case of relatively thin, permeable mineral soil layer, and B of thick permeable layer, respectively. 1 = direction of water flow in the soil, 2 = peat, 3 = permeable mineral soil, 4 = impermeable boundary, 5 = piezometric groundwater level of the deepest, permeable horizon.

Kuva 4. Kaavamainen esitys pohjaveden muodostumis- ja purkautumiskuvioinneista suosysteemeissä ja akviferin yhdistämissä suoryhmissä. Malli A edustaa yleistä tapausta, jossa läpäisevä mineraalimaakerros on melko ohut, B edustaa tapausta, jossa läpäisevä kerros on paksu. 1 = pohjaveden virtaus, 2 = turve, 3 = läpäisevä mineraalimaa, 4 = läpäisemätön kerros, 5 = pohjaveden pietsometrinen taso syvimmässä hyvin vettä läpäisevässä kerroksessa.

water table with a micro-scale threshold-reservoir pattern.

6. Subsegment *receiver-convergent flow* is best characterized by outlet fens, which form a meso-scale threshold where the gradient of the water table is steeper than in the proximally and distally situated string flark fens on its both sides (see the situation in Hoikkasuo, Figs. 2 and 3). The laggs of raised bogs also belong to this subsegment or to the subsegment receiver-parallel flow.

Hydrogeological flow patterns within and between mire systems

The groundwater recharge-discharge pattern completes the mire water flow pattern by taking into account the vertical movements of water between the peat layers and underlying mineral soils. If there are considerable vertical movements, the acrotelmic and surficial flow pattern does not indicate the total (hydrogeologic) flow pattern. The question of groundwater recharge and discharge in relation to mires is very complicated and it is impossible to provide any simple classification comparable to the MWFT. However, some general guidelines can be presented.

Groundwater recharge-discharge patterns can be reliably assessed through piezometric measurements, though their influence can also be seen in vegetation and morphology within single mire systems. The parts of mire systems situated in groundwater recharge areas typically have vegetation indicating unstable surface moisture conditions or bogs (Laitinen et al., in press). The parts of the mire systems situated in the groundwater discharge area, instead, can contain mire vegetation with groundwater influence. Groundwater discharge may occur in the centre of mires also in the form of spring mounds, which in Central Lapland (Lahermo 1973, Lahermo et al. 1984) are visible as drier islands in aerial photos. They are round or elongated in the direction of water flow and sometimes surrounded by a horseshoe-form more wet surface. There may be active groundwater discharge in some of them (seeps or springs occur), whereas others show no visible discharge (e.g. Heikkilä et al. 2001a).

Aquifer-connected mire groups may be formed by separate mire systems having a hydraulic connection because of a well-permeable mineral soil. The groups fall in the category of mire supertopes in the IMCG-classification. These groups may be accompanied by local and intermediate-regional groundwater recharge-discharge patterns. A group of mires accompanied by a large glaciofluvial formation has been described in the Olvassuo area (Kälväsvaara). There are small separate mires on the glaciofluvial formation and two large aapa mire systems on its both sides (Heikkilä et al. 2001a). The Kälväsvaara formation with its small separate mires and small mires between sandy raised beach ridges around it acts as a groundwater recharge area of a regional and intermediate scale (cf. Heikkilä et al. 2001a). The small mires in this area are bogs, poor fens fed by local groundwater and seasonally dry mires accompanied by aro wetlands. Groundwater discharge mainly takes place in intermediate or rich fens in the centre of large aapa mire systems 1–3 km from the glaciofluvial formation.

The geological situation influences the groundwater recharge-discharge pattern within mire systems and aquifer-connected mire groups. A schematic cross-profile model is presented in Fig 4 for various situations, which are simplifications from the Kälväsvaara area (Heikkilä et al. 2001). In the case with a thin, permeable layer of mineral soil, groundwater discharge largely takes place at the margin of the aapa mire system, and the groundwater discharging into the mire is of local origin (Fig. 4a). As far as the case with a thicker, permeable layer of mineral soil is concerned, the groundwater discharges in the central parts of the large aapa mire system, partly causing the occurrence of an exceptionally large outlet fen pattern (Fig. 4b, see also Table 4). This groundwater discharge pattern is an indication of groundwater flow systems of a larger scale. Local flow systems also occur: groundwater is yielded into small mires in the recharge areas of a larger-scale flow system (Fig. 4b). Accordingly, the groundwater flow of the local scale in this case makes up a kind of a superimposed system on the larger-scale flow system. The mineral soil layer on the bedrock is mostly thin in Finland: the mean thickness of Quaternary soil layers is 6.7 m and the median only 3–4 metres (Rankama 1964). It thus seems that the geological situation often resembles that in Fig. 4a. This also indirectly refers to the fact that the mire water flow pattern in the acrotelm and on the mire surface (surface flow) (Fig. 3) quite satisfactorily indicates the overall water flow pattern of most mire systems in Finland. Areas with thick mineral-soil layers, large aquifers and hence large regional and intermediate groundwater recharge-discharge patterns, however, are encountered especially in large marginal formations (Salpausselkä) in Southern Finland, in sandy lowlands in Northern Ostrobothnia and around the ancient ice divide area in Central Lapland (Lahermo 1973, Hyyppä 1983). Permeable sedimentary rocks, which possibly affect groundwater flow, are exceptional in Finland (Muhos formation in Northern Ostrobothnia, Lauhanvuori in Southern Ostrobothnia).

Biological significance of morphologic and hydrologic mire classifications

The most important biological topic when considering the significance of various morphologic and water-flow classifications for mires is the dependency of species richness and its maintenance over time on environmental heterogeneity: the reduction in environmental heterogeneity generally reduces species richness (Ricklefs 1977). Major agents for this environmental heterogeneity in mire systems are specifically the diversity in peatland morphology of different scales (the occurrence of various microhabitats in relation to e.g. water level) and the diversity in ecohydrology of those microhabitats. Several repeated, relatively recent inventories of boreonemoral and boreal mire systems covering a period of 60 years or shorter have shown that such pH and vegetation changes, from which it is not always easy to state, if they are mainly natural (autogenic succession) or enhanced by man, have taken place during relatively short periods. In a bog- dominated mire system in Southern Sweden, the vegetation changes after 40 years show a drier mire surface and the increased availability of nitrogen. Most of decreased species were low-grown vascular plants of wet microhabitats (Gunnarsson et al. 2002). It has also been suggested that the lowered regional groundwater level might be a reason for the reduced *Sphagnum* cover in southern Swedish bogs (Malmer & Wallen 1999). Instead, small changes were observed in a bog and poor fen site in boreal Central Sweden after a period of 60 years (Backeus 1972), but in a classic central Swedish mire system Skattlösbergs Stormosse, which represents an almost untouched site with prevailing bog massifs and smaller aapa-like mire massifs (judged by the maps of Sjörs 1948), pH and species richness had decreased after 50 years in the richer parts of the mire system, but not in the poorer parts (Gunnarsson et al. 2000). A boreonemoral, southern Swedish rich fen site experienced a drastic change from a rich fen to *Sphagnum*-dominated poor fen with scattered rich fen patches (Hedenäs & Kooijman 1996). Acidity of the peat is a key mechanism in the vegetation changes. This is as expected, because strong correlation of pH, among all water chemical variables, was found with the main vegetation gradient and plant species richness (Tahvanainen 2004). Mire water pH reflects the reaction of water to the ionic balance that is locally regulated by hydrology.

Most of the aforementioned studies presents however, raised bogs and separate small rich fens, which are located in more southern areas compared to the location of the aapa mire zones of Finland. In those areas, some considerable human impacts (e.g. atmospheric pollution) have been exercising an influence longer than in the more northern areas, but several kinds of human impacts cannot be excluded in the northern aapa mire zones of Europe either. In Finland, there may be several environmental factors, which make aapa mires drier and poorer, perhaps involved with the increasing proportion of *Sphagnum* dominance in the naturally *Sphagnum*-poor receiver segments of aapa mires. Decreasing proportions of some low-grown and rare fen vascular species (e.g. *Carex heleonastes*) and intermediate and rich fen mosses can also be expected. The factors may be, e.g., the climate change, the water table drawdown, abundant occurrence of older marginal ditches around pristine aapa mire systems, acidification through atmospheric deposition and partly the ceased mowing in parts of aapa mires (see Aune et al. 1996, Moen et al. 1999). Thus, several open questions concerning the short-term vegetation dynamics and possible environmental changes in the aapa mire systems of the northernmost parts of Europe: (1) are the possible changes similar and do they occur equally fast in the mire systems of different aapa mire zones?, (2) what kind of vegetation changes take place in the donor and receiver segments of the various aapa mire systems undergoing i.e. what is the internal dynamics of aapa mires?, and (3) how the short-term dynamics of rich-fen aapa mires and poor-fen aapa mires differ between each other?

Conclusions

The Combined Finnish Mire Typology (CFMT) summarizes the principles of the Finnish mire complex classification by considering the early starting point with several mire complex types (Cajander 1916) and the subsequent development of the typology with a minimum of two main mire complex types i.e. aapa mires and raised bogs (Eurola et al. 1984, 1995). The revised typology is intended to elucidate the idea of the Finnish mire typology during the decades and to act as a basis for the further development of the system for practical purposes.

The CFMT operates mainly with the mire morphology of various scales (zonal mire systems), aided by the consideration of the time-factor (young mire systems), the elevation and the gradient of the mire surface (slope fen systems), the topography of the environment of the mire (various local, topographic mire systems) and local hydrology (spring, swamp and aro wetland systems). Especially the accurate morphology of the lawn aapa mire massifs and corresponding mire systems as a whole deserves additional research. This may be difficult because of the disappearance of total mire systems in the southern part of the southern aapa mire zone in Finland. Aapa mire systems with palsas, and other northernmost aapa mires, should also be subjected to a morphological analysis from the point of view of the whole mire systems. The typology of the local mire systems has not yet been tested in the field and thus lower-scale units have not been presented for them. The distribution of ordinary slope fen systems and aapa mire-slope fen systems deserves additional inventories throughout Northern Finland (cf. Havas 1961)

The Mire Water Flow Typology (MWFT) suggests a dual (donor-receiver) morphological structure for a zonal mire system (Hoikkasuo) in relation to the acrotelmic water flow pattern. This dual structure seemingly reappears in most zonal mire systems in the boreal zone. The typology roughly elucidates the water flow rates in different parts of mire systems and may be applicable for mire restoration in zonal mire systems. In local mire systems the donor-receiver pattern has not been tested, and evidently the flow rates in those mire systems partly resemble those of donor segments (more low flow rates) and partly those of receiver segments (higher flow rates).

Hydrogeological flow pattern i.e. groundwater flow pattern must be taken into consideration especially in cases where the mire water flow in the mire system or in its parts does not mainly occur in permeable surface peat (acrotelmic flow). Piezometric studies would be needed for mire systems with floristic groundwater influence, indications of seasonal drought (possible groundwater recharge at times) and in the mires combined by aquifers.

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Appendix 1**.** Present terminology of the article in English and in Finnish. The concepts are about in the order of the text and tables.

Introduction

Combined Finnish Mire Typology	yhdistetty suomalainen soiden luokittelu
Mire Water Flow Typology for boreal, zonal mire systems	boreaalisten, vyöhykkeellisen suosysteemien suoveden virtausluokittelu

Material and methods
Synthesis of Finnish mire and water-flow classifications
Basic concepts

Mire morphology	suomorfologia
Mire surface levels	suonpinnan tasot
Hummock level	mätäspinta
Lawn	välipinta
Flark level	rimpipinta
Mosaic level	mosaikkipinta
Threshold	kynnys
Reservoir	varasto (vesivarasto)
Surface water	pintavesi
Geological groundwater (general g.)	geologinen pohjavesi (yleinen pohjavesi)
Mire water	suovesi
Mire groundwater (specific g.)	suopohjavesi
Groundwater flow pattern	pohjaveden virtauskuviointi
Groundwater recharge area	pohjaveden muodostumisalue
Groundwater discharge area	pohjaveden purkautumisalue
Mire water flow	suoveden virtaus
Diplotelmic mire, acrotelm mire	akrotelmasuo
Percolation mire	läpivirtaussuo, suotosuo
Water-flow rate	vedenvirtauksen määrä
Specific discharge of the surface layer	pintakerroksen ominaisvirtaama
Supplementary nutrient effect	reunavaikutus (lisäravinnevaikutus)
Inherent nutrient effect	keskustavaikutus
Surface water influence	luhtaisuus (pintavesivaikutus)
Groundwater influence	lähteisyys (pohjavesivaikutus)
Mineral soil influence (spruce mire i.)	mineraalimaavaikutus (korpisuus)
Mire site type (mire type)	suotyyppi
Main mire vegetation unit	suokasvillisuuden päätyyppiryhmä
Aapa mire	aapasuo
Bog	ombrotrofinen suo
Fen	minerotrofinen suo
Mixed mire	yhdistelmäsuo; suo, jossa ombro- ja minerotrofia erottuuvat pienpiirteiden (mikropografian) mukaan

Combined Finnish Mire Typology

Zonal	vyöhykkeellinen (ilmastovyöhykkeellinen)
Local	paikallinen
Mire unit	suoyksikkö
Macro scale	suurtaso
Meso scale	keskitaso
Micro scale	pientaso
Upper macro scale	yläsuurtaso
Lower macro scale	alasuurtaso
Upper meso scale	yläkeskitaso

continues next page

App. 1 continues...

Lower meso scale	alakeskitaso
Mire system	suosysteemi
Mire basin	suoallas
Young mire system	nuori suosysteemi
Zonal mire system	vyöhykkeellinen suosysteemi (ilmastovyöhykkeellinen s.)
Ordinary raised bog system	varsinainen keidassuosysteemi
Raised bog system with aapa mires	aapakeidassuo, aapakeidassuosysteemi
Raised bog-aapa mire system	keidas-aapasuo, keidassuo-aapasuosysteemi
Aapa mire system with raised bogs	keidasaapasuo, keidasaapasuosysteemi
Ordinary aapa mire system	varsinainen aapasuo, varsinainen aapasuosysteemi
Local mire system	paikallinen eli piensuosysteemi
Local, topographic-climatic mire s.	paikallistopografiset ja -ilmastolliset suosysteemit
Local, topographic mire systems	paikallistopografiset suosysteemit
Local, hydrogenetic wetland systems	paikallishydrologiset suosysteemit
Ordinary slope fen system	varsinainen rinnesuosysteemi
Aapa mire-slope fen system	aapasuo-rinnesuo, aapasuo-rinnesuosysteemi
Paludified areas on rock surfaces	kalliosoistumat
Small depression mires	pienpainannesuot
Depression-network mire systems	painanneverkostosuosysteeemit
Spring & spring fen systems	lähde- ja lähdesuosysteemit
Swamp wetland systems	luhtasuosysteemit
Aro wetland systems	arokosteikkosysteemit
Mire-aro wetland systems	suo-arosysteemit (suo-arokompleksit)
Mire massif	suomassiivi
Marginal area	reuna-alue
Main mire massif types	suomassiivien päätyypit
Raised bog massif	keidassuomassiivi
Aapa mire massif	aapasuomassiivi
Plateau bog	laakiokeidas
Concentric domed bog	konsentrinen kermikeidas, kilpikermikeidas
Patterned eccentric bog	eksentrinen kermikeidas, viettokermikeidas
Unpatterned eccentric bog	eksentrinen keidas, mätäsviettokeidas
Fuscum bog	Fuscum keidas, rahkakeidas
Forest bog	metsäkeidas
Lawn aapa mire	välipinta-aapa
Lawn-flark aapa mire	väli-rimpipinta-aapa
Flark aapa mire	rimpipinta-aapa
Lagg	laide
Form parts of mire massifs	suomassiivien muoto-osat
Central plain	(keidassuomassiivin) keskustasanne
Marginal slope (peripheral slope)	reunaluisu
Central basin	(aapasuomassiivin) keskusallas
Peripheral part	(aapasuomassiivin) syrjäosa
Lower meso units	alakeskitason yksiköt
String flark fens	jännerimpinevat
Unoriented flark fens	suuntautumattomat rimpinevat
Stringless central flark fens	jänteettömät keskusrimpinevat
Reservoi-infiltration basins	varasto-suotoaltaat (varasto-imeytymisaltaat)
Outlet fens	purkusuot
Peripheral lobes and fringes	(aapasuomassiivin) syrjälohkot ja –saumat
Interlobate soaks	(aapasuomassiivin) syrjälohkojen väliset juotit
Small features	pienpiirteet

Flow typology of mire water for zonal mire systems

Flow segment	virtauskuvioinnin pääosa
Donor segment	luovuttajaosa, vedenluovuttajaosa

Receiver segment	vastaanottajaosa, veden vastaanottajaosa
Flow subsegment	virtauskuvioinnin pienalue
Divergent flow	hajaantumavirtaus
Parallel flow	yhdensuuntaisvirtaus
Convergent flow	kokoomavirtaus
Subsegment donor-divergent flow	luovuttajaosan hajaantumavirtausalue
Subsegment donor-parallel flow	luovuttajaosan yhdensuuntaisvirtausalue
Subsegment donor-convergent flow	luovuttajaosan kokoomavirtausalue
Subssegment receiver-divergent flow	vastaanottajaosan hajaantumavirtrausalue
Subsegment receiver-parallel flow	vastaanottajaosan yhdensuuntaisvirtausalue
Subsegment receiver-convergent flow	vastaanottajaosan kokoomavirtausalue
Hydrogeologic flow patterns within mire systems and between mire systems	
Aquifer-connected mire group	akviferin yhdistämä suoryhmä
Spring mound	lähdekumpu

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Tiivistelmä: Suomen suosysteemit — erityistarkastelussa aapasuot ja niiden vedenvirtauskuviointi

Artikkelissa esitetään kaksi rinnasteista soiden luokitusjärjestelmää: (1) 'Yhdistetty suomalainen soiden luokittelu' (Combined Finnish Mire Typology — CFMT) yhdistää Cajanderin vanhan laajan suokompleksikäsitteen ja nykyisen suppeamman ilmastollisen ja vyöhykkeellisen suokompleksikäsitteen. Järjestelmässä pyritään luokittelemaan kaikki erilaiset maastossa tavatut suoalueet —'suosysteemit'— pääosin ilmakuvia hyödyntäen. (2) 'Boreaalisten, vyöhykkeellisten suosysteemien vedenvirtaustyypittelyssä (Mire Water Flow Typology for boreal, zonal mire systems), oletetaan ko. suosysteemien suurelta osin olevan sellaisia soita, joissa vedenvirtaus pääosin tapahtuu suon huokoisessa pintakerroksessa, jolloin Ivanovin vedenvirtauskuviontimenetelmää käyttämällä voidaan melko hyvin havainnollistaa ko. suosysteemien vedenvirtauskuviointia. Artikkelissa käsitellään lisäksi laajempia pohjaveden muodostumis- ja purkautumisjärjestelmiä ja pohditaan yleisemmin morfologisten ja hydrologisten suoluokitusten biologista merkitystä. Vyöhykkeelliset suosysteemit esitetään suomassiiviensa (aapasuo, keidassuo) vallitsevuuden mukaisena jatkumona. Paikallisten suosysteemien alajako tehdään suomassiivien syntyä ehkäisevien seikkojen perusteella. Aapasoiden ns. keskitason suoyksiköt ja vedenvirtauskuviointi on esitetty tyypillisen keskiboreaalisen suosysteemin (Simon Hoikkasuo) ilmakuvatarkastelun pohjalta. Soiden pohjaveden muodostumis- ja purkautumiskuviointia sekä morfologisten ja hydrologisten suoluokittelujärjestelmien biologisia perusteita on pohdittu kirjallisuuden avulla.