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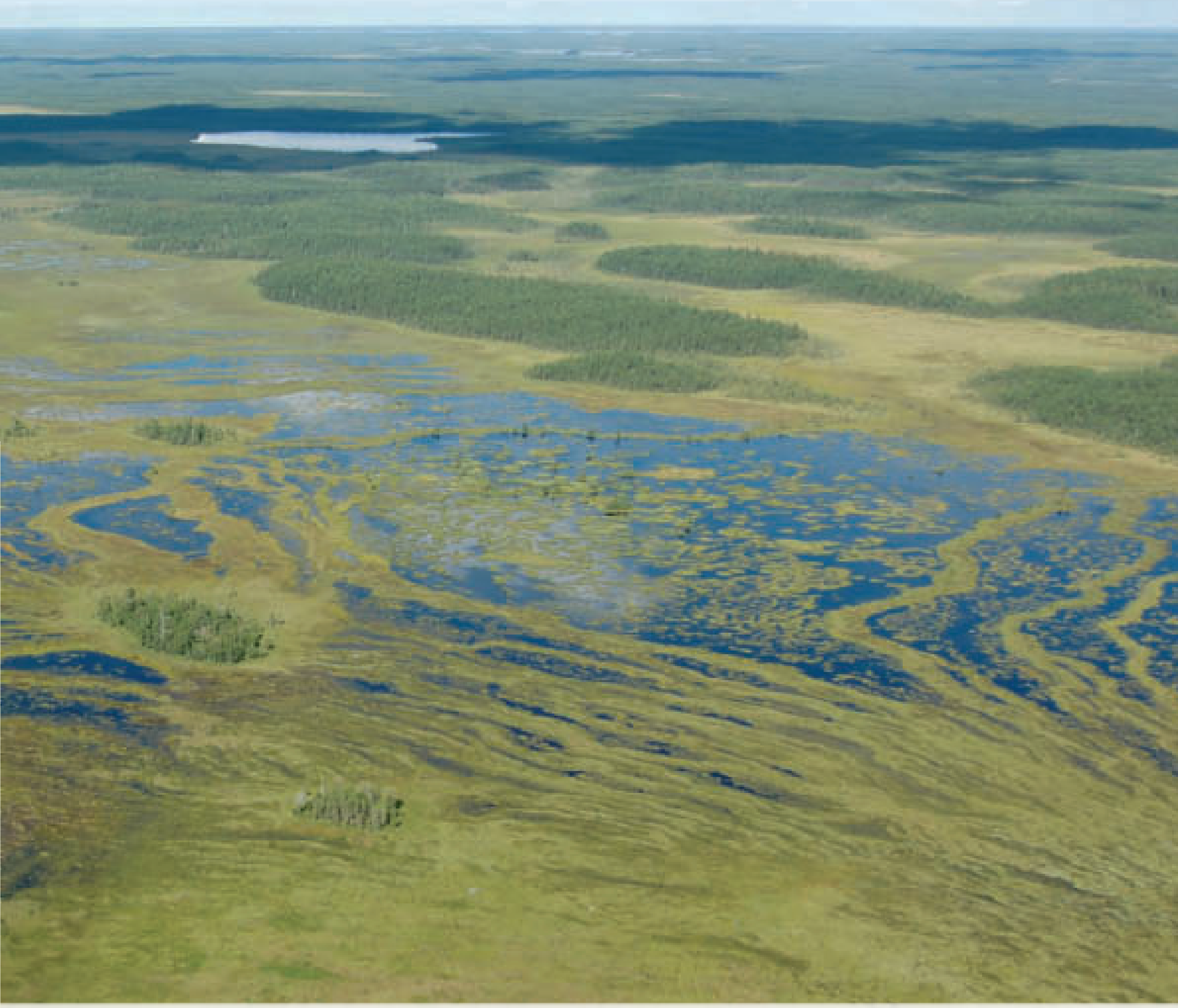
NATURE

Finland – land of mires

Tapio Lindholm and Raimo Heikkilä (eds.)



Finnish Environment Institute

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Mires in the natural and changing Finnish landscape

Finland lies between Scandinavian mountains and northern Russian plains. The Finnish landscape is characterized by a variation of small hills, valleys, depressions and small plains. It makes Finland a varying mosaic. The Finnish landscape is a mixture of forests, lakes and mires. People have lived here during the last 10 000 years, starting on quickly rising land between the retreating glacier and the Baltic Ice Lake.

Earlier the change of nature has been only local, but during the last 100 years a big change and dramatic destruction of natural habitats has taken place. The second half of 20th century was a time of effective utilization of nature resources. Lakes and the Baltic Sea were polluted, forests were cut and mires were drained. Nature conservation became urgent, when the exploitation of nature became more or less total. Thus a debate on nature conservation started. Due to different environmental control systems, our lakes and rivers are not as polluted as they were about 50 years ago. The state of the Baltic Sea, however, is alarming. Several nature conservation programmes have been the rescue of many sites, habitats and areas. Today we can proudly present many nice pearls of our nature. Nature has an ability to recover or to develop into secondary habitats. Finally we have had to learn different ways to restore destroyed habitats.

In Finland different habitats, fauna and flora have been rather well studied. This book presents results of various studies concerning Finnish mires. The editors have wanted to give different schools of mire studies a possibility to meet. We have a total of 27 articles on different topics, presenting mires in Finnish mosaic landscape. The climatic differences from south to north cause variation.

The end of Ice Age has been the beginning and the basis for our nature. It has a direct influence on the present situation, while we still have the land uplift phenomenon. The results of studies on mire biodiversity are presented in several articles.

Finally, this is a book on the relationship between man and nature. We have paid attention to the traditional use of nature, as well as on modern and more destructive uses of mires for agriculture and forestry, the effect of water reservoirs and peat mining. The environmental and biodiversity effect of these activities is analyzed. On the other hand, nature conservation has been treated.

We could not understand mires without concepts and words. Finland is a peculiar country, where the main language, Finnish, is far from most languages in the world. Finnish people understand their mires in their own way and have a rich vocabulary for mires. We try to open that approach in a couple of linguistic articles.

Finland – Land of mires is a book, which is dedicated to the International Mire Conservation Group (IMCG), which has got its initiative in Finland in 1983 during the *Field symposium on classification of mire vegetation, Hailuoto – Kuusamo*. In 2006, IMCG finally arrives in Finland as a mature organisation, visiting several Finnish mires. This book serves as a background material for the specialists of IMCG, but this can be regarded as a textbook for all people interested in boreal mires.

There are totally 29 different authors in the book. The compiling and editing of this book would not have been possible without the positive and active response from the authors, when they were asked to contribute to this rather exceptional book on mires. There is a lot of different books and articles on mires and peatlands. The information has been scattered to numerous different sources and very often written in Finnish only, and in former times in German. Finland – Land of mires, is the first time, when this kind of collection of information is available in English in one volume.

Finally the editors thank all the authors and referees of articles, and many other persons who have helped in different phases of the preparing of the book. We also appreciate the information and knowledge that the previous generations of mire specialists have had, and we wish to dedicate this book especially to our academic teachers and teachers in mire conservation: Rauno Ruuhijärvi, Pekka Isoviita, Kimmo Tolonen, Seppo Eurola, Ahti Mäkinen, Antti Reinikainen, Urpo Häyrinen, Yrjö Vasari and Toive Aartolahti.

Tapio Lindholm and Raimo Heikkilä

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Unsettled weather and climate of Finland

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Although Finland is a northern country, climatic conditions are more favourable than in many other regions at the same latitudes. The principal factors responsible for shaping the climate are the region's northern location and its position in the north-western corner of Eurasia, the largest continental land mass in the world, and in the immediate sphere of influence of the North Atlantic Current, a northerly continuation of the warm Gulf Stream, which together with the westerly and south-westerly winds, serves to transfer heat from south to north. Although the climate is in general fairly cold, it is more favourable than in many land areas located equally far north, so that the mean January temperature in Sodankylä, for instance, is 32°C warmer than that at Verkhoyansk, at a comparable latitude in Siberia (Tikkanen 2005)(Table 1).

Table 1. Temperatures and precipitations at the same latitudes in different places in the world (Tikkanen 2005).

	m asl.	Lat.	Longit.	Mean t.	Jan.	July	Precip.	Jan	July
Helsinki	**56**	**60°19' N**	**24°58' E**	**4,5**	**-6,9**	**16,6**	**651**	**41**	**73**
Oslo	96	59°57' N	10° 43'E	5,7	-4,3	16,4	763	49	89
Stocholm	7	59°34' N	18°06' E	6,6	-2,8	17,2	539	39	72
Syktyvkar	116	61°40' N	50°51' E	0,6	-16,7	17,2	557	32	60
Vanavara	260	60°10' N	102°16' E	-6,1	-29,6	17,2	419	22	67
Pr. Christ. Sund	75	60°03' N	43°10' W	3,2	-2,1	10,0	2504	250	131
Hay River	166	60°50' N	115°47' W	-3,5	-24,5	15,8	343	22	45
Anchorage	40	61°10' N	150°01' W	2,2	-7,4	14,7	405	20	43
Sodankylä	**179**	**67°22' N**	**26°39' E**	**-1,0**	**-15,1**	**14,1**	**501**	**31**	**65**
Tromsø	10	69°41'N	18°55' E	2,9	-3,8	11,8	1000	92	73
Zhigansk	92	66°46' N	123°24' E	-11,7	-39,2	15,9	286	8	47
Verhojansk	137	67°33' N	133°23' E	-15,3	-47,0	15,2	178	7	36
Godthab Nuuk	70	66°55' N	53°40' W	-1,4	-7.4	6,5	756	39	82
Broughton Is.	573	67°32' N	63°47' W	-11.5	-24.2	4.4	280	9	21
Norman Wells	95	65°17' N	126°45' W	-6.0	-27.4	16.7	318	19	49
Kotzebue/Wien	5	66°52' N	162°38' W	-5.8	-18.3	11.2	227	11	37

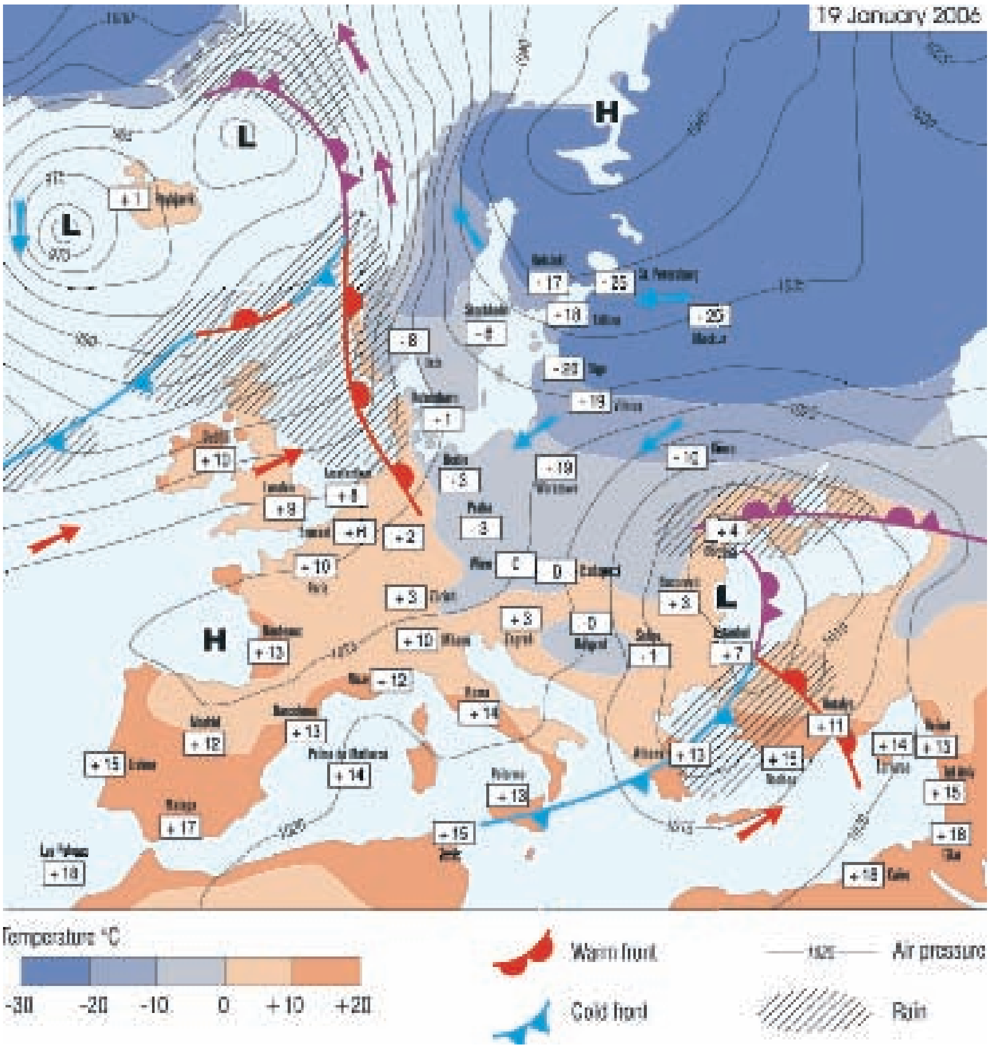

Fig. 1. Typical weather situation at the earth´s surface, showing circulation, fronts, temperatures and air masses over the eastern Atlantic and Europe during the winter, 19th January 2006.

The whole of Finland enjoys long periods of daylight around midsummer, when the length of the day, including twilight, reaches 22 hours even at the latitude of the national capital, Helsinki, while north of the Arctic Circle (66½°N) it remains light throughout the night at the summer solstice, as the sun does not drop below the horizon at all. There is in fact a period of more than two months for which the sun never sets in the far north of the region around midsummer, and the extreme north of the region has two months of uninterrupted night, known in Finnish as *kaamos*. One typical feature of the night sky in the north is the northern lights, or *aurora borealis*, which can be seen on more than 200 nights in the year in northern Lapland but only on 10 – 20 nights a year at the latitude of Helsinki (Kaila 1999).

Finland's location in a zone affected not only by westerly winds but also by a meeting of polar and arctic air masses entering from the north, with tropical air masses from the south means that meteorological conditions are subject to powerful disturbances in the form of low pressure systems (Wallén 1968). These usually cross

A cold front coming from the north in Kustruotomanaapa mire, Sodankylä, Lapland. The photo was taken at midnight 22nd June, 1977. The temperature was about +20°C, but 12 hours later there was a heavy snowfall, temperature around 0°C. Photo Raimo Heikkilä.

the region from west to east and give rise to strong winds and protracted spells of rain or snow, followed by an influx of cold air from the Arctic Ocean in their wake (Fig. 1). Alternatively, the region may experience effects of the weather system prevailing over the Eurasian continent, which implies hard frosts in winter and heat-wave conditions in summer.

On account of the low pressure activity, the weather in Finland is subject to rapid fluctuations, and it is often difficult to make long-term predictions. The low pressure systems mostly arise in the low pressure centre over Iceland (Fig. 1), which acts as the propelling force behind the wind system (Nordseth 1987), and are usually in an open state when they reach Finland, so that they take the form of a gradual warm front followed by a steep, rapidly advancing cold front, the former bringing with it long periods of continuous rain and the latter short but often heavy showers. If the low pressure has originated from further west, in the area of Newfoundland, for instance, it will mostly be close to its occlusion phase by the time it reaches Finland.

Finland belongs to the Snow Climates (type Dfc) in the Köppen-Geiger-Pohl system, with damp, cold winters, where the mean temperature for the coldest month in the year is below -3°C and that for the warmest month above +10°C (Strahler & Strahler 2005).

Temperatures

There are major differences in annual mean temperatures within Finland. The warmest area is the south-west of Finland where the annual mean is about 5°C (Helminen 1987; Pulliainen 1987), and the coldest are extensive tracts of northern Lapland, with -1 – -4°C (Fig. 2A). This implies a maximum differential in annual mean temperatures of as much as 9°C (Tikkanen 1997). The isopleth for a zero annual mean temperature runs through southern Lapland. The warmest month in the year is July, when mean temperatures in the southern parts of Finland are commonly around +16 – +18°C° (Fig. 2B). The highest monthly mean temperature ever recorded in Finland, 21,4°C, was in Kotka in July 1927. The northern parts of the region are somewhat cooler, with mean figures falling below +12°C in places, although all in all the areal differences in mean temperature are not very great in July. Temperatures can temporarily rise above 30°C at times, even in the northernmost parts of the region.

The Kölen Mountains have the effect of raising temperatures on their eastern side, as latent heat is released from the air masses as they move east and the moisture contained in them condenses to rain on the western slopes of the mountain range, sometimes leading to a significant rise in air temperatures on their lee side. This situation, known as the Föhn effect, is especially pronounced in winter, when temperatures in western Finland can rise rapidly from below zero to several degrees above, at the same time as the relative humidity of the air drops as low as 10-20% (Aune 1992; Salomonsson 1995). Temperatures between +5 and +7°C can frequently be recorded on the eastern shores of the Gulf of Bothnia even in the middle of winter when the Föhn winds are blowing (Arvola 1987). The Föhn effect seldom lasts more an a few days at a time, however.

The coldest months in the year are January and February, when marked differences in mean temperature can be found within Finland, with figures for the southwest coast of Finland remaining about -5 °C at the same time as those in the inland areas northern Finland can be below -15°C. Meanwhile, minimum temperatures in the inland districts of Lapland can drop momentarily below -50°C, the lowest ever recorded in Finland being –51.5°C, at Pokka in Kittilä in January 1999 (Rinne & al. 1999; Tikkanen 2005) (Fig. 2C).

Heat waves involving temperatures above 25°C can be experienced in Finland from April to September, but they are most common in July. The south of Finland, for instance, usually enjoys some 10 – 15 heat wave days in a year, often in sequences of 3 – 5 days at a time. The hottest summer of the 20th century in this respect was that of 1997, when the temperature in Turku, for example, exceeded 25°C on 39 days. The highest temperature ever recorded in Finland is 35.9°C, in Turku in 1914 (Fig. 2B).

The mean annual minimum temperature in eastern Lapland is -38°C, and the interior of Lapland has an average of 100 – 120 days a year on which the mean temperature is below -10°C. The difference between the mean temperatures for the warmest and coldest months of the year, which is frequently used as an indicator of continentality, is 28°C in Lapland (Wallén 1968).

The areal fluctuations in temperatures naturally also mean major variations in the length of the growing season, which is calculated as the time for which daily mean temperatures remain at or above +5°C. The longest growing season is found on the south west coast, where it can last for up to 180 days (Fig. 2D). The length then decreases towards the north, where it is usually no more than 100-120 days (Laaksonen 1979; Rikkinen 1992). The growing season begins early in May in the south of Finland, but only at the beginning of June in the north. Likewise, it ends in mid-October in southern Finland and in September in northern Lapland. The effective temperature sum, which is of importance for the vegetation, is over 1300 d.d. in the south, but only 600 d.d. in northern Lapland (Laaksonen 1979).

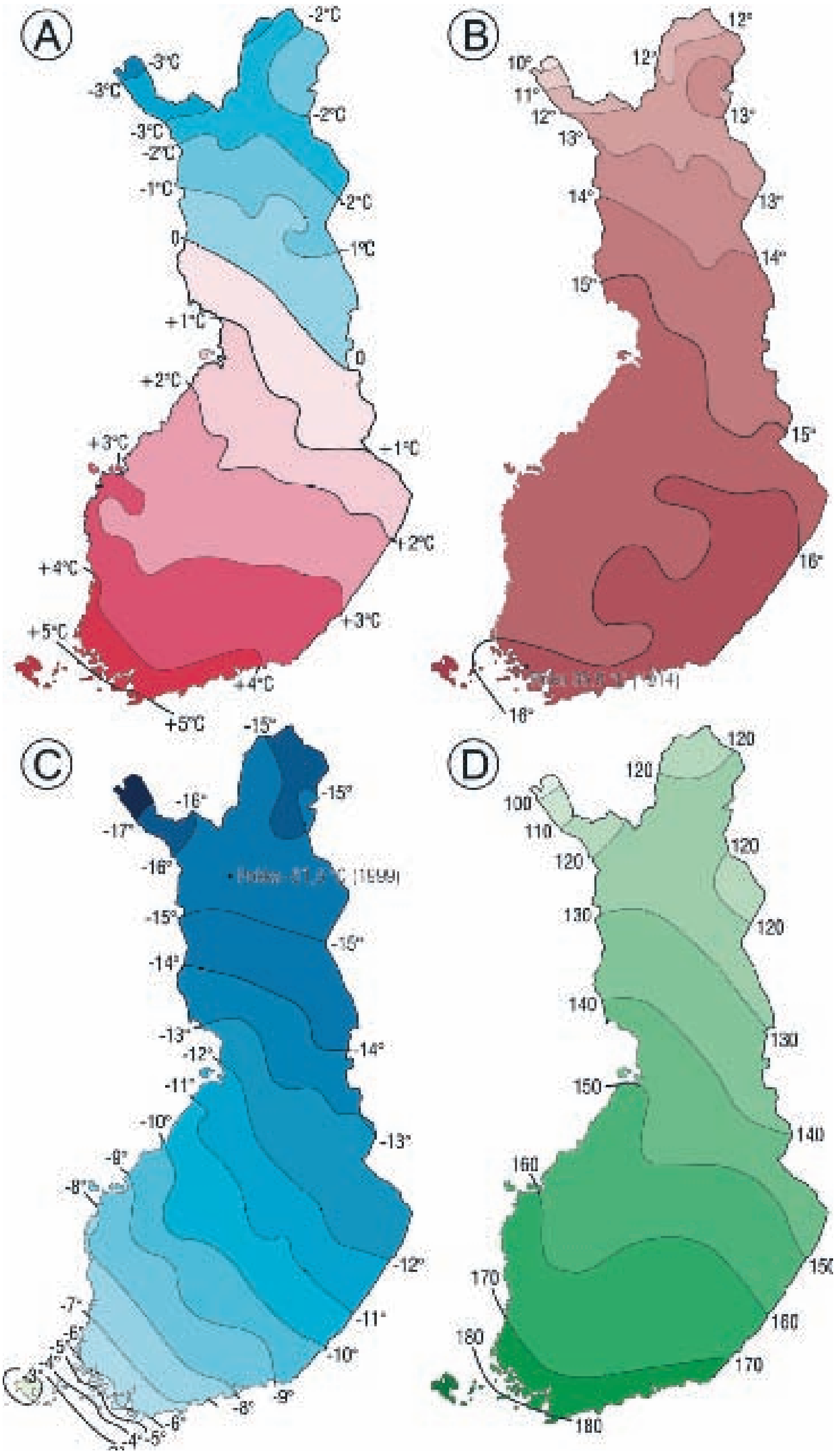

Fig. 2. A. Mean annual temperature for the period 1961-90 (Rinne et al. 1999), B. Mean July temperature 1961-90 (Karttunen & al. 1997), C. Mean January temperature 1961-90 (Karttunen et al. 1997), D. Length of the thermal growing season in days (Atlas of Finland 1987).

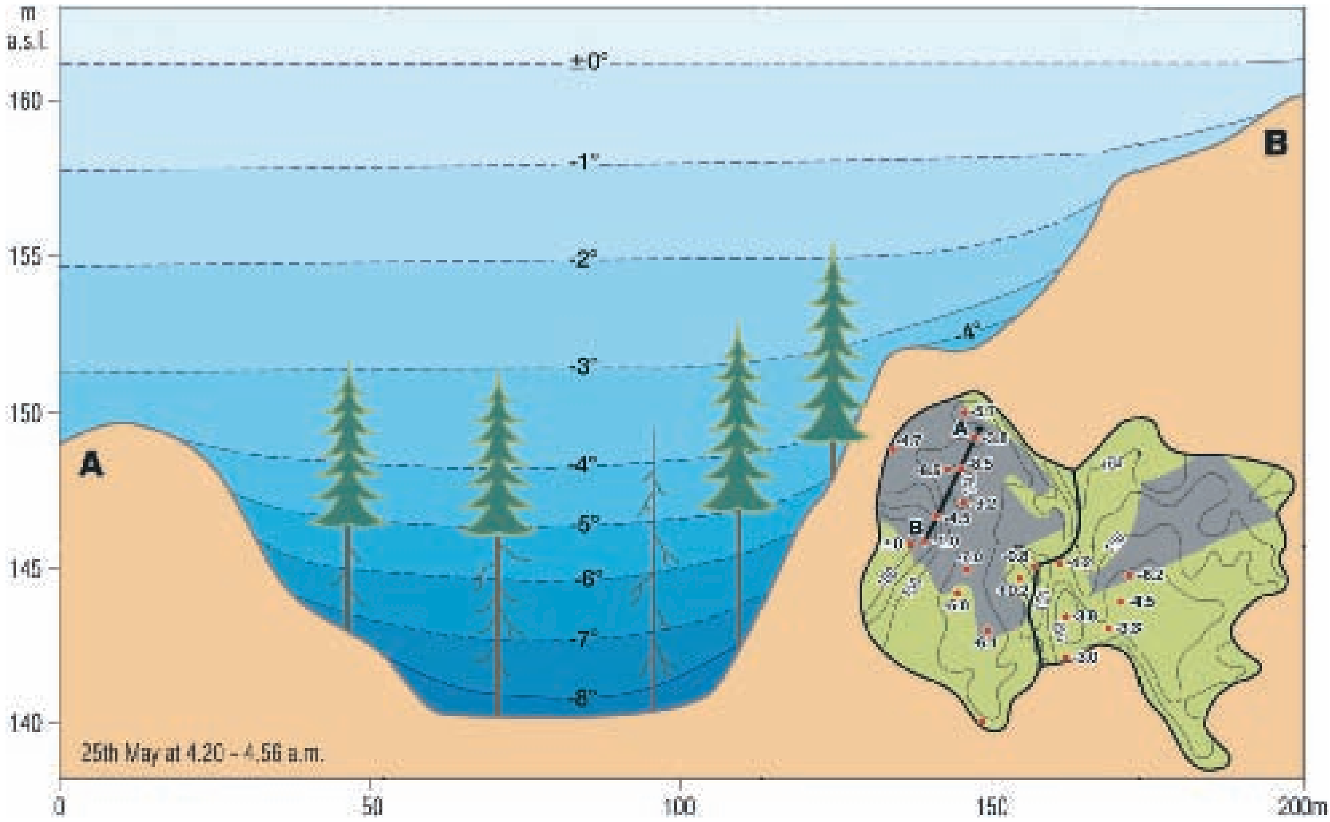

Fig. 3. Temperature stratification along transect A-B across a kettle hole in a clear-felled esker area, recorded between 4.20 and 4.56 a.m., May 25th, 1987 at Lammi, southern Finland. The figure B shows temperatures measured at various points in the area at the same time. Frost damages are visible in the lower part of young spruce trees. The shading denotes the location of the clear-felled areas (According to Tikkanen & Heikkilä 1991).

Four clearly distinct seasons of the year can be recognised in the climate of Finland. Winter is defined as the period for which daily mean temperatures remain below zero, which may last for 210 days or more in the interior of northern Lapland, i.e. these areas have about seven months of winter and mean daily minimum temperatures of around -20°C in January. The length of winter then decreases south and towards the coasts, so that it is about 120 days in south-western Finland. There can be great annual fluctuations in these figures, however, as the mild winter of 1991-1992 lasted only 53 days in Helsinki. Summer, defined as the period for which daily mean temperatures are above 10°C, is longest on the south west coast of Finland, over 120 days, and commonly exceeds four months in the south of Finland, decreasing towards the north until 75 summer days are recorded on the north western corner of Finland (Tikkanen 2005).

Fig. 4. Some young spruces with night frost damage in their lower parts standing on the bottom of the kettle hole (see Fig. 3) Photo Matti Tikkanen.

Under conditions of temperature inversion, which tend to develop on clear, windless or cold, frosty nights, air temperatures can drop closer to the land surface and towards lower-lying spots. The inversion horizon in which temperature conditions are the reverse of the normal tends to be 100 – 200 metres thick (Huovila 1987), and the consequence is that cold air flows down into the gullies and valleys in the terrain, which can be as much as 10 - 20°C colder than the surrounding upper slopes and summits of the hills at night or in midwinter, especially in Lapland (Huovila 1987; Autio & Heikkinen 2002). Clear felling can serve to promote temperature inversion locally, and can also lead to vegetation damage by night frosts in summer, especially in depressions where there is no way for the cold air to flow out (Tikkanen & Heikkilä 1991)(Figs. 3 and 4).

Precipitation

The prevailing westerly and south-westerly winds bring not only warmth to Finland but also moisture. Precipitation is usually connected with the low pressure systems that arise especially at the polar fronts between southern and northern air masses. Annual precipitation in Finland is low, and regional differences within the country are small (Fig. 5A). The adjusted figures vary from 700 mm in southern and eastern Finland to 500 mm in Lapland (Solantie 1987; Rinne & al. 1999). The driest areas are on the coast of the Bothnian Bay and in the northern Lapland, where annual precipitation is of the order of 400 – 500 mm (Tveito & al. 1997; Rinne & al. 1999). Evaporation is highest in the lake areas of southern Finland, amounting to over 600 mm a year. The highest annual rainfall in Finland, 1109 mm, was recorded at Nupuri in Espoo in 1981, and the lowest, 121 mm, at Inari in Lapland (Solantie 1987; Rinne & al. 1999)(Fig. 5A).

Where 50% of the annual precipitation in northern Finland is received in the form of snow, the figure for southern Findand is only 30-40%. The first snow usually falls in the first half of October in northern Lapland, but only around mid-November on the soutwestern edge of Finland. Correspondingly, a permanent snow cover forms by the end of October in the former area, but the latter is often still free of snow in the beginning of January. Similarly the snow will have melted by April in the south but will persist into early June in the north (Solantie 1987). There are many places on the upper slopes of the mountains, of course, where the snow may linger until July. Thus the snow cover may last for more than 220 days in the mountain areas but for less than 110 days on the southern and western coasts. The mean depth of snow reached in a season will be in the range 40 – 80 cm over the majority of the area, and annual accumulations of snow in excess of 190 cm were recorded at Kilpisjärvi in Enontekiö in April 1997 (Karttunen & al. 1997) (Fig. 5B).

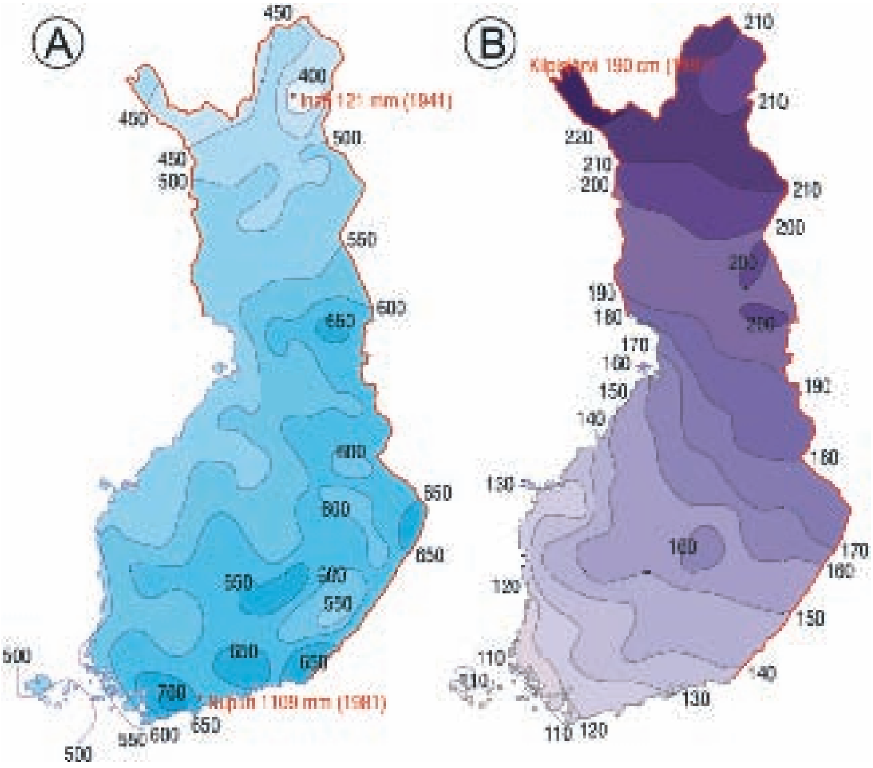

Fig. 5. A. Mean annual precipitation for the period 1961-90 (Rinne & al.1999), B. Duration of sow cover on open ground in days (Atlas of Finland 1987).

The snow that falls on the ground is a good insulating material which will have a considerable effect on soil temperatures and can protect the soil from freezing. If a thick carpet of snow persists throughout a mild winter, it may be that no frost forms in the ground at all, which may cause problems for the transport of timber out of the forests and for the overwintering of plants. It is in any case common for the depth of the ground frost to be restricted to 20 cm or so in areas with a thick snow cover, whereas it may be 40 – 50 cm on the Baltic Sea coasts, where less snow falls. The greatest penetration of frost into the ground is found in the interior of Lapland, where it can reach 1.5 m in general and over 2 m in places that are not protected by snow, while depths of more than a metre can be recorded at unprotected sites further south, as well. There are places on the mountain tops and on palsa mires where the frozen ground can fail to thaw in the course of the summer, giving rise to sporadic patches of permafrost (King 1984; Seppälä 1997).

Some of the annual precipitation is received in the form of thunderstorms. These are relatively rare, owing to the northerly location of the region, but can occur from time to time over all parts of the area in summer. They are most common in the south of Finland, which has about 20 thundery days a year (Laitinen 1987b). This figure is nevertheless low compared with frequencies of up to 200 days a year quoted for equatorial regions. Thunderstorms are less likely to occur on the coasts than they are in inland areas, their mean frequencies in the former case being 5 – 10 times a year. Although normally confined to the period May – September, they have been known to occur occasionally in winter. Also, they often bring with them strong, gusty winds, and sometimes even small whirlwinds or tornadoes, which can cause considerable destruction over restricted areas, uprooting trees and damaging buildings. Similarly, local damage, mostly to plants, can be caused by hailstorms emanating from thunderclouds.

Impacts of climate on vegetation and human activities

Both nature and human society have adapted to the sometimes quite harsh climate of this region in the course of time. Although Finland has a more favourable climate than its location might warrant, the limits of distribution of numerous plant species are met with in its northern parts, where the forests grade into treeless tundra, even though the polar treeline actually recedes beyond latitude 70°N in places (Hustich 1983). Contrary to the situation in other parts of the world, the northern treeline here is formed by the mountain birch, *Betula pubescens* ssp. *czerepanowii*. The climate is favourable for forest growth over the majority of the region, however. Also, on account of the considerable excess of precipitation over evaporation, the region has an abundance of mires, these accounting for as much as a third of the surface area of Finland, where the terrain is in general relatively even.

Many crops can be growth further north in Finland than anywhere else in the world, so that potatoes, for instance, are cultivated far beyond the Arctic Circle. On the other hand, the cold winters lead to many problems that have to be allowed for in everyday life, especially in the north of the region. The long cold season means that the houses have to be well heated and insulated, which consumes large quantities of energy and increases building costs, e.g. necessitating the installation of double or triple glazing in the windows. Allowance also has to be made for ground frost when constructing the foundations of buildings and roads, as these can otherwise be damaged or destroyed within a short period of time (Seppälä 1999). Another factor that raises the cost of living is the fact that the lakes, rivers and coastal waters freeze over to a great extent in winter, making transport more difficult. Finland and its neighbour Estonia are in fact the only countries in the world that have all their harbours iced up in the winter.

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Climate of Finland and its effect on mires

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Finnish climate

Finland belongs to the main boreal ecoclimatic zone (except highest mountains north), comprising its all four subzones (Tuhkanen 1984), i.e. the northern, middle and southern boreal zones, and the northern rim of the hemiboreal zone. Located in Europe, its climate is milder and more maritime than on most mainland areas between the 60th and 70th latitudes. The mean temperature of the three summer months T6-7-8, effective temperature sum (in excess of +5 °C), denoted by L, the duration of the vegetation period, denoted by V (limit +5 °C), and the absolute frost record in winter at 2 m level on mires, denoted by Fr, change stepwise by zones having means by zones as follows (Solantie 1986a, Solantie & Drebs 2000, Solantie & al. 2002, 2004).

	Hemi-boreal	Southern boreal	Middle boreal	Northern boreal
T6-7-8 (°C)	15.5	15	13.5	12
L (°Cd)	1280	1160	950	700
V (d)	178	168	148	128
Fr (°C)	-35	-40	-45	-50

The mean number of snow cover days and the winter (December-March) mean temperature have a somewhat different areal distribution, the former increasing towards north-east ranging on the Finnish mainland from 90 to 220 days (Solantie & al. 1996), and the latter decreasing on Finnish mainland from -3.5 to -13.5 °C. Mean snow depth on March 15th increases from west southwest to east northeast ranging from 18 to 78 cm (Solantie 2000). Precipitation in Finland has been practically unchanged during the last 110 years (Tuomenvirta 2004). October-April precipitation increases broadly south-eastwards ranging from 200 to 450 mm (Solantie 1976) while May-September precipitation is rather evenly distributed on mainland around 320 mm, having however only 250 to 300 mm at coasts and at the northern edge of northern boreal zone, and an area of values of 325 to 350 mm around the boundary between southern boreal and middle boreal (Solantie 1987).

In June, evapotranspiration exceeds precipitation in all these regions except in the northern boreal zone while in July this is the case only in hemiboreal and southern boreal zones (Solantie 1974). Considering further that in June snow melt water is

Sedge fen in Levaneva mire reserve, western Finland in January, 1977. Due to thin snow cover, frost penetrates deep in the peat. Photo Raimo Heikkilä.

left on mires only in middle boreal and northern boreal zones, mires in these zones cover appreciably larger proportion of area than in hemiboreal or southern boreal, and particularly fens are more common in the two northernmost zones. Before large-scale drainages, 50 years ago, mires comprised 37% of the Finnish land area; the respective percentage in northern boreal zone was 40, in middle boreal zone 45, and in southern boreal zone 20 (Ilvessalo 1957). In that time, 9% of mires in Finland as a whole as well as in middle boreal zone were drained (cf. ¾ of mires in middle boreal zone and approximately 1/2 in Finland at present). Of all Finnish mires, undrained pine bogs covered 42%, undrained fens 25% and undrained spruce mires 21%, while in the middle boreal zone the corresponding figures are 50%, 23%, and 17%, and in the northern boreal zone 36%, 36%, and 18%, respectively. Due to the large coverage of mires in middle and northern boreal zones, their climate affects largely on the average climate in these regions.

The large-scale drainages of mires, carried out 50 to 15 years ago in the frame-work of a large-scale national project in order to make mires to produce timber, cover 17% of Finland's land area (Hökkä & al. 2002), i.e. twice the total area of cultivated fields; this essentially changed the general appearance of Finland, decreasing radically open or half-open mire landscapes. For this reason, the average climate on mires and in middle boreal zone as whole has changed; in the active period of drainage, nights got colder (Solantie 1999), but at present as tall forest stands grow on the majority of drained mires, their climate is closer to that in forest stands than to the circumstances 50 years or prevailing still in Scandinavia and Russian Karelia. Consequently, in the most affected area, middle boreal zone, where drained areas cover as much as 30% of the land area, we may speak of 'the national climatic change'.

Mire complex types and climate

The mire complex type zones have a connection with ecoclimatic and hydrological zones (Fig. 1, Table 1, Solantie1986b). Broadly speaking, aapamires occur in middle and northern boreal zones, where evapotranspiration in June is less than precipitation so that water surfaces on bogs continue to exist, while raised bogs occur in southern boreal zone and plateau bogs in hemiboreal zone, but not exactly. In the east, aapamires occur at the northern edge of southern boreal zone; while raised bogs occur at the southern edge of middle boreal zone, due to greater volume of snow melt waters in the east. Concentric raised bogs occur in the southwestern part of southern boreal zone, where winter steepens slowly so that the season with alternation between periods of melting and increasing snow cover is particularly long causing a surface topography typical of raised bogs; this limit is also hydrological due to the prolonged occurrence of autumn floods. In those parts of the northern edge of the region of raised bogs, where precipitation in early winter is abundant, the topography of raised bogs is strong but 'fossilized' as a relic from the period about 3000 years ago as climate had already appreciably cooled from its optimum but was still milder than today; at present the climate there does favour aapamires (Solantie 1986b). Plateau bogs occur farthest southwest where snow cover is short of duration, thin and often fragmentary in time and space.

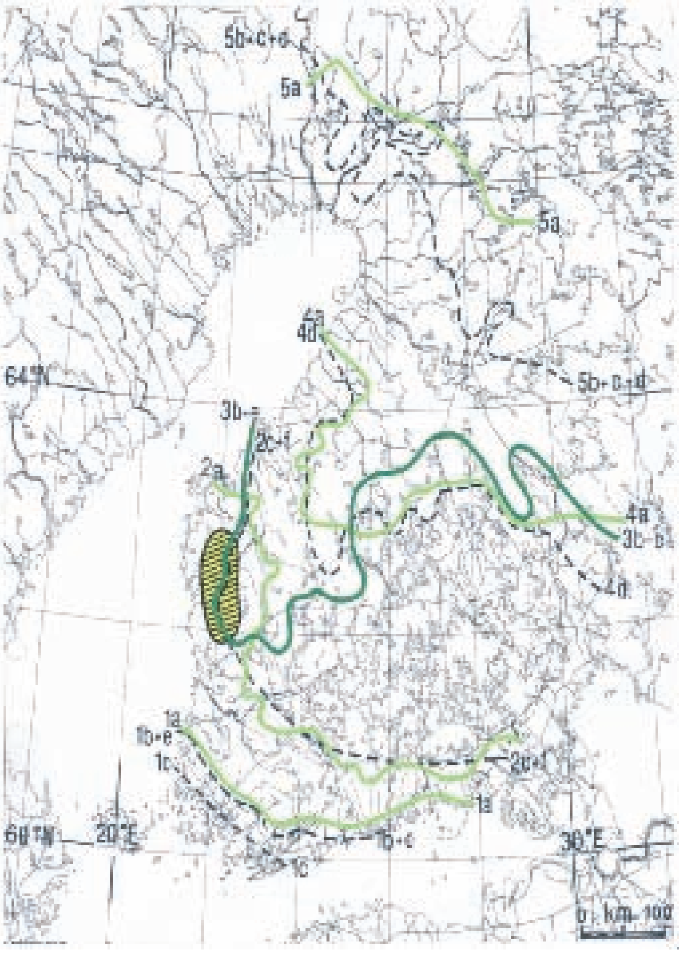

Fig. 1. Boundaries between mire complex type zones (1a to 5a), vegetation zones (1b to 5b), hydrological boundaries (1c to 5c), humidity boundaries of climate (4d to 5d), thermic boundaries of growing season (1e to 3e) and the winter climate boundary (2f). Hatched area = region of abundant orographic precipitation during westerly winds (Solantie 1986b, see Table 1).

Table 1. Zonation of mire massifs, hydrology and vegetation-climate (See Fig. 1).

Zones according To their boundaries (up to 68° N)	Mire massif type	Mires % of land area	Hydrological zone	Vegetation and climate zone
South of 1	Plateau bogs	<30	Baltic zone	Hemiboreal
1-2	Concentric bogs	<30	Transition zone	Southern boreal
2-3	Eccentric bogs	<30	Lakeland Finland	Southern boreal
3-4	Eccentric bogs	>30	Pohjanmaa	Middle boreal
4-5	Sedge aapamires	>30	Pohjanmaa (N part) and Maanselkä	Middle boreal
North of 5	Flark aapamires	>30	Perä-Pohjola	Northern boreal

The thermal climate on mires

Temperatures considered here are those 2 m above the ground. Bogs have larger diurnal temperature amplitudes than any other landtype. Highest 'pure' amplitudes of 2 m level temperatures (°C) in well-developed inversion situations on bogs on plateau-terrain at the 63rd latitude (Solantie 2003, Solantie & al. 2004):

Dec 20	Feb 1	Mar 15	Jul 20	Oct 20
9	20	28	25	19

The highest rises per one hour are about 38% of these values.

In all seasons, nightly minima in pine bogs are lower but daily maxima higher than in forest stands; in summer the difference in minima is on average -1.8 °C and in inversion situations -4 °C, also in winter. The difference in day-time maxima in summer is +0.7 °C, while in bright mid-winter days it may amount to +2.5 °C. Pine bogs get warmer than forest stands 1 to 2 hrs after sun rise (at solar elevation of 8 degrees) and get colder again 0.5 to 1.5 hrs before sun set (at solar elevation of 5 degrees). Thus, at the 63rd latitude the relatively warm period in mid-summer on bogs begins at 3:45 ST (solar time) and ends at 20:30 ST, while in bright, calm mid-winter days it lasts 2 to 3 mid-day hours. Compared with forest stands, bogs are relatively coldest at 0 to 2 ST during the vegetation period till September but at 5 ST in October. On the other side, bogs are relatively warmest 2.2 to 3.2 hrs after sunrise, i.e. in midsummer at the 63rd latitude at 5 ST and in mid-winter at 12:45 ST. This relative morning maximum in summer is on average +0.8 °C and in inversion situations +2 to +3 °C.

On fens in middle boreal zone, daily maxima and night minima are between those on bogs and forest stands. Close to the western edges of fens, bordered by pine bogs, relative morning maxima of temperature, compared with forest stands, may be even higher than on bogs, amounting in inversion situations to +3 to +4 °C. In northern boreal zone, where fens are largely covered by shallow waters while forest stands are low and sparse, fens in night-time are even warmer than forest stands.

The mean duration of the frostless period (frost meaning temperatures below 0 °C at 2 m level above ground) in average middle boreal conditions is 37 days for drained, relative dry bogs, 45 days for drained, relative wet bogs, 50 days for bogs in natural stage, 55 days for fens with some water surfaces, 72 days for forest stands grown on bogs after a successful drainage (120 m^3 $hectare^{-1}$), and 95 days for pine stands on mineral soils (150 m^3 $hectare^{-1}$).

The mean temperature during the vegetation period on bogs is lower than in forest stands. On fens it is higher than on bogs, in wettest fens of northern boreal even higher than in forest stands. Concerning the mean temperature during the period beginning in the morning at solar elevation of 8 degrees and ending in the evening at solar elevation of 5 degrees, it is higher on bogs than in forest stands, and on fens between these.

Depth and water equivalence of snow cover on bogs are about 15% greater than in average pine forests. This is because sparse and low pine stands on bogs are effective to slow down wind, and also energy input into and evapotranspiration out of the snow cover, while they are less effective to retain snow on branches. Despite the fact that frost sums on bogs are 6 to 7% higher than in forest stands, soil frost is thinner because of thicker snow cover and wetter soil.

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Bedrock in Finland and its influence on vegetation

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The Earth's crust in Finland consists of Archaean bedrock and young Quaternary deposits. The bedrock consists mainly of 3100-1800 million years old bedrock while the Quaternary deposits have mainly been formed about 11 000 years ago.

The bedrock of Finland belongs to the Precambrian block of northern and eastern Europe, which is the oldest part of the continent (Fig. 1). The crystalline bedrock is exposed only in Fennoscandia (the Baltic Shield) and Ukraine. Most of the Precambrian bedrock is covered by thick (up to several kilometres) Paleozoic and younger sedimentary layers. The Precambrian bedrock of Fennoscandia is bordered in the west and north, in Sweden and Norway, by the Caledonian mountain belt. In the southern and eastern margins, in Russia and Estonia, the bedrock gently slopes below Paleozoic and younger sedimentary layers (Simonen 1990, Korsman & Koistinen 1998).

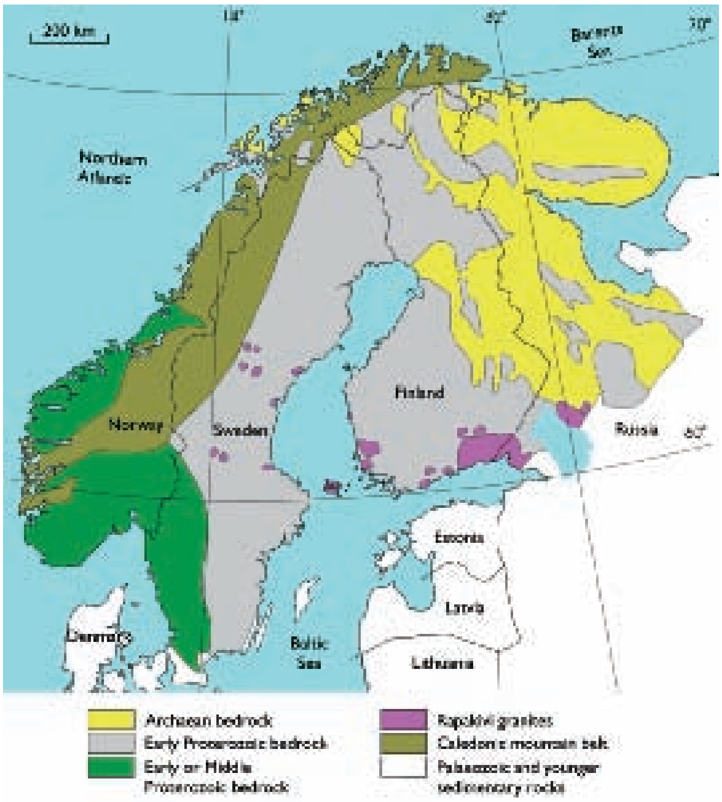

Fig. 1. Main features of the bedrock in Fennoscandia. After Korsman & Koistinen (1998)

Northern and eastern parts of Finland belong to the 3100-2500 million years old Archaean bedrock area, and southern and western parts of the country belong to the 1930-1800 million years old Early Proterozoic bedrock. Only a small part of the bedrock is younger than 1800 million years. The most widespread younger formations are the 1650-1540 million years old rapakivi granites in southern Finland.

The bedrock of Finland consists of rock types with different origin and mineral content. Schist belts consist of metamorphic rocks, which have originally been sediments, e.g. sand or clay, or volcanic rocks. In connection with mountain folding ancient sediments and volcanic rocks have gone through metamorphosis and formed into crystalline schists. Between schist belts there are wide areas of plutonic rocks, which mainly consist of granites and granodiorites. Also mixed granitic rocks, migmatites, are common.

Table 1. The distribution of main rock types of Finnish bedrock (Sederholm 1925).

Rock types	Percentage of bedrock area
Granites, granodiorites, quartz diorites	52,5
Migmatites	21,8
Fyllites, mica schists, mica gneisses	9,1
Gabbros, diabases, amphibolites	8,2
Quartzites and sandstones	4,3
Granulites	4,0
Calcareous rocks (marbles, dolomites)	0,1
Total	100,0

It is characteristic for the bedrock of Finland that acidic silicaceous granitic plutonic rocks and migmatites are abundant. The mean mineral content of the Finnish bedrock is close to the content of silicaceous ($SiO2 = 67,45$ %) plutonic rock (Simonen 1990).

Only about 3 % of the plain Finnish landscape is exposed bare rock. Great majority of the landscape is covered by loose Quaternary sediments, the thickness of which can be up to some tens of metres. The mineral soil covering the bedrock has originated from the local bedrock. It has been estimated that the last glaciation has carved at least 7 metres of the bedrock. In all the bedrock worn out during the Quaternary would have produced a loose layer about 25 m thick (Taipale & Saarnisto 1991, Tikkanen 1994). However, part of the loose soils have been glacially transported outside Finland and the mean thickness of Quaternary sediments is about 7 m.

The rock types of Finnish bedrock can be grouped on the basis of their influence on vegetation (Kalliola 1973, Pykälä 1992, Kontula & al. 2005). The rock types favouring the most diverse vegetation and flora are calcitic marble and dolomite, which are very rare in Finland (0,1 %). Most of the bedrock (82 %) consists of acidic granites, gneisses, granulite, sandstone and quartzite. Intermediate mafic rocks, mica schist, diabase, gabbro, diorite and amphibolite take about 17 % of the bedrock. A special fourth group with regard to vegetation are the rare ultramafic rocks with a low content of SiO2 (<45 %) and high content of Mg.

Along with climate, acidic and poor bedrock and soils are very important factors determining vegetation and flora. Due to the rarity of calcareous areas, species favouring high pH are rare and in many cases threatened in Finland.

The variation in the chemical composition of bedrock can be most clearly seen in the vegetation of the rock outcrops themselves. The flora connected with acidic bedrock is diverse in our country, especially moss and lichen flora. Comparison of acidic and intermediate rocks shows often clear differences in species composition. E.g. in nearby rapakivi granite and olivine diabase rock outcrops in southwestern Finland some species, such as *Silene rupestris* and *Spergula morisonii*, concentrate on acidic bedrock, while others, e.g. *Asplenium trichomanes, Geranium robertianum* and *Lychnis viscaria*, can be found only on diabase rocks (Kallio 1954). However, by far highest species numbers can be found on calcareous rocks, which have their own characteristic flora. Among mosses *Encalypta streptocarpa* is an indicator species, which grows in almost every calcareous rock outcrop, but very seldom on intermediate and never on acidic bedrock. The flora of calcareous rock outcrops is especially diverse in the climatically mild southern Finland, but on the other hand high species numbers can be found also in the north. The speciality of Kuusamo are the dolomitic gorges and river canyons, where southern and northern flora meet.

A special case of rock vegetation is related to ultramafic rocks, especially to some igneous rocks of the peridotite group (e.g. dunite and komatite) and their metamorphic derivatives (e.g. serpentinite and soapstone). These rock types are rare in Finland, most commonly found in eastern Finland as well as central and eastern Lapland in small areas. Serpentine rocks have an abnormally high Mg content compared to Ca. On the other hand, some heavy metals (e.g. Cr and Ni) are more abundant than in the bedrock on average and the content of N, P and K is low. Typically the vegetation on serpentine rocks is very sparse and the species number is low. However, there are taxa, which grow only on them, e.g. *Lychnis alpina* var. *serpentinicola* and *Cerastium fontanum ssp. vulgare var. kajanense* (Eurola 1999).

The variation in bedrock is also reflected in forest and mire vegetation. Herb-rich forests and rich fens are concentrated in areas of calcareous or intermediate bedrock where pH is higher than elsewhere (Fig. 2). The most remarkable of these centres are Kuusamo and the so-called Lapland triangle, where e.g. *Calypso bulbosa* and *Cypripedium calceolus* are locally rather common (Perttunen 1991, Perttunen & Hanski 2003).

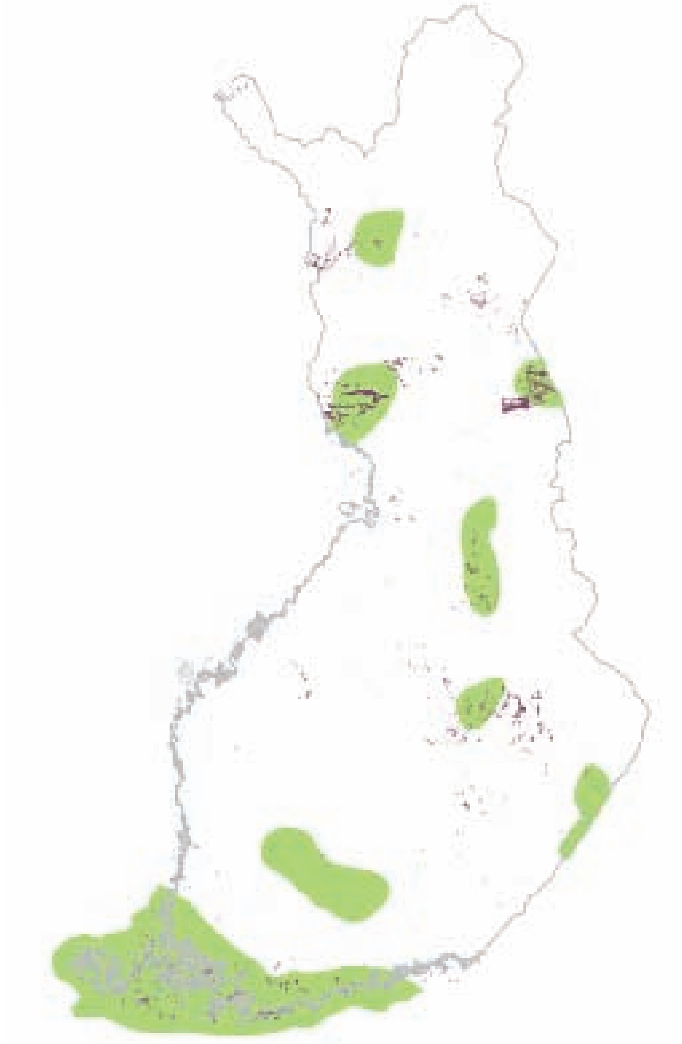

Fig. 2. Distribution of calcitic bedrock (purple) in Finland and areas with abundant herb-rich forests and rich fens (green).

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The landforms of Finland

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The basic framework for the relief in Finland is formed by the highly eroded Precambrian bedrock, between 3500 and 1500 Ma in age, which is covered in most places by layers of much younger and clearly distinct surficial deposits. The ancient fold mountains that occupied the area of Finland have been worn down by weathering and erosion processes to form a fairly even peneplain by the end of the Precambrian. The palaeomagnetic measurements indicate that Finland spent long periods in the relatively warm climatic zones close to equator at one stage (Pesonen & al. 1989),

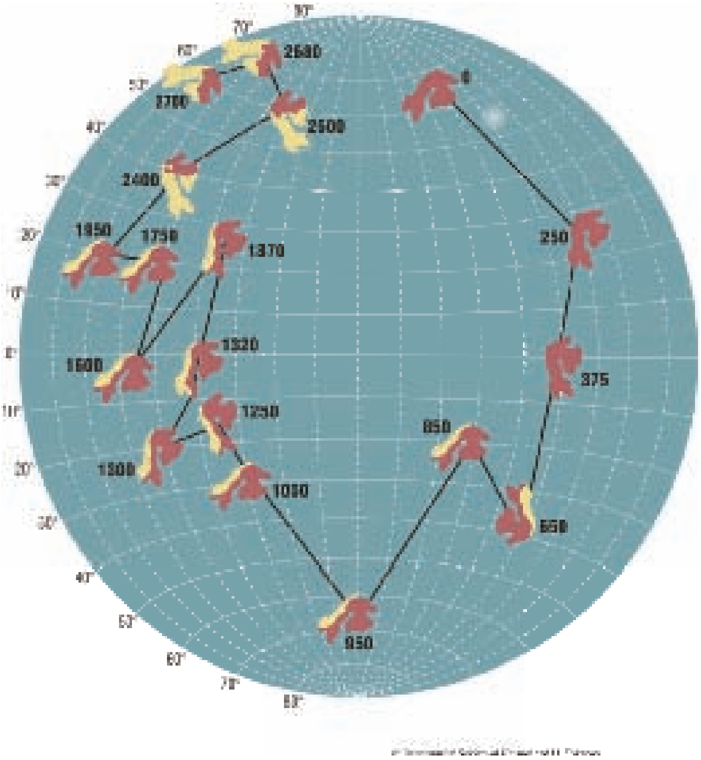

Fig.1. Migration of the Fennoscandian continental land mass. The diagram depicts its movements over the Earth's surface in a N-S direction from Late Archaean times up to the present. The time scale is in millions of years. The circular movement of the shield and the new bedrock areas added to Fennoscandia at different stages, indicated in brown, are shown on the diagram (Tikkanen 2002).

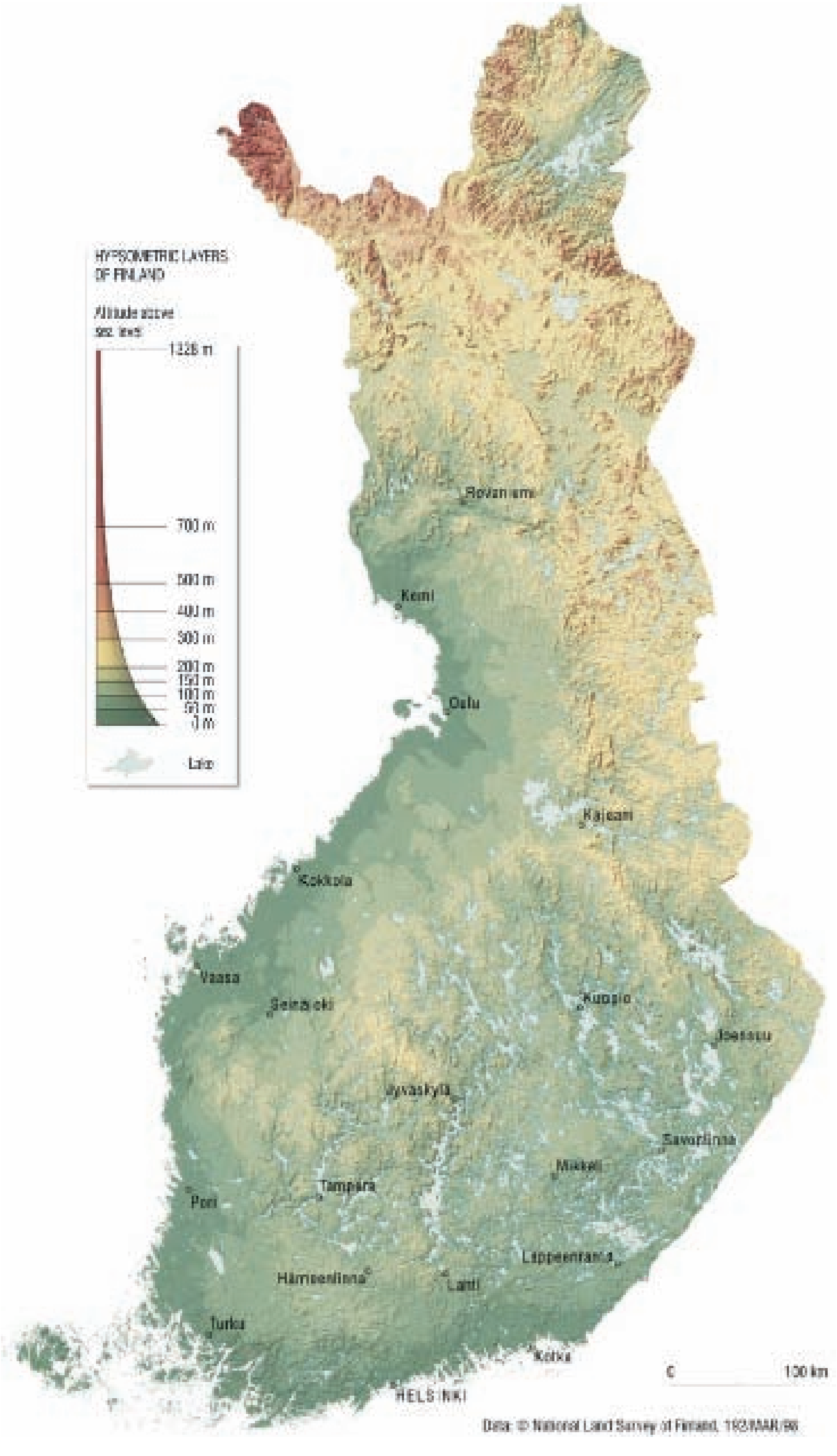

Fig. 2. Topography of Finland (Tikkanen 2002, cartographic design by Juha Oksanen).

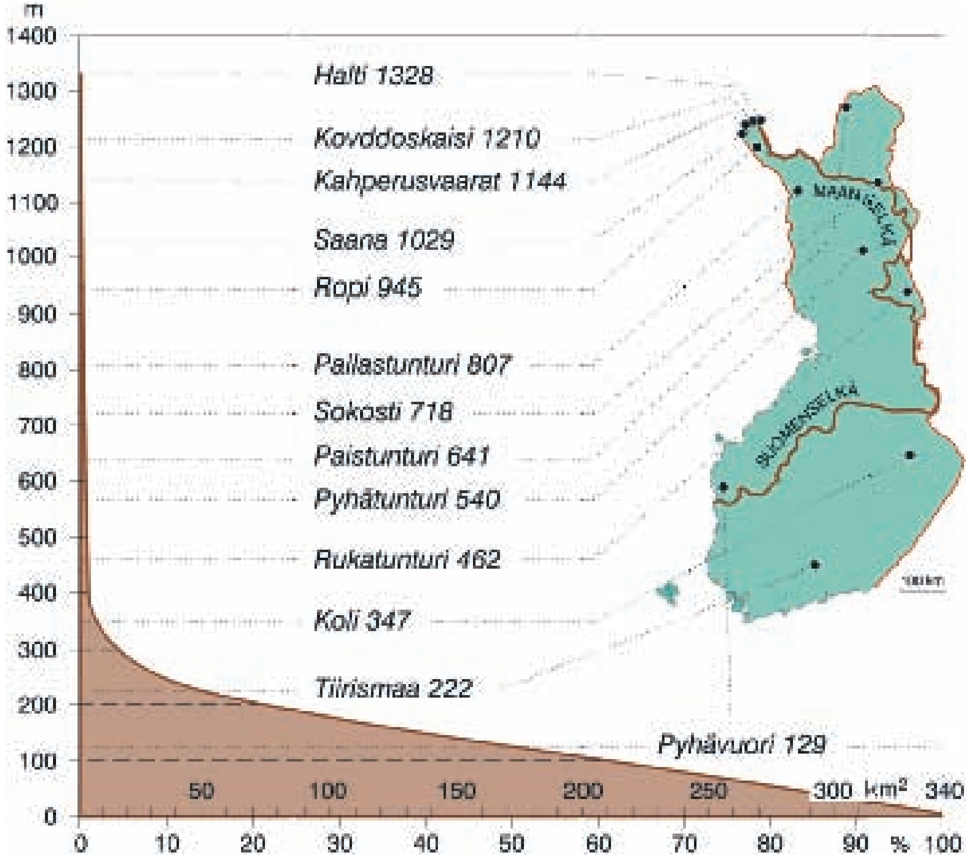

Fig. 3. Hypsographic curve and some summit heights of Finland (Atlas of Finland 1986 and Tikkanen 1994)

which must have accelerated weathering and the erosion of the land surface (Fig. 1).

The mean height above sea level in Finland is 154 m (Seppälä 1986) and the highest point, the mountain of Halti on the border with Norway, 1328 m. About 80% of the country's surface area consists of low-lying land below 200 m a.s.l., and continuous areas of land of 300 m in altitude are to be found only in north-western Lapland (Tikkanen 1994)(Figs. 2 and 3). The relief in Finland has been substantially evened out in general terms, although its more detailed topography is still highly variable. The topography as a whole is determined by the interaction of two elements, the solid bedrock and the loose surficial deposits.

Bedrock topography

The fractured nature of the bedrock is reflected in the existence of elongated fissure valleys and fault cliffs, and also rift valleys and erosion-smoothed horsts in places. In some places these fault lines are obscured by sediments, so that they are scarcely visible in the topography at all. The lakes and rivers will nevertheless tend to favour fracture zones of this kind, and Lake Päijänne and Lake Näsijärvi in particular among Finland's larger lakes are located in zones of intersecting bedrock faults and fractures. Where the rock wall against the ice movement was steep and high enough, abrasion produced a proximal trough basin, which, after deglaciation, might form a trough lake (Heikkinen & Tikkanen 1989; Seppälä 2005). Lake Inari in Northern Finland is

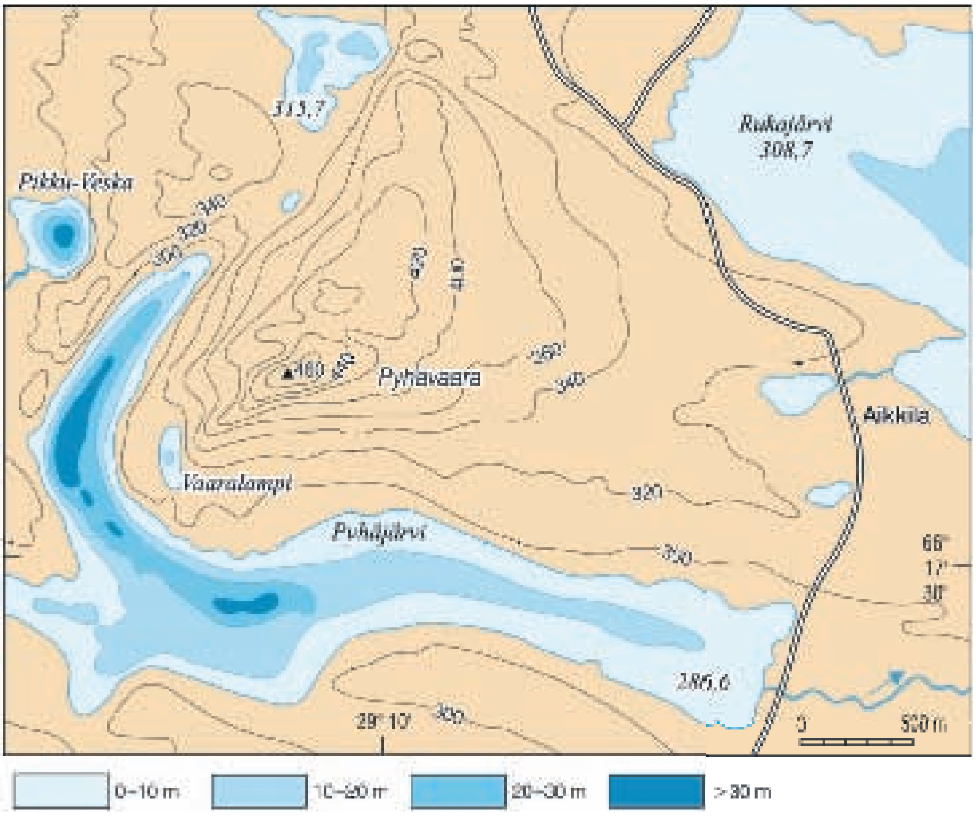

Fig. 4. An impressive proximal crescentic trough in Kuusamo, eastern Finland. Depth zones of lakes indicated in metres, contour intervals 20 m (Heikkinen & Tikkanen 1989).

located at least in part in a bedrock depression, or graben, and some of the groups of fjelds surrounding it are horsts rounded off by erosion. The tectonic movements in this area are thought to have taken place in the Tertiary, about 25-10 Ma ago (Aartolahti 1990). Similarly the Satakunta and Muhos areas of sedimentary rocks on the west coast occupy graben formations, which are estimated to reach a depth of 600-1000 m (Elo & al. 1993).

Apart from the depressions and protrusions brought about by tectonic forces, the relief also reflects the relative hardness of the various rock types, in that some remain stand out as others are eroded away, giving rise to monadnocks. The quartzite hills of Eastern and Northern Finland rise up several hundred metres above their surroundings, for instance, although the differences in relief attached to the other rock types are by no means so pronounced, e.g. the surfaces of the diabase dykes that cross the sandstones of Satakunta are around 50 m above the surrounding terrain (Tikkanen 1981). Where the rock walls against the ice movement were steep and high, glacial abrasion might produce proximal trough basins at the bottom of the hills, which, after deglaciation, might form trough lakes (Heikkinen & Tikkanen 1989; Seppälä 2005)(Fig. 4.).

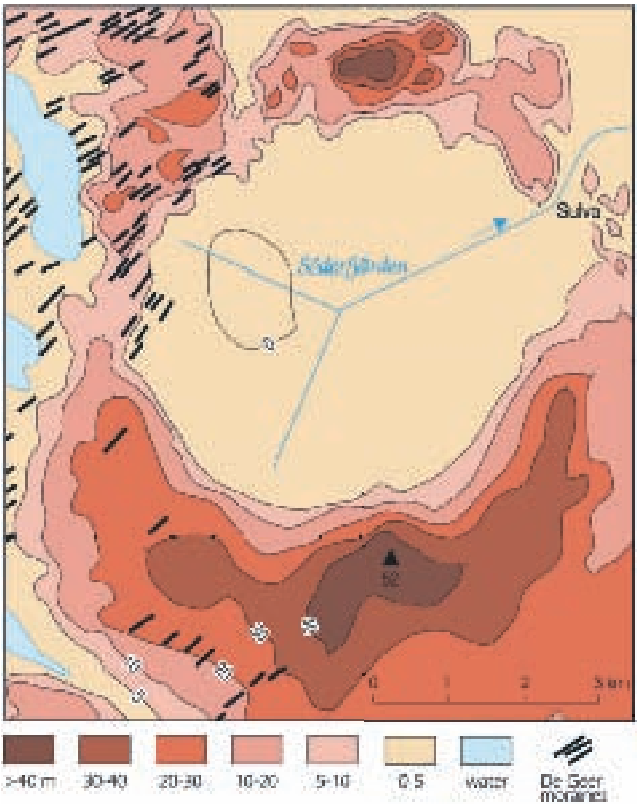

Fig. 5. Deeply eroded remnant of the Söderfjärden meteorite impact crater, south of Vaasa. The diameter of the 550 million year old crater is 5 km, and it is filled with sedimentary rocks and quaternary clay and silt sediments (Tikkanen 1994).

The remains of ten ancient meteorite craters have also been found in the bedrock, the youngest being the basin of lake Lappajärvi in Ostrobothnia, created some 77 million years ago, which had previously been thought to be the crater of a former volcano (Lehtinen 1976). Considerably older than this is the circular area of flat agricultural land south of Vaasa town that marks the Söderfjärden impact crater (Fig. 5), the edge of which rises some 20-40 m above its surroundings (Tikkanen 1994).

Topography of surficial deposits

The bedrock of Finland is covered in most places by a 3-4 metre layer of surficial deposits, and it is only in certain places that accumulations of over 100 m have been observed, in connection with specific glaciofluvial landforms (Aartolahti 1990; Taipale & Saarnisto 1991). The loose deposits mostly date back to the Quaternary glaciation or afterwards, and the country's glacial topography may be said to have received more or less its present shape during the deglaciation stage, some 12 000 – 9 000 BP (Aartolahti 1990; Tikkanen 1994, 2002; Saarnisto & Salonen 1995)(Fig. 6.).

Geomorphology in Finland

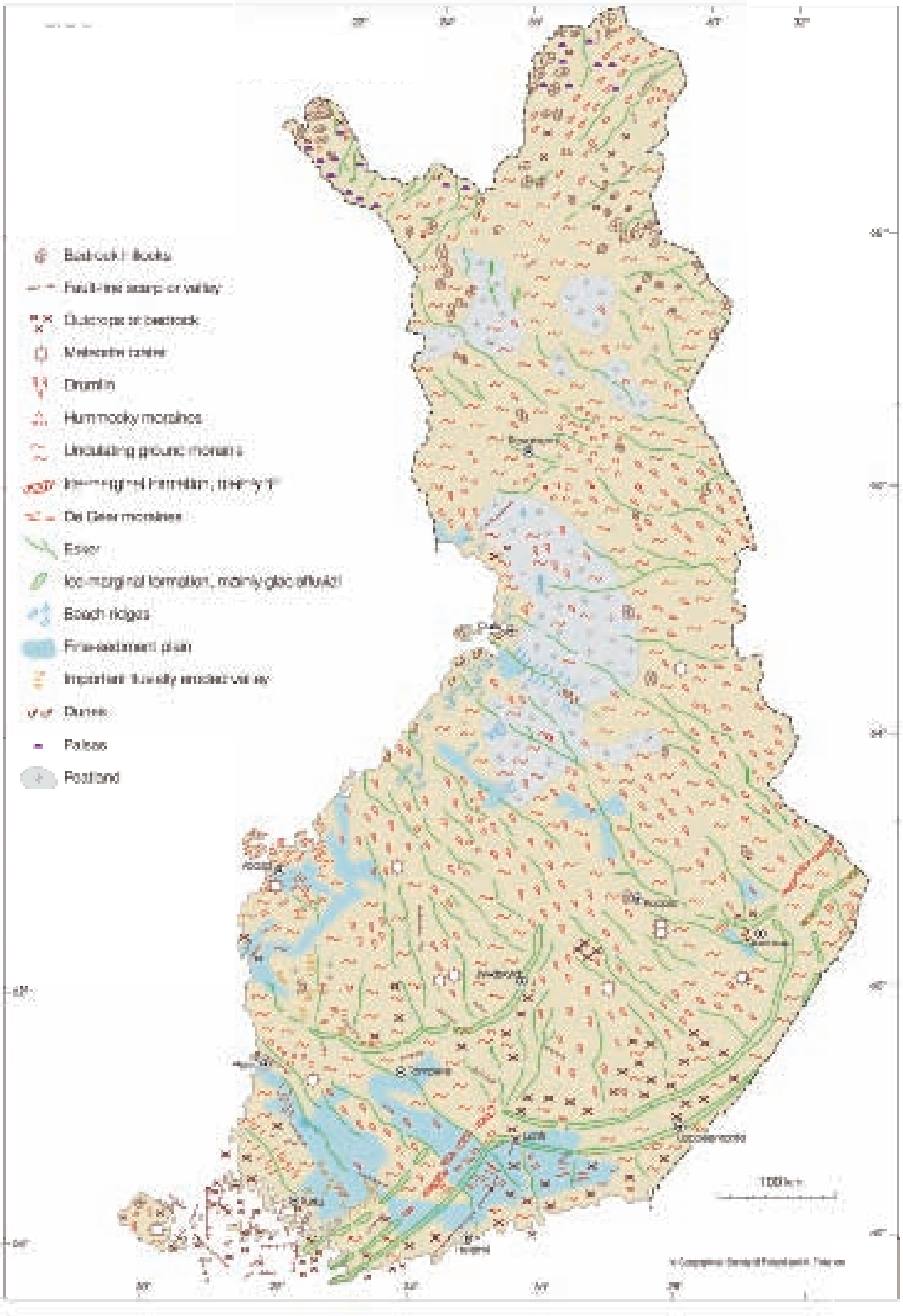

Fig. 6. Geomorphological map of Finland (Tikkanen 2002).

The most common material, which covers the bedrock, is glacial till. On account of the active flow that took place in the glaciers, this till was deposited in places as streamlined drumlins that indicate the direction of movement of the ice. Individual drumlins can be as much as a hundred metres high and ten kilometres long (Tikkanen 1994)(Fig. 7), and they can occur in extensive fields in the Lake Region (up to 25 000 km²), Eastern Finland or Northern Lapland (Glückert 1973; Seppälä 2005). Most drumlins have a bedrock core, and some occur in conjunction with shallow flutings, which can differ in orientation from the drumlins themselves (Aario 1977; Heikkinen & Tikkanen 1989).

Rogen moraines, which are oriented perpendicular to the direction of ice movement, are usually regarded as glacial accumulation landforms (see Aario 1977), but their origins have also been linked to melting processes in a passive ice margin that have allowed gravel and sand sorted by the meltwater streams to be deposited in transverse cracks at the ice margin (Kurimo 1979). These landforms of height 5-15 m are to be found in low-lying, flat areas in Southern Lapland, Ostrobothnia and Northern Karelia, and appear to be connected with the occurrence of drumlins and hummocky moraines.

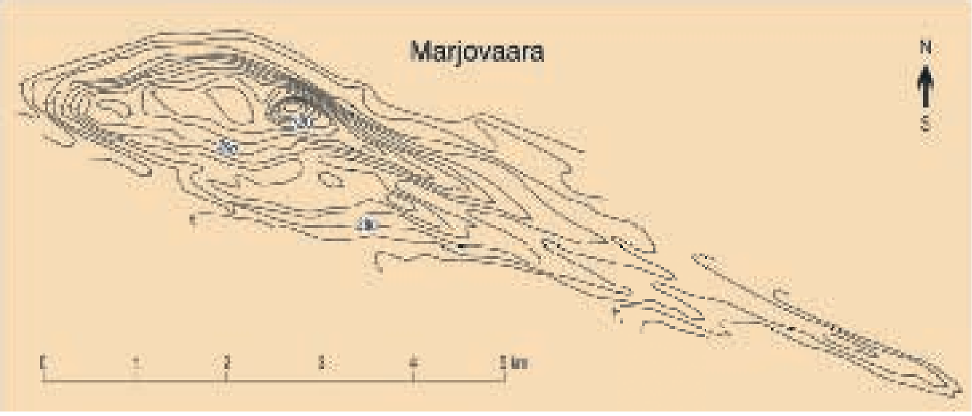

Fig. 7. An exceptionally large drumlin in Kuusamo, eastern Finland. Contours in 5 m intervals.

Till material released from the ice can accumulate to form hummocky moraines of varying shapes, and these are particularly common in Southern Lapland, on the west coast and in Eastern Finland. The most extensive area of hummocky moraines in Northern Finland occupies some 1600 km^2 (Taipale & Saarnisto 1991). Individual hummocks are usually between 5 and 20 metres in height and do not normally have any distinct orientation. There are ring-shaped mounds, a few metres in height to be found in Lapland that have been termed Pulju moraines (Kujansuu 1967; Aartolahti 1974).

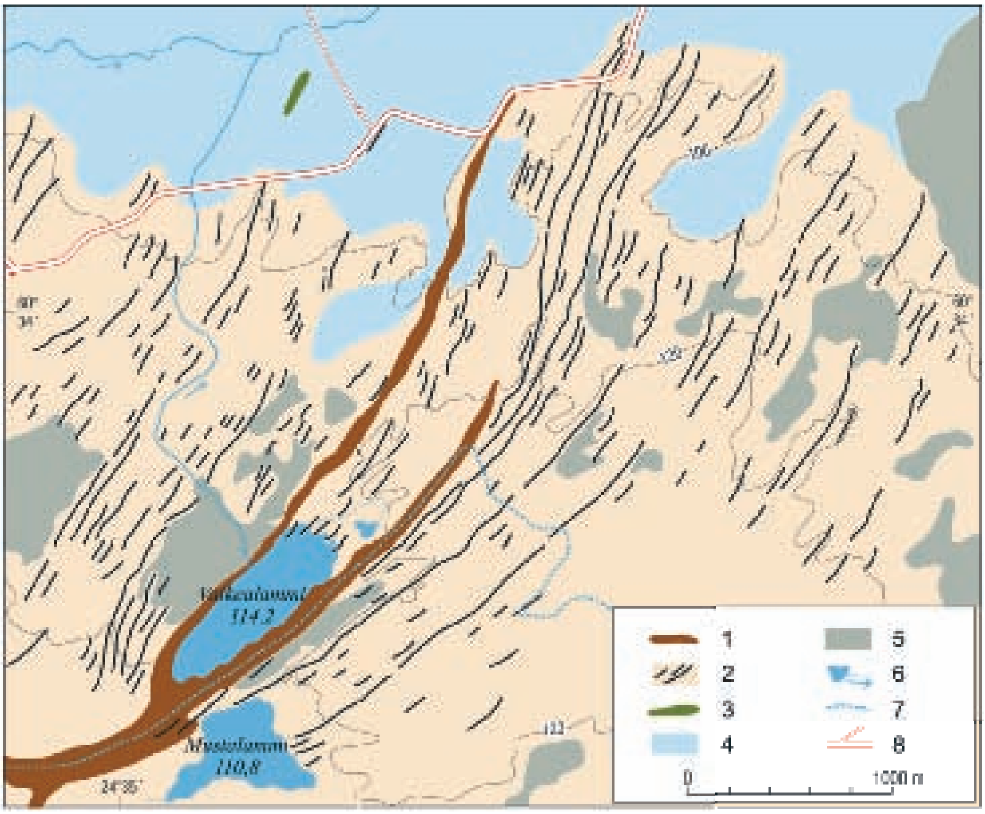

Fig. 8. End moraines at Valkealammi, southern Finland. (1) large push moraine ridge, (2) De Geer moraines, (3) glaciofluvial marginal formation, (4) plain of fine sediments, (5) mire, (6) lake and river, (7) watershed, (8) road (Tikkanen 1989).

Till that has accumulated at an ice margin or in transverse cracks running parallel to the margin may be interpreted as forming end moraines, the largest of which in Finland are 20-30 m high and located in conjunction with the Salpausselkä formations. Small end moraines, usually 1-3 m high and 50-1000 m long and termed De Geer moraines, are to be found in swarms of several hundred at a time, especially in the subaquatic coast areas of Southern and Western Finland (Zilliacus 1987; Aartolahti 1995)(Figs. 8 and 9).

Fig. 9. End moraine ridges emerging from the Baltic Sea in Raippaluoto, western Finland. Photo Matti Tikkanen

Fig. 10. Glaciofluvial esker (Ritosärkänharju) in Lieksa, eastern Finland. Photo Matti Tikkanen

The First and Second Salpausselkä Ice-marginal Formations constitute a zone some 20-50 km wide and 600 km long of broad glaciofluvial deltas and narrow chains of ridges running parallel to the ice margin stretching from South-Western Finland well into the eastern part of the country. These formations are predominantly glaciofluvial, but they include some till forms. Other large formations of a similar kind are the Third Salpausselkä in Western Finland and the Central Finland Ice-marginal Formation. These major marginal formations have arisen in front of the reactivated ice margin in the cause of a protracted stagnant phase. The Salpausselkä I and II Formations were laid down during the cold climatic period known as the Younger Dryas Stadial, being dated by reference to the varve chronology to 11 300 – 11 100 years ago and 10 800 – 10 600 years ago, respectively. The whole deglaciation in Finland occupied the period 12 100 – 9 300 years ago (Saarnisto & Salonen 1995).

Apart from the major ice-marginal formations, large deposits of gravel and sand are to be found in the eskers that run across the country in chains that reach lengths of several hundred kilometres in the best cases (Fig. 10). The eskers are oriented approximately in the direction of glacial movement, the interlobate esker complexes being particular prominent landforms (Taipale & Saarnisto 1991). Other smaller landforms commonly occurring in conjunction with the eskers and large glaciofluvial ice-marginal formations are kames, deltas and also sandurs in supra-aquatic areas.

The terrain in the southern and western coastal areas in particular is evened out somewhat by the presence of clay and silt deposits, which can be more than 70 m in thickness (Haavisto & al. 1980), and in many places rivers have succeeded in gouging valleys 20-30 m in depth into these plains of fine-grained sediment in the course of post-glacial times, the slopes of these valleys being subsequently subject to landslip (Aartolahti 1975). Fluvial erosion has also been pronounced in the glaciofluvial fill material occupying some river valleys in Northern Finland (Koutaniemi 2000).

Fig. 11. Active part of the Yyteri dune field in Pori, western Finland. Photo Matti Tikkanen

None of the rivers of Finland has succeeded in developing an extensive delta, as land uplift has been constantly shifting the river outlets further out to sea.

Since the majority of the area of Finland has been under water, there are many places where beach ridges have been built up on slopes by wave action, or shores have been eroded to leave cliffs or boulder fields. Beach ridges composed of sand are frequently to be found on the sides of eskers, and they are particularly common in the coastal zone bordering on the Bothnian Bay (Helle 1965). The largest of these can be up to 100 m across and more than 5 m high (Tikkanen 1981). Especially large, clearly defined shore landforms were laid down during the transgressive phases of the Ancylus Lake and Litorina Sea.

Active dunes can be found on the present-day seashores mainly on the west coast (Alestalo 1979; Heikkinen & Tikkanen 1987; Hellemaa 1998)(Fig. 11), but the majority of Finnish dunes are nowadays bound by a vegetation cover and exist in the interior of the country, most notably in Eastern Finland and Northern Lapland (Aartolahti 1980). The largest parabolic dunes in the upland area of Rokuanvaara, situated to the south-east of Oulu, for instance, are about 25 m high (Aartolahti 1973). In the

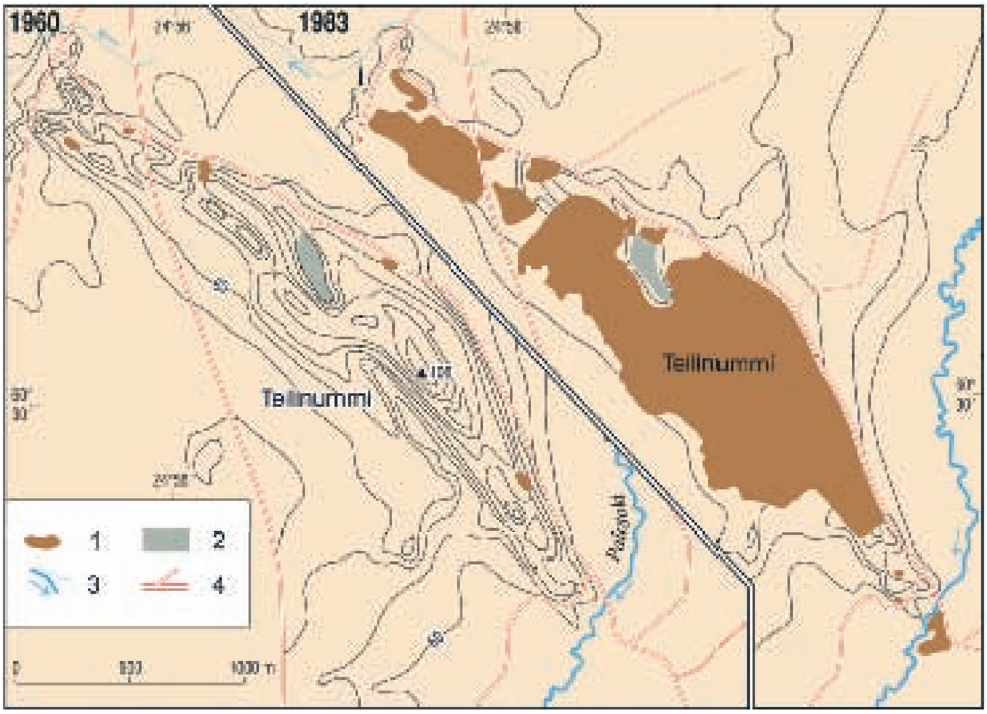

Fig. 12. Changes in the relief of an esker in the course of just over 20 years near Nurmijärvi, southern Finland. (1) gravel pit, (2) mire, (3) river, (4) road. Contours at five-metre intervals (Tikkanen 1989).

far north of Lapland, however, there are also some dune areas with vegetationless deflation surfaces, amounting to a total area of perhaps 300-400 ha (Tikkanen & Heikkinen 1995).

Almost a third of the land area of Finland is covered by mires, the peat in which can be over 10 m deep at its greatest. Since the mires are usually located in the lowest depressions, they also help to even out the topography, although raised bogs developing in flat clayey areas can rise as much as 7 m above their surroundings (Ikonen 1993). The aapamires of Northernmost Lapland commonly feature palsas, mounds with a permafrost core that can reach heights of 5 m or more (Seppälä 1979).

The most rapid changes taking place in the forms of the land surface nowadays are those brought about by human agency. The extraction of stone and loose materials for building and road construction purposes has quickly destroyed or eaten into many landscape elements such as eskers (Fig. 12.) and bedrock outcrops, even ones of substantial size, while at the same time, human activity has created new landforms such as embankments, cuttings, terraces, pits and mounds composed of waste or landfill material. Human activity also has indirect effects on surficial landforms by enhancing or accelerating natural processes.

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Postglacial history of Finnish inland waters

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Finland nowadays has 187 888 lakes of over five ares in area, of which about 56 000 are over one hectare (Raatikainen & Kuusisto 1990; Kuusisto 2005), and the total lake area, 33 522 km², amounts to 9.9% of the country's surface area. The largest individual lakes are Saimaa (1377,1 km²; Suur-Saimaa 4380 km²), Päijänne (1080,6 km²) and Inari (1040,3 km²). The lakes have 98 050 islands, and the combined length of lake shorelines is 215 000 km, 14 850 km of these are located around Lake Saimaa and its islands. On the other hand, although the deepest point, in Lake Päijänne, is as much as 95.3 m, the mean depth of the Finnish lakes is no more than 7.2 m. All the water contained in them would fit without difficulty into the Lake Onega in Russian Karelia and could not fill more than a quarter of Lake Ladoga (Tikkanen 1990, 2002; Kuusisto 2004).

The lakes are linked together by rivers to form watercourses, the vast majority of which flow into the Baltic Sea. Finland has 72 watercourses that are more than 200 km² in area, of which the five largest account for the majority of the country's surface area. The lakes have been created over the last 10 000 years, either through the emergence of their basins from beneath the ice sheet of the last glaciation or, over the major part of the country, through isolation from the Baltic basin.

As the pattern of land uplift in Finland has been uneven, the land surface has gradually tilted, causing many lakes to alter their direction of outflow. The majority of the changes in outflow channels occurred in the interval 8500 - 4500 C-14 years BP, but the youngest known natural change, in the outflow channel of Lake Längelmävesi system, is known to have occurred as late as AD 1604 (Blomqvist 1926). Numerous small lakes have become shallower in the course of time as a consequence of the deepening of their outlet channels and the accumulation of bottom sediments, and about 100 000 lakes have become filled in entirely (Salonen & al. 2002). There have also been cases in which rivers have been dredged, lake levels have been lowered artificially, or lakes have been converted into regulation basins for hydroelectric power schemes. Water quality has also varied greatly in many waterway systems, mainly as a consequence of human actions in recent times.

Photo 1. Dried up outlet channel of the ancient Lake Päijänne at Kotajärvi in Pihtipudas, central Finland . Photo Matti Tikkanen.

Changes in outflow direction and transgressions and regressions in the lakes

When the last parts of the great watercourses that make up the Lake District of Finland became isolated from the Baltic basin about 8000 BP, the majority of them originally flowed to the north-west into the Bothnian Bay. The largest of all was a labyrinthine watercourse that skirted round the present-day Saimaa and Päijänne systems and had its outflow over the present Suomenselkä watershed in Pihtipudas into the headwaters of the River Kalajoki (Saarnisto 1971; Ristaniemi 1987; Tikkanen 1990) (Photo 1). The central lake of this vast watercourse, the Great Lake of Central Finland, had much broader expanses of open water than the watercourses of today, especially in the north, and its surface was more than 20 m above the present level (Saarnisto 1970; Tikkanen 1990).

The Great Lake reached its maximum extent about 6100 BP, at which point the rising waters broke through the Heinola esker in the south to form a new outlet channel via the River Kymijoki. By that stage the water level at the southern tip of Lake Päijänne had risen about 20 metres (Saarnisto 1971). This meant that the watershed in the south shifted some 300 km further north in places, becoming established in the Suomenselkä area (Fig. 1). The rising waters of the Ancient Lake Saimaa similarly began to seek new outlet channels, and two such channels opened up, through the small lakes of Matkuslampi near Ristiina about 6000 BP and at Kärjenlampi near Lappeenranta around 5500 BP, and the present outflow channel arose around 5000 BP, when these waters broke through the First Salpausselkä formation and began to flow through the Vuoksi channel into Lake Ladoga (Saarnisto 1970).

Coastline, waterways and watersheds of Finland around 7000 BP

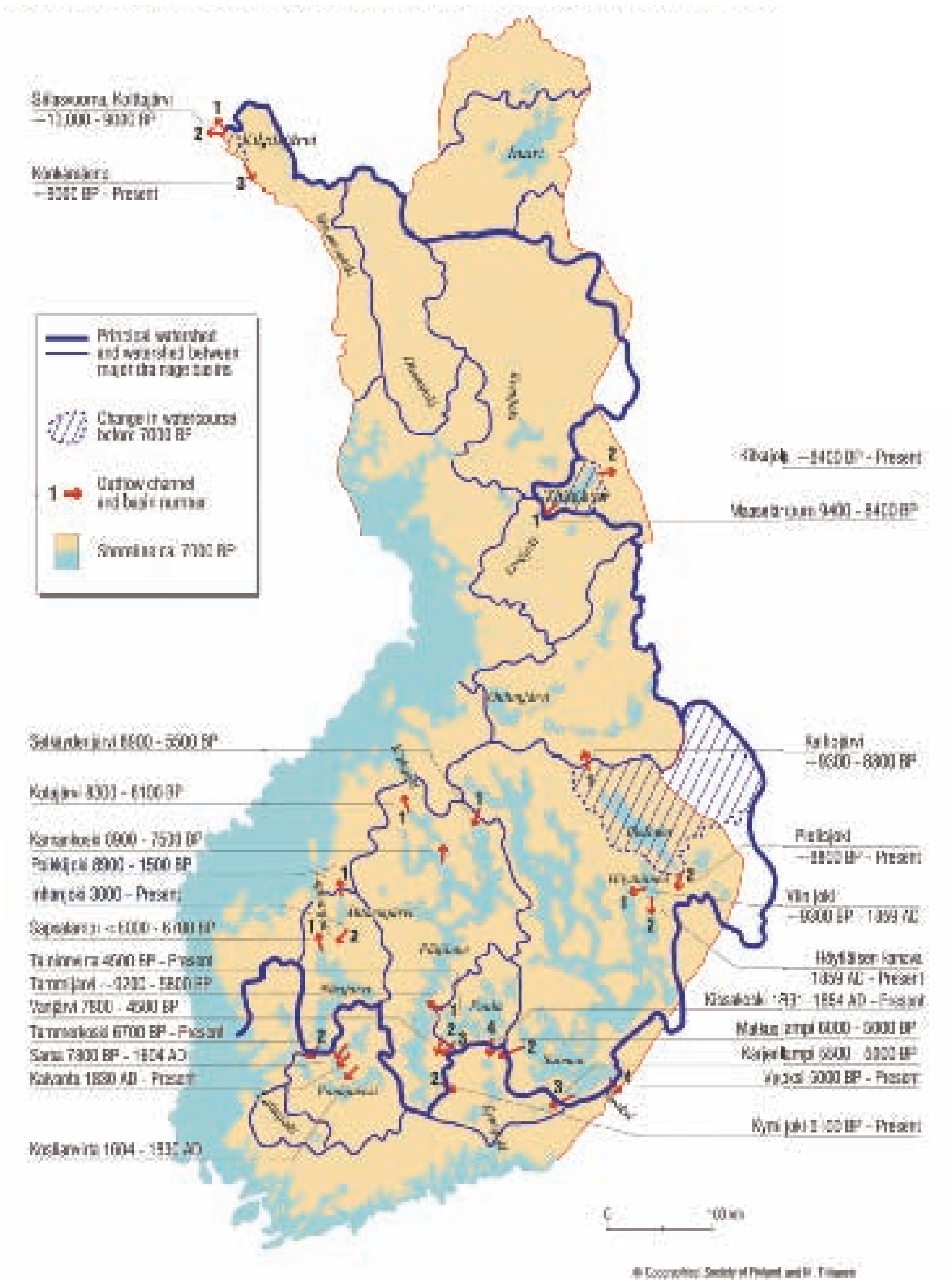

Fig. 1. Coastline of Finland and the main waterway systems and watersheds around 7000 BP. 1. principal watershed and watershed between major drainage basins, 2. change in watercourse before 7000 BP, 3. outflow channel and basin number. According to Tikkanen (2002).

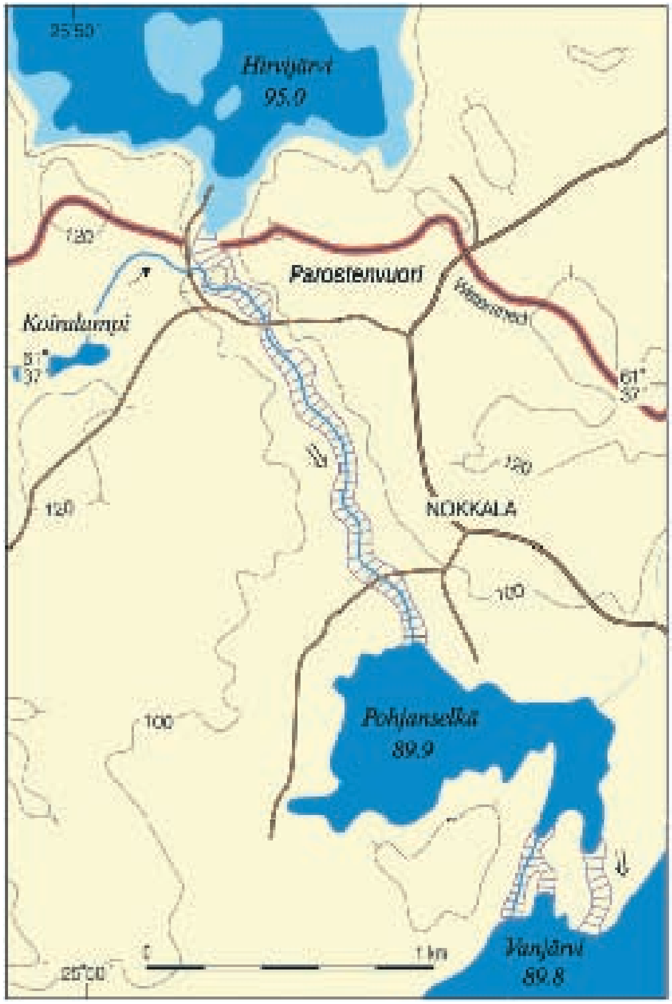

Fig. 2. Ancient outlet channel of Puula Lake complex between the lakes Hirvijärvi and Vanjärvi in Sysmä, central Finland. Area submerged beneath the waters of the ancient lake in light blue. (Tikkanen 1995).

The Kokemäenjoki watercourse likewise differed greatly in early times from what we know today. The waters of Lake Näsijärvi originally had their outlet in the north, passing into the headwaters of the Lapuanjoki system at Alavus. As the Ancient Lake Näsijärvi was also transgressive, the water level in its southern parts rose, opening a new outlet channel at Tammerkoski around 6700 BP (Tikkanen & Seppä 2001).

The lakes that make up the Puula watercourse, lying between Päijänne and Saimaa, have shifted their outlet channel in two stages, first from the north-west to the west (Fig. 2) and later to the south-west, where the present channel, Tainionvirta, opened up at Koskipää near Hartola around 4500 BP (Tikkanen 1995). Lake Puulavesi itself was artificially redirected in 1831-54 to flow into the Mäntyharju watercourse by the construction of a canal at Kissakoski, although a small stream had already developed at that site, functioning as a natural outlet channel (Hellaakoski 1928).

Even before the time of the changes in the directions of flow of the major watercourses of the Lake District, a number of transgressions had taken place that had led to alterations in outflow channels and significant reshaping of drainage basins. One water body affected in this way was Lake Pielinen in North Karelia, which originally had its outflow in the north-west, at the threshold in the Suomenselkä watershed marked by Lake Kalliojärvi. This threshold dried up around 8400 BP, however, when the waters of the transgressive lake opened up a new channel through the ice-marginal formation of Uimaharju at the south-eastern end (Hyvärinen 1966). The subsequent regression then cut down the length of Lake Pielinen by some 40 km and the Kalliojärvi threshold is nowadays about 66 m above the lake surface.

The Kitkajärvi lakes in Kuusamo arose in a supra-aquatic position about 9400-9500 BP on the retreat of the ice sheet, and their waters drained away at first over a threshold of Maaselänpuro and into the River Livojoki in the Iijoki basin. The Ancient Lake Kitka was transgressive from the outlet, and eventually the rising water reached

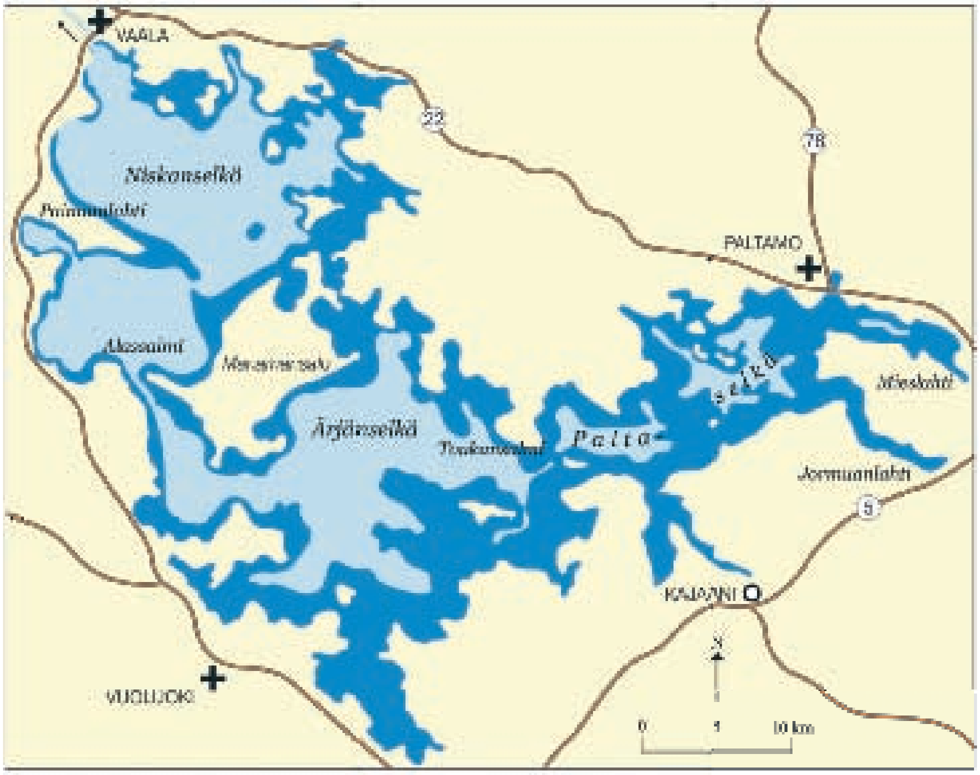

Fig. 3. Lake Oulujärvi during isolation about 8400-8300 BP (light blue). Areas submerged after that time are indicated in dark blue. According to Koutaniemi and Keränen (1983), generalized.

the height of the present threshold on the outflow into the River Kitkajoki in the east. The result was a long bifurcation stage, before finally the Maanselkä threshold dried up around 8400 BP (Heikkinen & Kurimo 1977). At the same time the watershed shifted entirely to a point west of the lakes and the whole basin was transferred from the Iijoki watercourse, flowing into the Baltic, to the Koutajoki watercourse, which flows into the White Sea (Fig. 1). The shoreline of the Ancient Lake Kitka, which is clearly distinguishable in the terrain, is now more than 10 metres above the present lake level in the west.

There are many more large lakes in which major changes have taken place in the course of time, even though the result may not have been an alteration in outflow channel. If the threshold was located in an area of faster land uplift, a transgression will have taken place which will have raised the water level considerably in the course of the millennia. One case in point is Lake Oulujärvi, which was isolated from the Ancylus Lake stage of the Baltic around 8300-8400 BP. Its outflow threshold has always been situated in the same place, at the north-western end, although the land is rising faster here than elsewhere in the basin. The resulting transgression has raised the water level at the eastern end of the lake by as much as 15 metres (Koutaniemi & Keränen 1983), so that the original series of basins have combined to form a single large lake, the surface area of which has doubled since the time of its isolation (Fig. 3.). A similar history may be traced for the Vanajavesi basin (Auer 1924; Saarnisto 1971) and Lake Pyhäjärvi in southwestern Finland (Eronen & al. 1982).

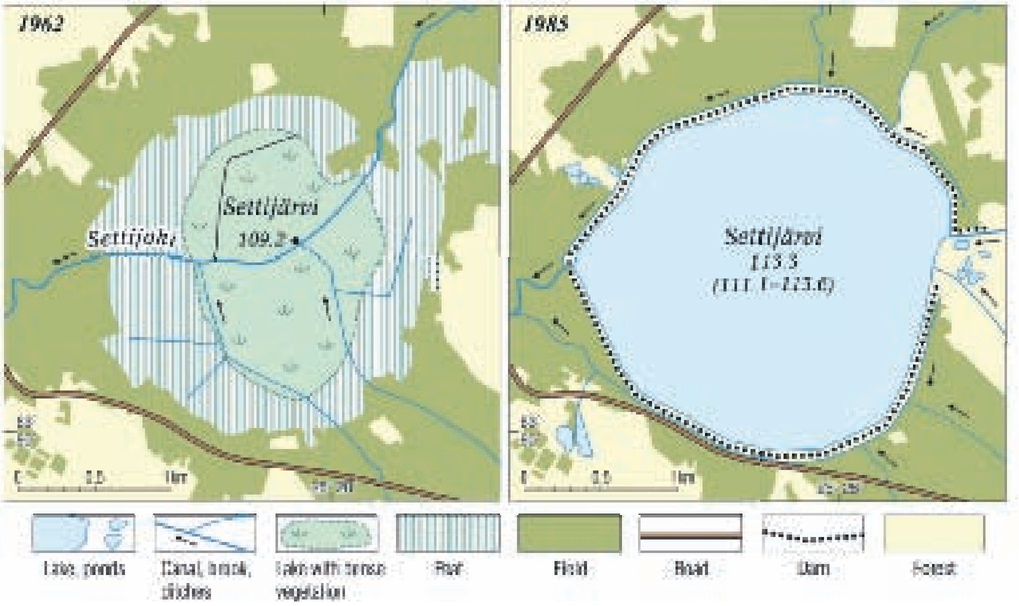

Fig. 4. Lake Settijärvi in Haapajärvi, Central Ostrobothnia, before and after damming and regulation (Tikkanen 2002).

Regulation, drainage and water quality of lakes

The inhabitants of Finland began to take advantage of the watercourses by the 14th century at the latest, harnessing the rapids to provide power for flour mills, planning machines for producing splints and roofing shingles, and later sawmills. In many cases this meant the building of dams to raise the water level. Nowadays about a third of the total area of natural lakes in the country, i.e. some 10 200 km², is subject to regulation, about a half of serving the needs of hydroelectric power, one fourth flood control and one fourth water supplies. Also, about 20 reservoirs have been constructed for regulation purposes, with a combined surface area of 800 km² (Ollila 1986). The largest reservoirs are those of Lokka (417 km²) and Porttipahta (214 km²), created by damming the headwaters of the River Kemijoki. There are also many small, shallow lakes in danger of growing over in which the water level has been raised to improve their ecological condition (Tikkanen 2002) (Fig. 4, Photo 2).

Although settlement has always tended to be concentrated beside the rivers and lakes, human influence on these waterways remained minimal until the mid-18th century (Anttila 1967; Vesajoki 1982), at which point there began a protracted period of some 200 years during which almost 3000 lakes were drained either totally or partially and innumerable other ones underwent at least some lowering of their water level (Huttunen 1981). The first known artificial lowering of a lake level in Finland was undertaken by Lauri Nuutinen in the parish of Eno in North Karelia in 1743, when

Photo 2. Lake Settijärvi at the present time. Photo Matti Tikkanen.

he and his family dug a drainage channel through the esker that was restraining the waters of Lake Sarvinginjärvi (Vesajoki 1982). Although the draining of lakes reached its peak in the 19th century, the practice continued into the 20th, and numerous small pools were also drained in order to dry paludified forests on their shores.

The work of shaping watercourses in the desired manner did not always go according to plan in other respects, either. Many drainage operations ended with the water getting out of hand and deepening the newly dug channel far more than had been intended, leading to an excessive drop in the water level. The best-known example of this is the disastrous discharge and lowering of Lake Höytiäinen in 1859, when the lake level fell by 9.5 metres and about 170 km^2 of former lake bed became dry land (Vesajoki 1980, 1982). In a similar case, the collapse of a dam in a channel being dug through the esker of Kangasalanharju in 1830 lowered the surface of Lake Längelmävesi by 2 m very rapidly and laid bare some 30 km^2 of land (Renqvist 1951).

The effects of human activity are also clearly reflected in the quality of the water in our lakes and rivers. Effluent from industry, settlements or agriculture, and also airborne deposits, have caused the ecological state of many watercourses to deteriorate. According to a usability classification over four-fifths of the lake basins in Finland were nevertheless in an excellent (38%) or good state (42%), while 16% were in a satisfactory state, 4% moderate and 0.3% in a poor state (Fig. 5). The best condition on average is achieved in the Lake District and in the north of Lapland (Antikainen & al.1999; Tikkanen 2002). Particularly marked improvements have been brought about in recent years in the state of the badly polluted lakes and rivers adjacent to large industrial complexes or settlements. On the other hand, the general condition of many lakes has been affected by a slowly advancing process of eutrophication.

The rivers of Finland are in a distinctly poorer condition than the lakes, only two out of five being classified as excellent (8%) or good (31%), while 30% are satisfactory, 29% moderate and more than 2% poor (Antikainen & al. 1999). The poorest results apply to the rivers of Ostrobothnia and the south coast (Fig. 5). The task of improving their state will be a difficult one, because activities such as fish farming and peat mining and the diffuse loading from forestry and agriculture affect the water quality of the rivers most seriously of all.

Many Finnish lakes have characteristically been undergoing a slow process of acidification throughout post-glacial times (Tolonen & al. 1986; Korhola & Tikkanen 1991), but the trend has been accentuated by the effects of sulphur and nitrogen compounds released in the generation of energy, in industrial processes and by motor traffic. According to Forsius (1992) the estimated proportion of acidic lakes in 1987 was 12 % of the total number of lakes but only about 0.8 % of the total lake surface area in Finland, and more than 45 % of the acidic lakes have been acidic already during pre-acidification times. As a result of recent curbs on sulphur emissions, many small acidified lakes are already showing signs of recovery and their pH has begun to rise, as elsewhere in Europe and North America (Mannio 2001).

Many efforts have been made to improve the condition of our lakes and rivers. Where lake levels have been lowered too drastically, measures have now been taken to raise them, and stretches of rapids that had been dredged have now been returned to their original state by rolling the larger rocks back into the channel. Water quality has been improved not only by intensifying and centralizing purification processes, but also by leaving protective zones alongside river banks and lake shores, constructing precipitation basins, removing excessively lush vegetation, oxygenating deeper waters that were suffering from oxygen deficiency, and dredging bottom sediments that contain excessive amounts of phosphorus or other pollutants. Internal loading in eutrophicated lakes has been reduced by intensified fishing for cyprinids such as roach and bream. Although there is still much room for improvement in the water quality of Finnish lakes and rivers, it can now be said with confidence that the decline in their condition has for the most part been arrested and signs of a distinctly better water quality have been observable in many areas in recent times.

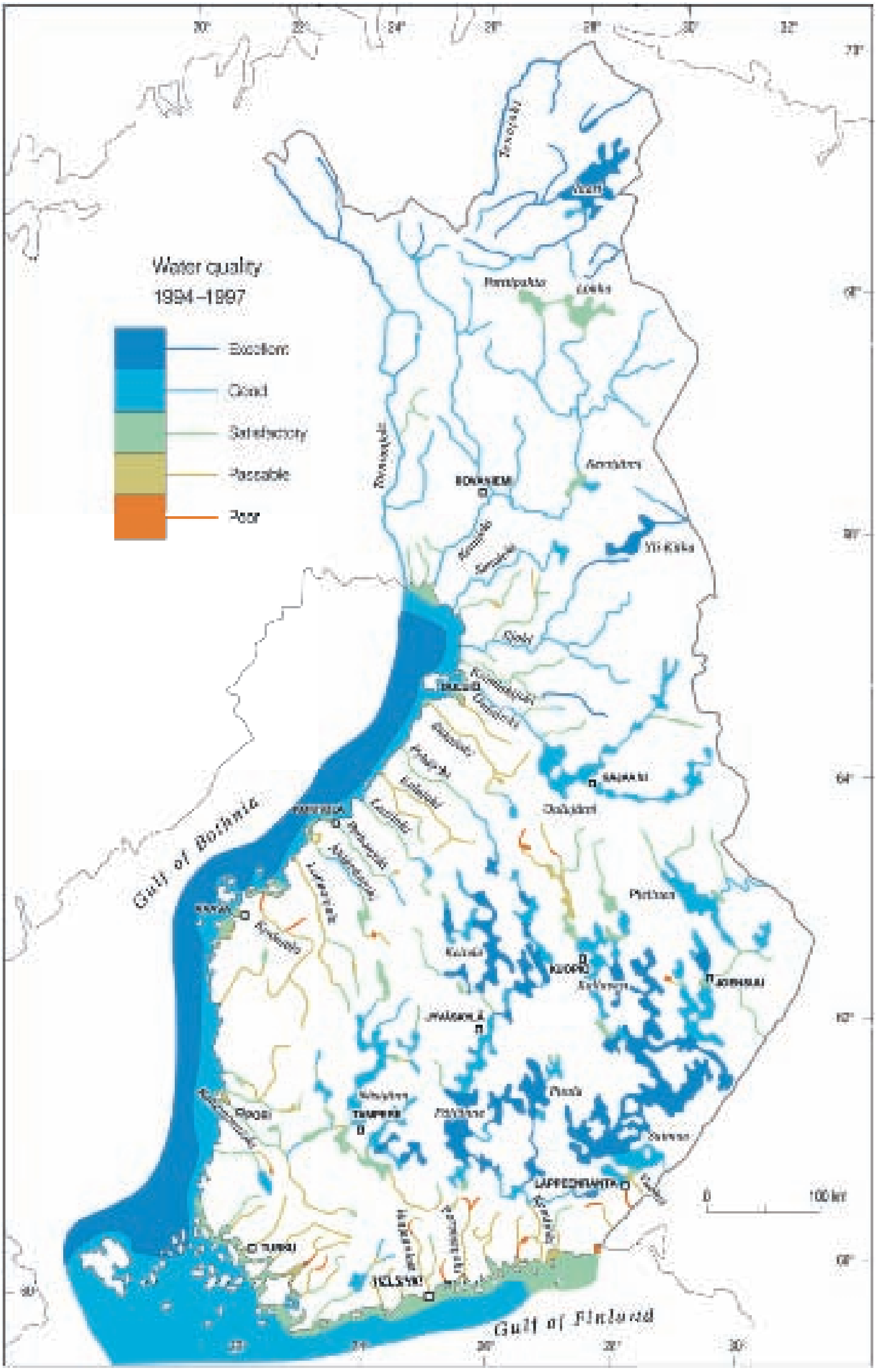

Fig. 5. Usability ratings of inland waterways in Finland in the mid-1990s (generalized from Antikainen & al. 1999).

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Lake and river systems in Finland

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Land of plenty

Water is an essential feature of landscapes in Finland. This can be confirmed by a set of large numbers. There are 187 888 lakes in Finland, although 131 876 of them have an area of less than one hectare (Raatikainen & Kuusisto 1990). However, there are 47 lakes with an area of more than one hundred square kilometres. The lakes have 98 050 islands, and in addition there are 80 897 islands along the Finnish Baltic coastline.

The total number of Finnish rivers with mean flow exceeding 2 m^3/s is over six hundred; thirteen of these have a mean flow of over 100 m^3/s. The combined length of all shorelines is 314 000 km. Lakes claim 215 000 km of shorelines; 14 850 km of these are located around Lake Saimaa and its islands. There is a 46 000 km marine coastline, and riverbanks total some 53 000 km.

There are 22 085 springs marked on the Finnish basic map (Fig. 1). About ten of these gush out more than 5000 cubic metres of water a day, the largest one in Utsjoki, northernmost Lapland, up to 30 000 m^3. The total number of classified groundwater areas in Finland is 7141. The number of those areas important for water supply is 2226, those suitable for such use 1300 and other groundwater areas 3615. The total water yield of all classified groundwater areas is 5.8 mill. m^3 per day.

Fig. 1. A spring in Ruovesi municipality in the upper part of Kokemäenjoki River basin.
Photo Esko Kuusisto

River basins

Finland has 74 river basins with an area larger than 200 km^2 (Fig. 2). Six of them flow to Lake Ladoga, 25 to the Gulf of Finland or to the Archipelago Sea, 36 to the Gulf of Bothnia, and seven to the Arctic Ocean or to the White Sea.

Nine river basins are larger than 10 000 km^2. These basins cover 78% of the country, some of them extend also to our neighbouring countries. In fact, two of them, Tornionjoki and Tenojoki, are mainly located in Sweden and Norway, respectively. These two rivers and their tributaries also form most of our border with these countries.

The total length of rivers wider than 20 metres is 14 550 km. The longest river route, Poroeno-Lätäseno-Muonionjoki-Tornionjoki, from the Norwegian border to the Gulf of Bothnia, is 550 km. However, most Finnish rivers are relatively short, less than 100 km. In addition, lakes divide many rivers into several stretches; some rivers could in fact better be called lake chains than river channels.

Fig. 2. River basins in Finland.

Discharge characteristics

The annual and monthly flows from Finland in 1912-2003 were recently analyzed. The mean annual flow was 3 294 m^3s^{-1} (Fig. 3). The wettest year was 1981 (4 723 m^3s^{-1}) and the driest 1941 (1 588 m^3s^{-1}). There is no trend in the annual series, but winter flows have increased. The linear trend in February is significant in the level of 99.9%. It is, however, difficult to judge, how much of the increase is due to regulation of watercourses and what part of it is caused by climate change and variations. Large northern rivers entering the Bothnian Bay have been regulated since the 1950s and the rivers of Ostrobothnia since the 1960s, and typical regulation schemes increase wintertime flows considerably.

In southern Finland the annual precipitation is larger than in the north, but evaporation decreases considerably from the south towards Lapland. Therefore the specific flow is typically 11-13 l/s km^2 in northern Finland, but only 8-10 l/s km^2 in southern Finland. As compared to lowlands of central Europe, even the latter values are quite high.

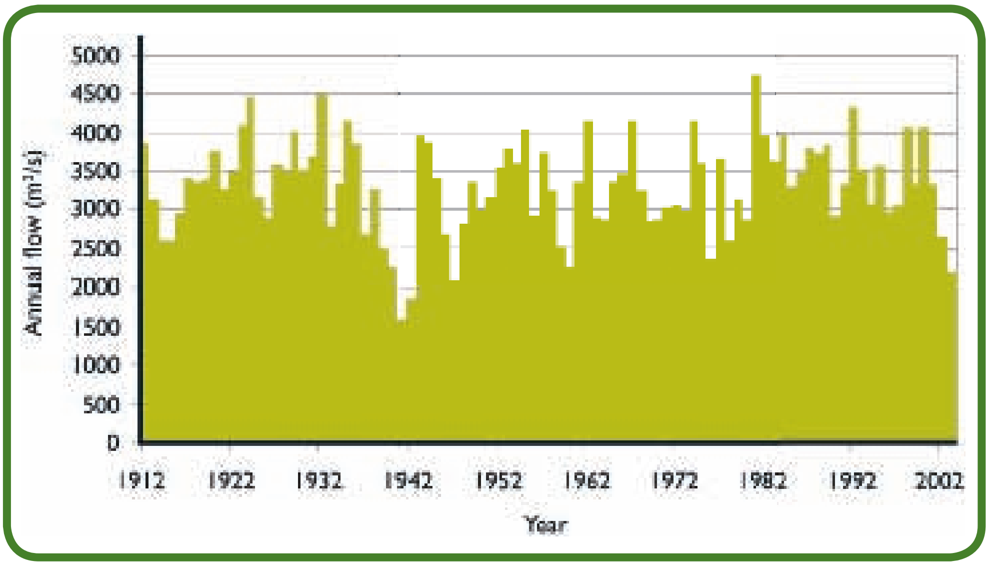

Fig. 3. Runoff from the total area of Finland in 1912-2003.

An essential characteristic is the seasonal variation of river flow. Due to snowmelt, all rivers in Finland usually have plenty of water in spring, but summer and winter flows are relatively small. Lakes – and to a certain extent also mires – attenuate flow variations. This is clearly exemplified by Table 1. In Vuoksi and Kymijoki basins the ratio of mean maximum and minimum flows is only 2-3, because these basins have plenty of lakes. The Aurajoki basin in southwestern Finland has no lakes, and consequently the corresponding ratio is as high as 860. In the large rivers of Lapland the ratio is 25-50, in the rivers of Ostrobothnia 50-110.

Table 1. Some Finnish river basins with their areas (A), lake percentages (L), mean flows (MQ) and the ratios of mean maximum and minimum flow (R).

River basin	A (km2)	L (%)	MQ (m3/s)	R
Vuoksi	61,750	19.8	554	2
Kymijoki	37,160	19.1	310	3
Vantaa	1,685	2.5	16	67
Aurajoki	885	0.1	8	860
Kokemäenjoki	27,050	11.7	216	16
Kyrönjoki	4,900	1.1	43	88
Lapuanjoki	4,110	2.9	31	51
Kalajoki	4,200	1.4	32	107
Siikajoki	4,440	2.3	40	89
Oulujoki	22,840	11.4	254	9
Iijoki	14,320	5.7	173	29
Kemijoki	51 130	4,5	538	26
Tornionjoki	40 130	4,6	378	27
Tenojoki	13 780	2,4	165	51
Paatsjoki	14 570	12,1	146	4

Floods and droughts

The most dramatic of all hydrological phenomena are floods – also in Finland, even if there never happen catastrophic floods that threaten human life. Flood damages may, however, cause rather severe economic losses. There are five main types of floods in Finland:

- Snowmelt floods, possibly combined with rains, usually in April-May (Fig. 4)
- Floods caused by heavy rainfall, in particular in river basins with only a few lakes
- High water levels in lake chains, after a prolonged wet season or several successive wet years
- Sudden 'flash' floods, in small catchments and in urban areas, caused by local heavy thunderstorms
- Floods caused by frazil and ice jams.

The spring and summer flood in 1899 was the largest ever observed in Finland. In that year the lake water levels were exceptionally high in southern and central parts of the country. They were half a metre higher than the highest levels observed subsequently and two metres above normal levels. As noted above, his flood was due to abnormally abundant snow, furthermore the summer was cold and rainy. The damages caused by the flood were examined by a committee appointed by the Senate and it submitted its report to the Czar in 1900 (Finland was a part of the Russian Empire in those days). According to the report the flooded area totalled 150 km^2. The return period for the 1899 flood has been estimated as 200-500 years.

Major floods before the observation period include the Keksi flood in Tornio River in 1677, the floods in Kokemäki river in the late 18th century and the Sauli Flood in Kemi River in 1859. Among the more recent floods, the spring flood of May 1966 was very high in southern Finland, like the rain floods in August 1967 in southern Ostrobothnia, and the spring flood in 1968 in Tornio River. Funny trick by Nature to generate three most exceptional floods of the 20th century in consecutive years!

Besides the natural processes, human activities may also cause floods. One of the best known is the breakthrough of Lake Höytiäinen in Eastern Finland in 1859. The waters broke through a canal under construction and some 800 million m^3 of water suddenly flowed out into Lake Saimaa. The surface of Lake Höytiäinen was lowered by eleven metres, and the area of displayed alluvial land was 170 km^2.

Fig. 4. A spring flood in River Ounasjoki in Lapland. Photo Esko Kuusisto.

Droughts do not usually cause major damages in Finland. The flow in small rivers or from the outlets of small lakes may run dry in the southern parts of the country during prolonged rainless periods of late summer. The only drought with nationwide effects occurred in 1941-42, i.e. during the II World War. The years 2002-03 were also relatively dry, causing difficulties to water supply and decreasing the electricity production by hydro power.

The Lake District

The region with a myriad of lakes in the central part of Finland has been known as Lake District for at least two centuries. However, it has never been exactly defined. There are no obvious natural boundaries; at least four different geomorphological regions in central Finland have high lake densities (Fogelberg & Seppälä 1986). Major divides could be considered as lake district boundaries; according to this interpretation, the Lake District would be composed of three large river basins, namely those of Vuoksi, Kymijoki and Kokemäenjoki with the total area of 116 900 km^2 (excluding the part of Vuoksi basin located in the Russian territory). The total area of lakes in these three basins is over 21 000 km^2, the average lake percentage thus being eighteen. However, the upper part of Vuoksi Basin and particularly the southwestern part of Kokemäenjoki basin do not have many lakes.

Fig. 5. A typical view from the Finnish Lake District. There are almost half a million holiday dwellings in Finland, many of them located on lake shores. Photo Esko Kuusisto.

The total number of water bodies in the Lake District is around 42 400, some 55 per cent of them being larger than one hectare. Thus this area has only 23 per cent of all Finnish lakes, although almost two thirds of the country's lake area is in the Lake District. Where are the other water bodies?

In fact, Finland has another Lake District – or actually 'Pond District' in the northernmost part of the country. It has only one major lake, Lake Inari. But north of this large lake, there are numerous ponds, up to 60 000 of them. The number of these small water bodies reaches 1960 per 100 km^2, while in the Lake District this number exceeds one hundred per 100 km^2 only on relatively few map sheets.

The Finnish Lake District is characterized by chains of interconnected lakes, the most extensive ones being well over 200 km long and having 20-30 separate lakes or lake basins. This implies that there are numerous throughflow lakes in the area. In many cases the average theoretical velocity of throughflow is extremely low, of the order of one millimetre per second or even less. In the narrow straits flow velocities are of quite a different order, up to 30-50 cm per second.

However, rather fast currents occur also in the open parts of large lakes. The main force causing these water movements during the open water seasons is the wind, which can produce surface currents the equivalent of 2-3% of its own speed. Thus the average Finnish wind can whip up a current of 5-10 cm per second, which is enough to carry the water across a fairly wide expanse of lake in 24 hours.

The development of measuring techniques has enabled direct measurements of current patterns in lakes since the 1960s. Technology in this field has made enormous progress, and Finnish researchers have been closely following these developments. There are numerous sites in the Lake District, where current measurements have been used to assist research or to solve engineering problems.

Ice regime of lakes

The ponds in the fjells of Lapland freeze normally in the early days of October. In the Lake District the largest lakes do not freeze before the middle of December. In the 20th century the winter of 1929-30 had the record for late freezing: e.g. Lake Näsijärvi froze on the 20th of January and Lake Päijänne on the 3rd of February.

The larger the expanse of water, the more reluctant it will be to ice over. A lake or a bay in the Lake District with a surface area of one square kilometre will freeze at an average sub-zero temperature sum of 27 degree-days, but if the area is 10 km^2 it will need 64 degree-days. The largest stretches of open water in the Lake District may need up to 100-120 degree-days.

Even when practically the whole of an open area has been covered by as much as 10 cm of ice, it is still possible for a storm to break up many kilometres of this, sometimes creating mounds of pack ice several metres high on the most exposed shores.

Typical maximum ice thickness in the lakes of southern Finland during a normal winter is 40-60 cm, in Lapland 70-90 cm. There may occur great areal differences in the ice thickness in various parts of a lake. Many straits with throughflow remain unfrozen for the whole winter, and although the ice on the open water forms very much later than that close to the shore, it will eventually develop to a greater thickness in many winters because the wind prevents the snow from accumulating to any great depth. If there is a lot of snow, the formation of large amounts of white ice can greatly increase the total ice thickness on snowy bays.

Ice is also an efficient force shaping the shores of lakes, its influence extending to many places where the effects of the waves is negligible. The ice moves rocks, pushes loose material up into banks or ramparts and has even succeeded in scouring out cracks and depressions in the bedrock.

Ice breaks in the lakes of southern Finland around the first of May. A highly exceptional spring occurred in the year of the great famine, 1867, when the ice melted in the Lake District around the 18th of June. That is the date when, in an average year, ice melts in Lake Kilpisjärvi in northernmost Lapland.

The most dramatic phase in the annual cycle of a northern river is the ice break-up, especially where the stream conditions have allowed the growth of a thick continuous ice cover. In the high latitudes the river breakup is probably the most well-observed annually occurring natural event. Long observation series exist; the longest in Finland and perhaps in the whole world, from River Tornio, dates back to the spring 1693.

There are less than one hundred lakes in the world with freezing and breakup data series over a century long. One quarter of these lakes are located in the Finland. The longest series is from Lake Kallavesi, in northeastern part of the Lake District, where the observations started in the autumn of 1833. Since that time, freezing dates have shifted about two weeks later and breakup occurs some ten days earlier. At the same time, mean annual temperature in Helsinki has risen by about 1.5°C. The trends in ice cover are similar in other lakes of the Finnish Lake District and also elsewhere in the northern Hemisphere (Magnuson & al. 2000).

Thermal conditions

The waters of the large lakes in the Lake District do not warm up evenly in spring. This is not because of the great extent of the basin from north to south, but rather because of the different conditions prevailing on the shores and in the open waters. A sheltered bay opening up to the south is an efficient sun-trap, and a dark patch of forest can increase the absorbance of radiation on the shore still further. This could mean that the water reaches +15°C only a few days after the ice has left, even though the open water is at +2°C and still has ice floes on it. It may in fact be some two or three weeks before the full circulation of water in an open lake area has brought the temperature to an even 4°C (Kuusisto 1999).

As summer comes, lakes excluding the most shallow ones become stratified. By midsummer the thermocline usually lies at a depth of about five metres, where the temperature drops 2-3 degrees within a metre. If there have been high winds during the early part of the summer, the thermocline will be at a greater depth, while after particularly calm weather one can expect a sharp drop in temperature or a small additional thermocline closer to the surface.

The surface water is at its warmest, about 19-22°C in southern and central Finland and 16-19°C in Lapland, at the end of July and beginning of August. The number of days with surface water temperature in Lake Saimaa over 20°C has varied between 0 and 72 during eighty years. No trend in this variable can be detected, while on the contrary the mean surface temperature in August seems to have increased by about one degree centigrade since 1924 (Fig. 6).

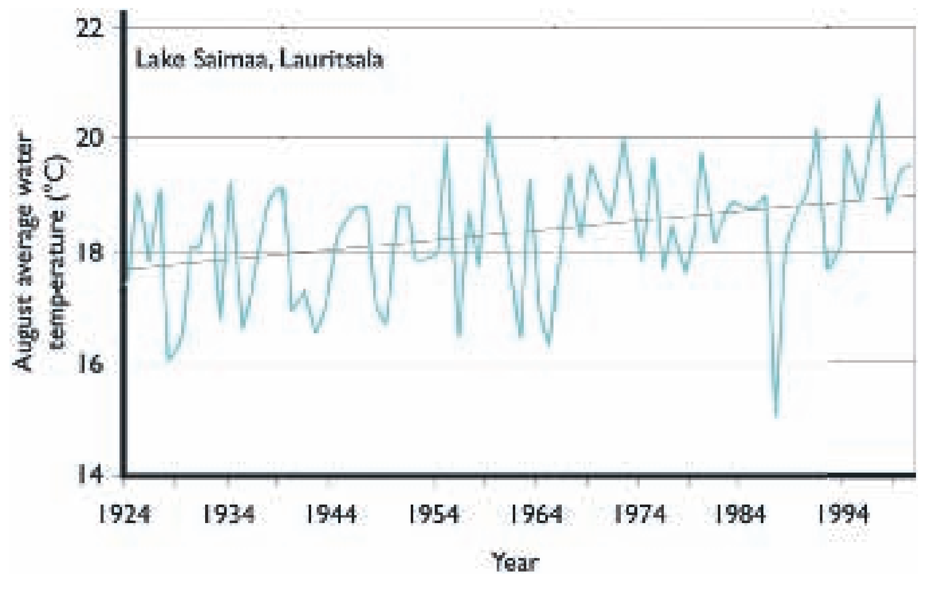

Fig. 6. The surface water temperature of Lake Saimaa has been observed since 1924. There is an increasing trend in mean temperatures in August, but not in other months (Korhonen 2002).

The deepest points of the lakes achieve their maximum temperatures in autumn, usually in late September or early October. The highest temperature in Lake Päijänne at depths of 60-80 m is 8-10°C. In fact at that stage the temperature is the same from the surface all the way down, a situation that will last for 4 to 7 weeks most autumns.

Groundwater

The imporatance of groundwater and its value for public water supply was recognized in Finland at a relatively late stage, although individual households have had their own wells for many centuries. As the quality of groundwater is in general better than that of surface water, the protection of groundwater has gained more attention in recent years.

Groundwater is formed both in spring from melting snow and in autumn from rainfall. The amount of groundwater formation depends also on vegetation, topography and, in particular, on soil type. In places also surface water from lakes and rivers infiltrates into the ground.

The groundwater table follows roughly the relief. In a gently sloping moraine land the groundwater table is at a depth of 1-4 metres, while in higher eskers it may be at ten metres and even more. In mires the groundwater table is at ground level. Seasonal variations of the groundwater table range from less than half a metre to 2-3 metres.

Groundwater may flow from springs at the foot of hills or it may seep out over a large area. The flow variations in springs discharging water from big eskers are very small in comparison with variations in springs on moraine slopes.

Although the Finnish bedrock is hard and impermeable, it has many faults, cracks and fissures. The amount of groundwater in bedrock is many times the amount found in eskers. But the utilization of groundwater in bedrock is so difficult that its importance for water supply is limited.

The role of mires in Finland's hydrology

Some of the 74 river basins in Finland do not have any lakes, but all of them have mires. The lake percentage is 0.0 for three river basins and less than 0.5 for twelve basins. The lowest mire percentages are 0.5 (Sipoonjoki) and 1.0 (Siuntionjoki), both located on the southern coast.

On three basins, lakes cover more than 15% of the total area, Vuoksi basin having the highest lake percentage (21.3). The number of basins with mire percentage (M) in excess of 15 is as high as 29; while 30% is exceeded at eleven basins. All of the basins with M>15% are located in Ostrobothnia and northern Finland. The three highest mire percentages are Olhavanjoki (46.6), Simojoki (46.5) and Kuivajoki (45.0). The largest basin in Lapland, Kemijoki, has 24.6% of mires.

The total volume of water stored in Finnish mires is around 63 km^3 (Virtanen & al 2003). This is 27% of the water volume of lakes. However, the former storage is more evenly distributed among the river basins, because over half of all lake water in the lakes of Vuoksi and Kymijoki basins. It can be roughly estimated that some 40 of the 74 river basins have more water in mires than in lakes. The extensive ditching of mires in Finland may have decreased the water storage of mires by around 15-20 km^3.

The hydrological role of mires has been studied in Finland particularly in connection to ditching – how do the flow characteristics change after a certain fraction of mires in a particular basin have been ditched for forestry purposes?

These studies were mainly performed in the 1970s and 1980s, and were summarized e.g. by Hyvärinen & Vehviläinen (1988). The effects depend on where in the basin the ditching takes place. If it has been made in the upper part of the basin, spring floods may increase by 0.3-0.8% per one percent of area ditched. In case of fairly even distribution of ditched areas, the effect is smaller and may turn towards lower spring floods, if mires in the lower part of the basin have been ditched. Summer high flows may increase by 1-3% per one percent of area ditched, because the extra storage volume is not large enough to attenuate flood peaks, or the storing of water is too slow. In small experimental areas, extensive ditching has increased spring floods by up to 50% and doubled summer floods. After 10-20 years, the growth of the forest will attenuate the floods to their original level lands; the water bearing capacity of the ditch network also tends to weaken.

In the first years after the ditching, the percentual increase of mean annual flow may be almost the same as the ditching percentage, particularly in case of open mires. Low flows may increase even more substantially, in some cases even up to 2-4-fold. The effect of ditching to low flows also tends to weaken more slowly than in the case of floods.

If the volumes of mire and lake storages are equal in a river basin, do mires attenuate flood peaks more effectively than lakes?

In most cases, on the contrary. Many mires have rather small drainage areas, and the raised bogs have to rely almost completely on local precipitation and meltwater. The lake surfaces typically rise during spring snowmelt at least 30-50 cm, which exceeds the depth of water layer on mires.

However, undisturbed bogs play an important hydrological role in Finland. They have a two-layered structure to regulate the storage and discharge of water. When the water table is high, flow is through and over the relatively permeable upper layers, and thus mires readily release ‘excess’ water. When the water table falls in summer, flow occurs through layers of lower permeability, and runoff may cease completely.

In a number of countries, mires have been used for flood protection by artificially storing water on their surface during wet periods. This has also been discussed in Finland, but the method is still under consideration.

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Glacial and postglacial history of the Baltic Sea and Finland

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Finland and the whole Baltic basin have been buried beneath a continental ice sheet on several occasions during the Quaternary period (Taipale & Saarnisto 1991), but these glaciations have been separated by more favourable climatic periods, during which the Baltic basin has been occupied by water and land uplift has caused progressively greater areas of dry land to emerge on its coasts, in the same manner as during this last postglacial period. During the Eemian interglacial, about 130,000 – 115,000 BP, the basin contained what we refer to as the Eemian Sea, the waters of which were evidently much more saline that those of the Baltic Sea nowadays, as deduced from diatoms recovered from sediments dated to that period. It is possible that there was a connection from the Baltic basin to the Arctic Ocean across Karelia at the beginning of this Eemian Sea stage, although it was closed later due to the effects of land uplift (Björck & Svensson 1994).

The ice sheet associated with the Weichselian glaciation, which followed the Eemian interglacial, reached its maximum extent about 18 000 – 20 000 BP and was more than three kilometres thick in the area of Finland, so that it depressed the earth's crust to such a degree that a considerable part of the country's present area lay beneath the waters of the Baltic basin immediately after deglaciation. The deglaciation in Finland took place between 12 100 and 9 200 varve years ago (Lundqvist 1991; Saarnisto & Salonen 1995)(Fig 1).

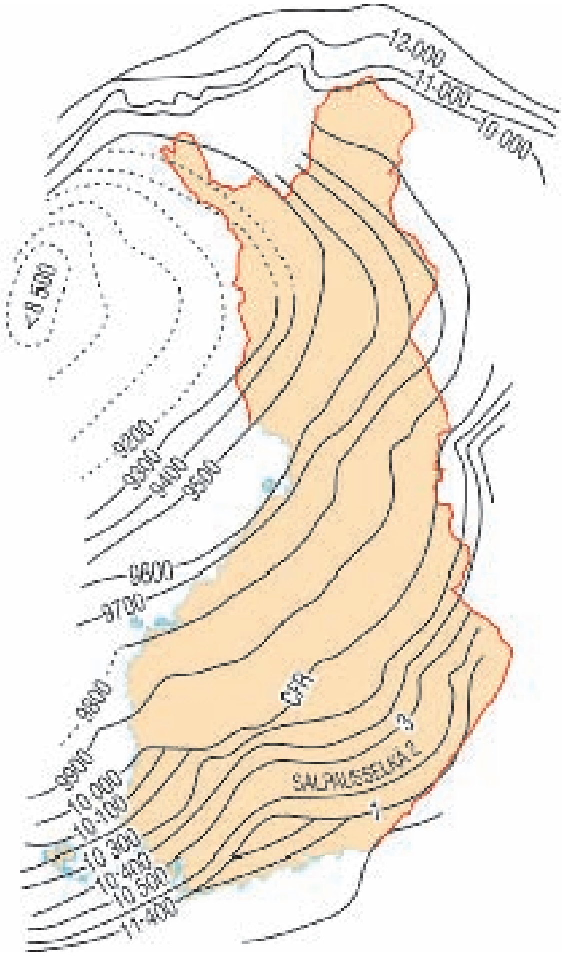

Fig. 1. The deglaciation of Finland illustrated by successive ice-marginal lines (Adapted from Lundqvist 1991).

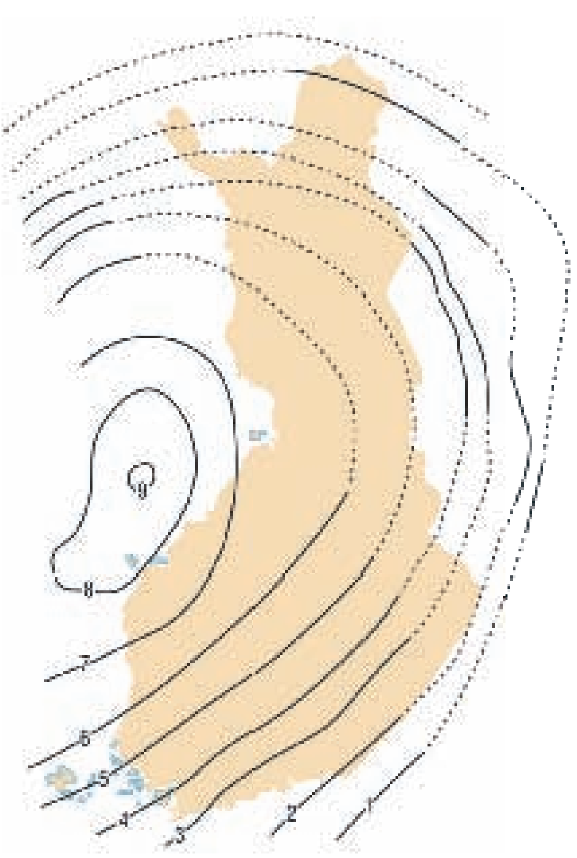

Fig. 2. Recent land uplift (mm/yr) in Finland (Adapted from Ekman & Mäkinen 1996).

As the burden of the overlying ice was released, however, the crust began to rise rapidly, so that it is estimated that the total rise up to the present time has been 600 – 700 m on the coast of the Bothnian Bay, 400 – 500 m in the middle part of Finland and in central Lapland and around 300 m on the coast of the Gulf of Finland and in northern Lapland (Mörner 1980). The majority of this rise nevertheless took place as the ice was melting, before the ground surface became exposed. The rate of uplift in the central area of the shrinking Scandinavian ice sheet was more than 10 times faster than the present maximum value of 9 mm/year in the northern part of the Gulf of Bothnia (Eronen 2005)(Fig. 2.).

Four main stages can be recognized in the history of the Baltic basin since the last glaciation, influenced by a complex interaction between deglaciation, regional differences in land uplift and eustatic changes in sea level (Tikkanen & al. 1999). The connection with the outside ocean has been located variably in the Straits of Denmark or central Sweden. There is a long tradition of research into the history of the Baltic basin and shore displacement in Finland and the other countries of the Baltic region (see Eronen 1990; Björck 1995; Heinsalu & al. 2000), and the regional changes in shore displacement during the various stages can nowadays be traced fairly accurately by combining the vast amount of data available with altitude data using GIS techniques (Tikkanen & Oksanen 2002)

Baltic Sea as we know it has a long and chequered history, in the course of which the area nowadays occupied by Finland has undergone substantial changes. The phenomenon known as land uplift, which still operates in the Baltic region and currently amounts to some 8 mm per year on the Finnish coast of the Bothnian Bay (Kakkuri 1990; Eronen 2005), has had the effect of reducing the sea area over a period of several thousand years and has correspondingly increased the land area of Finland. The present area of the Baltic Sea is about 377,000 km^2, and it has a freshwater influx of some 660 km^3 a year from a drainage basin of 1.6 million km^2. In addition, some 475 km^3 of saline water a year flows into the Baltic through the narrow Straits of Denmark. The total outflow of brackish water is of the order of 950 km^3 a year (Björck 1995).

The Baltic Sea is the largest brackish water basin in the world, although it is fairly shallow, its deepest point being only 459 m, and is divided by thresholds into a number of separate sections. Its salinity varies from 0.1% in the north to 0.6-0.8% in the central parts, and can reach as much as 1.5-2.0% in the deeper waters (Björck 1995). The salinity has also varied greatly in the course of the history of the basin.

The Baltic Ice Lake

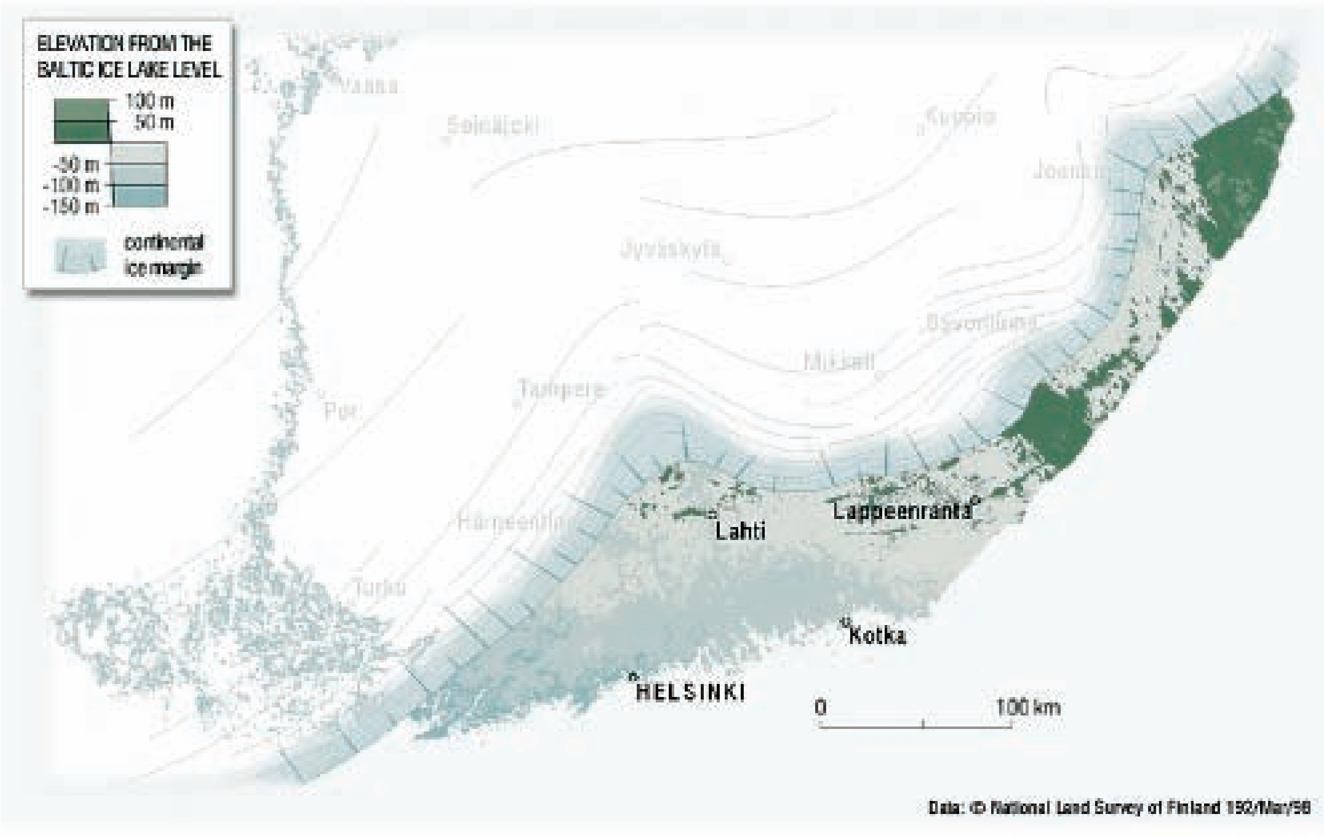

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Fig. 3. The Baltic Ice Lake 10 300 BP (C-14 years).

The ice margin began to retreat from the southernmost parts of the Baltic basin around 13 500 – 13 000 BP, leading to the creation of the first postglacial water bodies in the region (Björck 1995). Deglaciation then proceeded very rapidly, so that the margin was situated close to the south coast of Finland by about 12 000 BP (Niemelä 1971; Saarnisto & Salonen 1995). By that stage the large volumes of meltwater from the ice sheet were able to discharge from the Baltic Ice Lake into the ocean via the Strait of Öresund (Agrell 1976; Björck 1995). Before the ice margin had reached the point now marked by the First Salpausselkä moraines, however, the bedrock threshold in the Strait of Öresund had risen above the ocean level and the waters of the Baltic basin had begun to be dammed up to form a freshwater ice lake. By the end of this transgressive stage the level of the freshwater basin had risen ca. 25 m above the ocean level and the ice sheet margin in southern Finland had retreated to the Second Salpausselkä end moraine zone

There were only a few small areas of high ground in the south of Finland that projected above the level of the Baltic Ice Lake, together with the Salpausselkä deltas, which were laid down at the water level. The most extensive areas of dry land were to be found close to the eastern and south-eastern boundaries, in the present-day districts of Ilomantsi – Tuupovaara and Ruokolahti - Rautjärvi (Tikkanen & Oksanen 2002)(Fig. 3).

By the time the Younger Dryas cold phase came to an end the sharp warming of the climate around 10 500 BP then caused the ice margin to retreat rapidly (Björck 1995). As a consequence of this, the Billingen "gateway" opened up around 10,300 BP and the waters of the Baltic Ice Lake began to discharge into the ocean through central Sweden . This caused the water level in the Baltic basin to drop by 25 – 28 m within a few years to regain the level of the outside ocean (Tikkanen & Oksanen 2002; Eronen 2005).

The Yoldia Sea

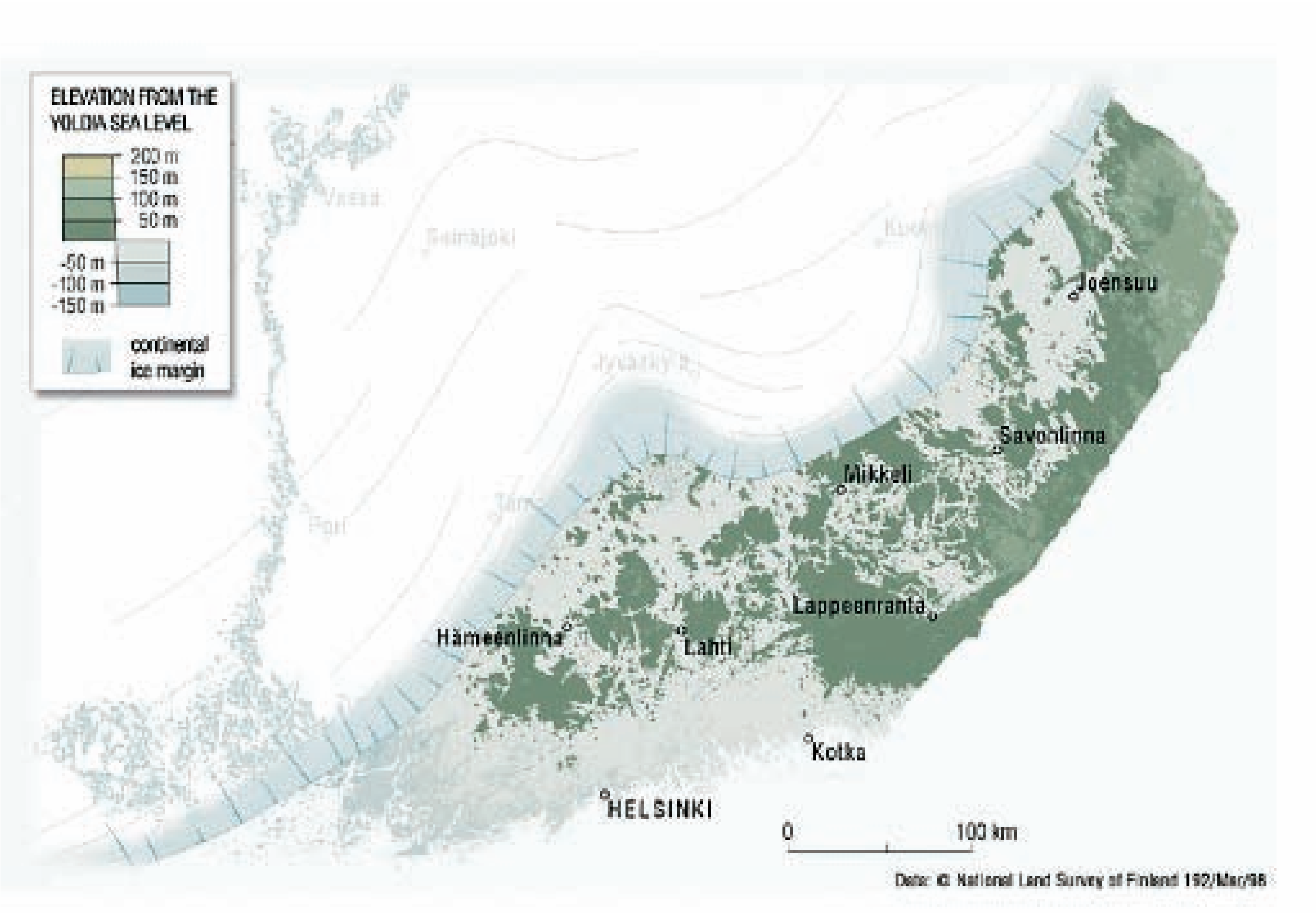

Fig. 4. The Yoldia Sea 10 000 BP (C-14 years).

The new warming of the climate finally brought the Ice Age to an end, and the opening of the Billingen channel and the drop in the level of the Baltic Ice Lake also marked the end of glacial conditions in the Baltic basin. The next stage in the history of the basin is referred to as the Yoldia Sea, after the bivalve *Portlandia (Yoldia) arctica*. The Närke Strait in the lowlands of central Sweden north of Billingen opened up about 10 000 BP, allowing saline water from the ocean to flow into the Baltic basin (Eronen 1990; Björck 1995). This weakly saline brackish water phase remained relatively short, however, and within 100 – 200 years the salinity of the Baltic began to decline again. The saline effect reached the area of Finland with a certain delay, and the Yoldia stage was evidently characterised by freshwater conditions throughout in the present-day inland areas, on account of the large volumes of meltwater (Taipale & Saarnisto 1991).

The land area in what is now Finland expanded greatly during the Yoldia Sea stage. The drop in water level that marked the end of the Baltic Ice Lake caused land to be exposed very suddenly, and a zone ranging in width between 10 and 100 km along the present boundary of Finland in the east and south-east had become isolated from the Baltic by just over 10 000 BP (Fig. 4). There were also extensive islands in the present-day Lahti and Hyvinkää areas, and an archipelago emerged in the interior of Finland almost as soon as the ice had retreated (Tikkanen & Oksanen 2002).

The Ancylus Lake

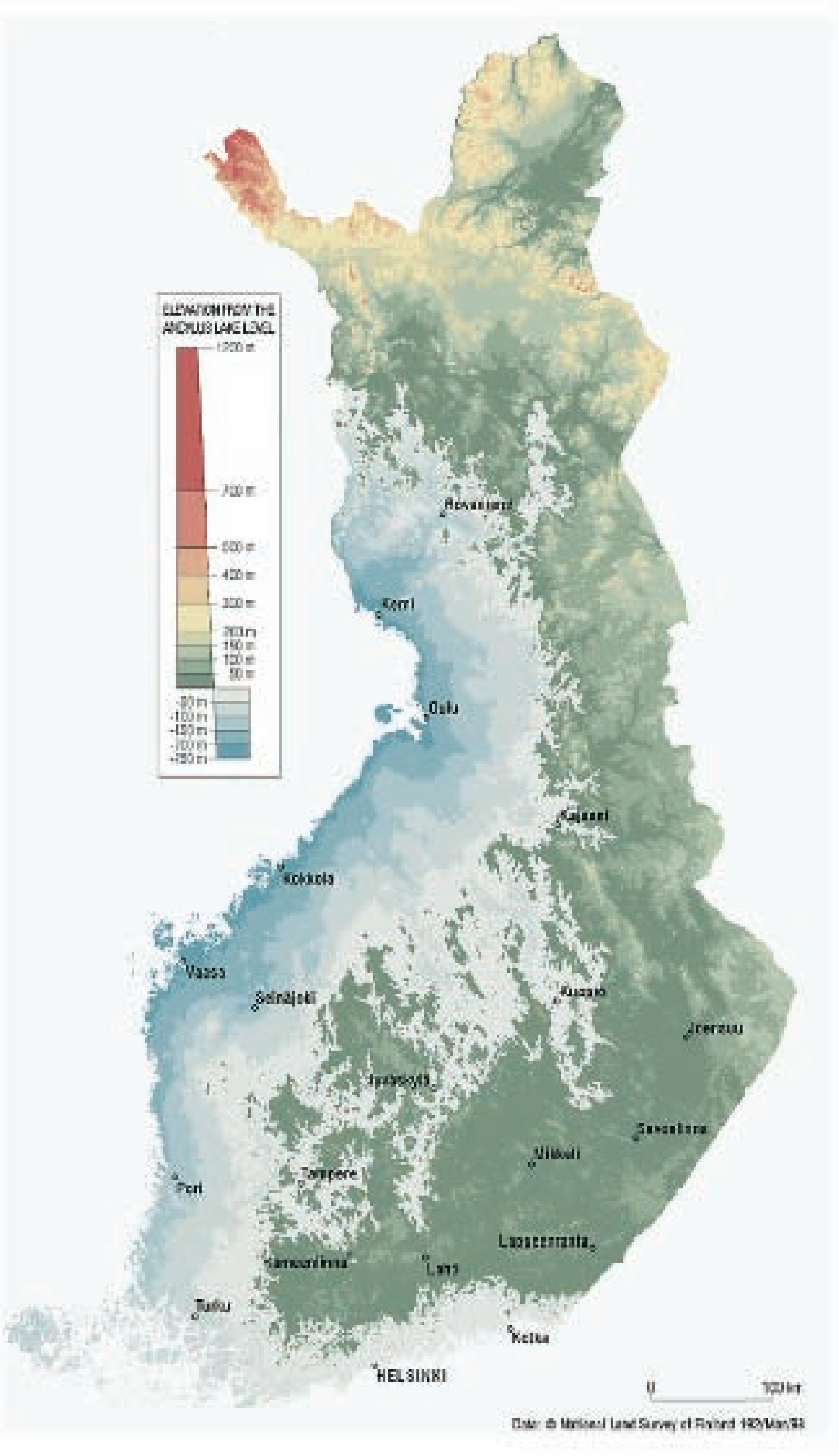

Fig. 5. The Ancylus Lake 9000 BP.

As the rate of land uplift in central Sweden was faster than the rise in ocean level, the thresholds in the connecting straits began to approach the latter level around 9500 BP, which meant that the Baltic basin was once more isolated to form a freshwater lake, which was named the Ancylus Lake after the gastropod *Ancylus fluviatilis*. The early Ancylus Lake (9500-9200 BP) was strongly transgressive, and the transgression as a whole is estimated to have been of the order of 15 – 25 m (Eronen 1990, 2005; Björck 1995). This was also felt on the south coast of Finland, in the form of a rise of a few metres in water level, causing the creation of clearly defined ancient shorelines.

The rising waters of the Ancylus Lake eventually exceeded the threshold known as the Darss Sill in the southwestern part of the Baltic basin and water began to flow out through the Dana River, at the site of the present-day Great Belt (Store Bælt), around 9200 BP, and this brought the Ancylus transgression to a close. The rapid regression of the Ancylus Lake, combined with land uplift, soon caused the channels across central Sweden to dry up (Björck 1995).

The surface of the Ancylus Lake was at least 10 metres above the ocean level at the time when the Dana River arose, and the Ancylus Lake reached the level of the outside ocean around 9000 BP. This did not mean any influx of saline water into the Baltic basin, however, as the Dana River, being narrow and more than 100 km in length, remained the only connection for a long time (Björck 1995).

Large expanses of dry land emerged in the area of Finland during the Ancylus regression, and the great lake basins of the interior of the country were separated from the Baltic at this time (Saarnisto 1971; Tikkanen 1990, 2002) (Fig. 5). On the other hand, when the last of the ice disappeared from the Tornionjoki valley around 9000 BP, the outermost islands in the Gulf of Bothnia were still more than 100 km away from the present shoreline, which in the Bothnian Bay was still covered by more than 200 m of water (Eronen 1990; Tikkanen & Oksanen 2002).

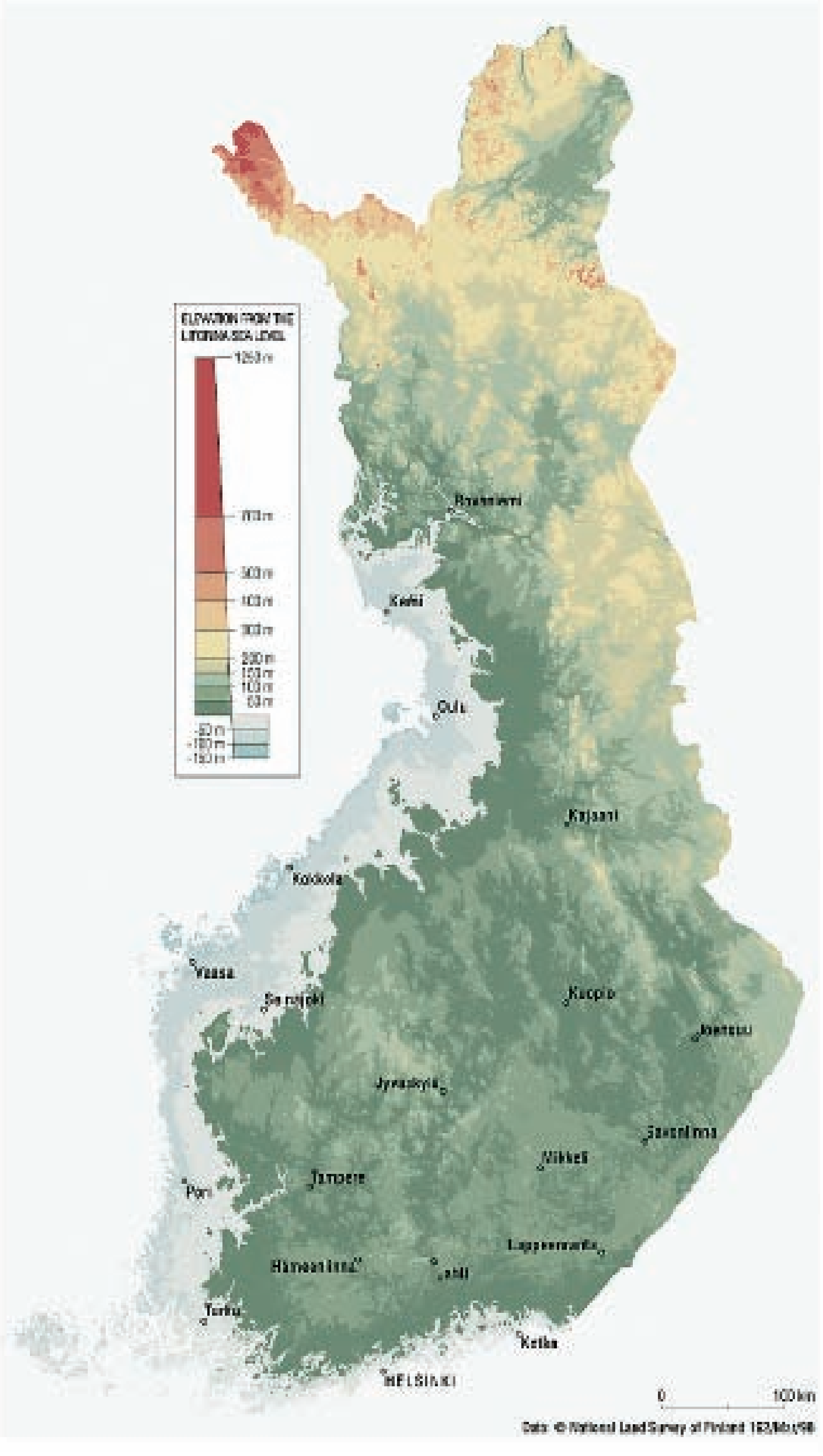

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Fig. 6. The Litorina Sea 7200 BP.

The Litorina Sea

As ocean levels were still rising by more than 1 cm a year (Fairbanks 1989), saline water eventually rose above the threshold in the Straits of Denmark and began to enter the Baltic basin, perhaps around 8400 – 8300 BP (Eronen 1990). The effects of this saline addition began to be felt more clearly around 8200 BP (Berglund 1964; Björck 1995), when the transition period known as the Mastogloia Sea is deemed to have begun (Eronen 1974, 1983; Taipale & Saarnisto 1991). Around 7500 BP the Litorina Sea, named after the gastropod *Littorina littorea*, may be regarded as having reached the south coast of Finland and around 7000 BP the saline effect reached the head of the Gulf of Bothnia (Eronen 1974, 2005; Björck & Svensson 1994). The eustatic rise in ocean levels led to a transgression at the beginning of the Litorina Sea stage, as a result of which water levels on the south-east coast of Finland rose by a few metres and a slight rise was recorded in the Helsinki area (Eronen 1990; Miettinen 2002). The Litorina Sea was followed at ca. 4 000 C-14 years BP by the Limnea Sea, a less saline transition stage, after which the present conditions gradually developed.

The shoreline still lay about 100 km inland of its present location in the river valleys of the Gulf of Bothnia coast at the beginning of the Litorina Sea stage (Fig. 6). There were a few large islands on the Gulf of Bothnia coast at the beginning of the Litorina Sea stage, and the ring encircling the ancient meteorite crater that now makes up Lake Lappajärvi stood out close to the shoreline (Tikkanen & Oksanen 2002).

The highest shoreline of the Baltic in Finland

The highest shoreline at a particular point is the uppermost level to which the waters of the Baltic basin have reached, and marks the dividing line between supra-aquatic and subaquatic terrain. It is usually represented in the landscape by belts of washed rocks or stones, and the vegetation is frequently very much more lush on the slopes above this point than below it. The highest shoreline is a metachronic feature, and will have arisen as the ice margin retreated, i.e. within the period 11 000 – 9000 BP (Taipale & Saarnisto 1991). As far north as the Salpausselkä zone, the highest shoreline will mark the level of the Baltic Ice Lake, as reflected by the delta surfaces on the Salpausselkä formations, while elsewhere in the southern and middle parts of the country it will have arisen during the Yoldia Sea stage, and further north, in Ostrobothnia, Central Finland and Peräpohjola, similar shore markers will have been laid down by the Ancylus Lake (Eronen 1990). The dividing line between the Yoldia Sea and Ancylus lake shorelines run from Pori through Jyväskylä to Kajaani (Saarnisto 2000)(Fig. 7).

About 62% of the surface area of Finland has been beneath the waters of the Baltic at some stage (Tikkanen & Oksanen 2002). The only parts of the country where there are extensive supra-aquatic areas are Lapland and eastern Finland, and even here many places have been covered by local ice lakes for brief periods. The highest known ancient shore marker in Finland, at a current altitude of 220 m, is located on the slope of Vammavaara hill, south of Rovaniemi, and was created by the waters of the Ancylus Lake, while the highest markers of the Baltic Ice Lake in the area close to the border in the south-east of Finland lie at about 100 m.

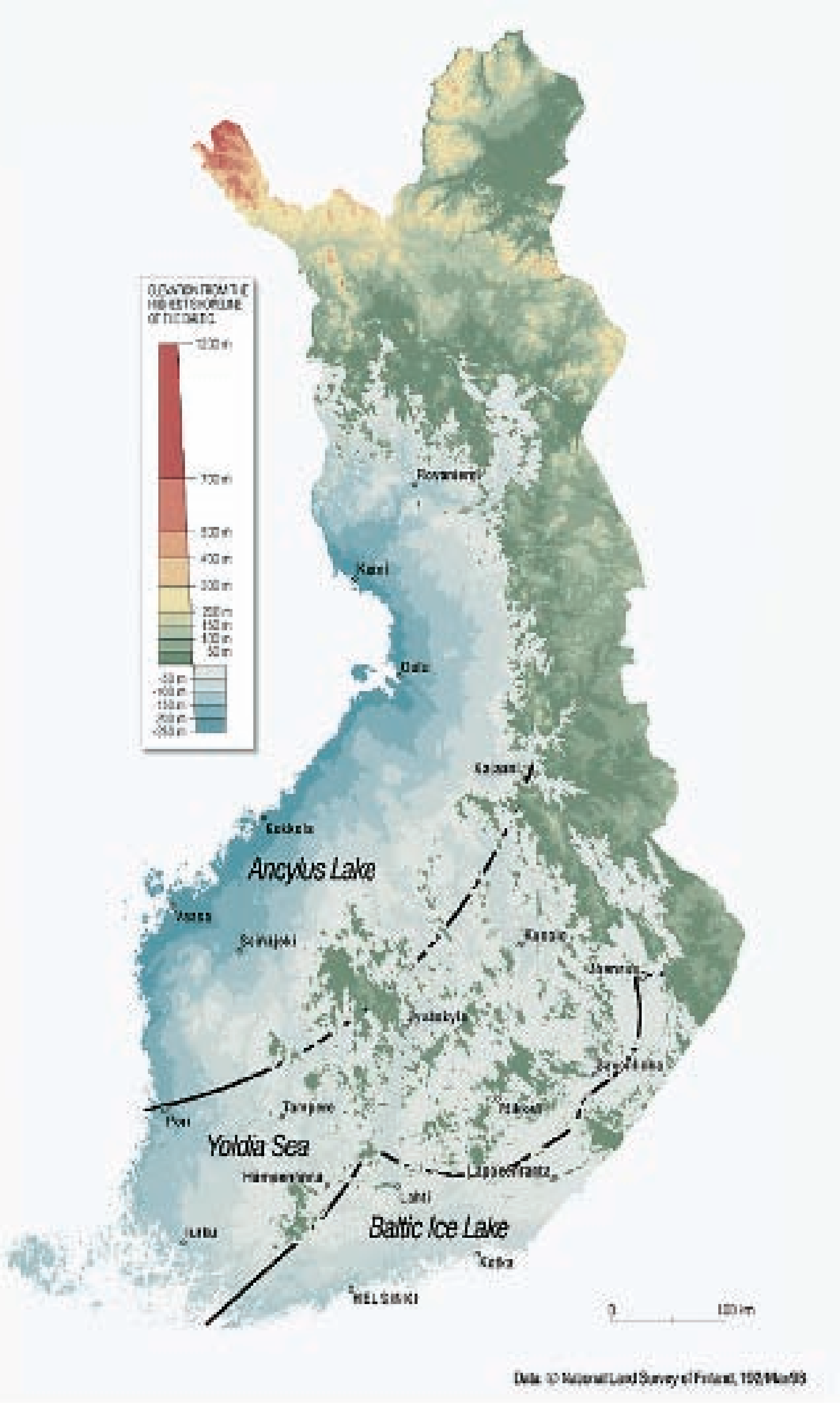

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Fig. 7. The highest shoreline: supra-aquatic and subaquatic areas of Finland. The areas in which the uppermost shoreline dates from the Baltic Ice Lake, Yoldia Sea or Ancylus Lake are marked separately (Tikkanen & Oksanen 2002). The boundaries between these areas are after Saarnisto (2000).

Fig. 8. Wave-cut scarp near the present shoreline in Kemiö, southwestern Finland. Photo Matti Tikkanen.

Recent and future shoreline changes

Since the clear Litorina transgression at 7500-6500 BP, the shore displacement has been a stable, gradually slowing process (Seppä & al. 2000; Tikkanen & Oksanen 2002; Miettinen 2002; Eronen 2005). The present land uplift rate of the order of 2 mm/yr on the south-eastern coast of Gulf of Finland and 8 mm/yr on the Finnish coast of Bothnian Bay means that shore displacement is still going on (Fig. 8). Finland's area is increasing every hundred years by about 1000 km^2, of which two-thirds can be attributed to land uplift and the remainder to sedimentation and colonization by vegetation (Jones 1977). Due to the land uplift many harbours and towns have been moved and re-established on the rapidly uplifting coast of the Gulf of Bothnia (Ristaniemi & al. 1997; Eronen 2005).

The geophysical data indicate that glacio-isostatic rebound will continue yet for several thousands of years (Eronen & al. 2001). The most recent calculation suggests an amount of c. 90 m for residual uplift (Ekman & Mäkinen 1996). If the land uplift will continue in the same manner as in the past, the northern part of the Gulf of Bothnia will be cut off to form an inland lake after the next 2,000 years (Ristaniemi & al. 1997).

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Interglacial and interstadial organic deposits in Finland

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Abstract

Most of the 456 million hectares of the world's peatland area derives from the Holocene during the last 12 000 years. Changes in the water level in lakes and the sea, as well as the rising of the earth's crust after the last glaciation, have regulated peatland formation, especially in the Northern Hemisphere where most of the world's mires are situated.

Finland and the rest of the Northern Hemisphere are characterised by till-covered organic deposits that have been deposited before the last glaciation. In till stratigraphical studies in Finnish Lapland and Western Finland, 200 such deposits have been discovered since the 1970s. The deposits that consist of peat, mud and diatomite are typically relatively thin, from a few centimetres to 2,5 metres. However, the thickest deposits are up to 6 metres thick. The majority of the deposits are situated underneath the present-day mires, occupying depressions that were in existence already before the last glaciation. The thickest mud deposits have remained in their original places of deposit almost undisturbed, apart from being compacted by the weight of the glacier.

Introduction

As recently as 40 to 50 years ago, the general view was that the geology of Finland resembles a book of which only the covers remain: a milliard-year-old archaen bedrock is covered by a young deposit of the last glaciation, whereas the other deposits, the "interleaves of the book", were thought to have eroded away. The deep sections of industrial excavations in the 1960s and systematic till stratigraphical studies, drillings and excavations in the 1970s, first in Northern Finland and later in the rest of the country, have changed the view of the geology of Finland. According to the above studies, there has been at least five different Ice Ages or glaciations stages in Finland with ice-free interglacial or interstadial periods (Hirvas 1991). An Ice Age consists of several glaciations and ice-free but cold (interstadial) periods. Ice Ages are separated by interglacial periods, such as the current, or even warmer, interglacial period.

During each of the glaciations, the ice sheet deposited a separate till bed. Till is unstratified soil deposited by a glacier, consisting of clay, sand, gravel and rock boulders, detached from the bedrock and ancient regolith and transported by the ice sheet. The youngest till bed was deposited about 9 000 to 10 000 years ago when the

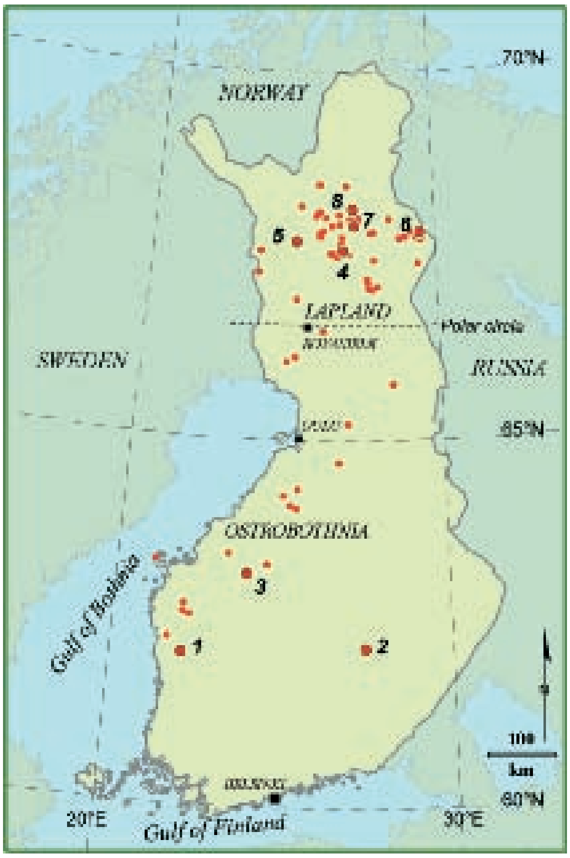


Fig. 1. Localities of the most important findings of organic soils below till and the places mentioned in text. 1. Penttilänkangas, Isojoki, 2. Heponiemi, Virtasalmi, 3. Ryytimaa, Vimpeli, 4. Paloseljänoja, Sodankylä, 5. Naakenavaara, Kittilä, 6. Kaulusrovat, Savukoski, 7. Maaselkä, Sodankylä, 8. Vuotso, Sodankylä.

last remains of the ice sheet of the Weicshelian glaciation melted in Western Lapland. The oldest till bed is probably about 500 000 years old, if not older.

During the ice-free interstadial and interglacial periods, stratified gravel, sand, silt and clay have been deposited in the water. In places organic remains, including peat, gyttja and diatomite, have also been deposited.

Organic Deposits Under Till

The first peat deposits between till beds in Finnish Lapland were discovered in 1962 near Rovaniemi in connecion with the moving of earth at Permantokoski power plant (Korpela 1962, 1969). At present, the number of known organic deposits underlying till in Finland is about 200 (Fig. 1), as a result of the systematic studies of the Finnish Geological Survey in approximately 6 000 excavations and 4 000 earth drilling sites. The findings are concentrated in Lapland, especially Central Lapland, and in Ostrobotnia where glacial erosion has been less significant than in other parts of the country (e.g. Niemelä & Tynni 1979, Hirvas 1991, Nenonen 1995). Central Lapland is the central area of glaciation in Scandinavia, the so-called ice-divide zone, where the erosional and deposital activities of the ice sheet has always been weak (Penttilä 1963, Kujansuu 1967, Hirvas 1991). The weak erosion is manifested in the prevalence of preglacial, weathered bedrock, well-preserved from the erosion of the ice sheet, as well as the thinness of the Quaternary deposits, especially basal till, in the region. The average thickness of the Quaternary deposits in Finnish Lapland is only 5,9 metres (Mäkinen 1975). In the ice-divide zone of Central Lapland, the deposits are substantially thinner. Due to the thinness of the till beds, excavators have been able to penetrate the youngest till beds to allow researchers to study the older deposits, including the organic deposits situated underneath and between the till beds.

The first organic deposit underneath a till bed in Eastern Finland was discovered only in 1991 during a kaolinite study of the Geological Survey of Finland. In Finland, by far the thickest organic deposit underlying a till bed is situated in Heponiemi, in the area of Virtasalmi (Locality 2 in Fig. 1). The thickness of the mud deposit in the depression in the bedrock, consisting of till deposit more than 20 metres thick, is 6 metres (Nenonen 1995).

The majority of organic deposits underlying till beds have been found during the systematic geochemical drilling and till sampling of the Geological Survey of Finland. About 90 % of the peat and mud deposits covered by till are situated under present-day mires, i.e. in depressions that have existed before the last Ice Ages or glaciations. Since the disturbance has been avoided in construction, earthmoving and research of mires, systematic geochemical till sampling has been practically the only way to bring the organic deposits to light. The most interesting and favourable findingds

Fig. 2. A heavy excavator exposing a subtill gyttja deposit at Paloseljänoja, Sodankylä (see Figs. 1 and 8). The gyttja deposit (the brown unit above water level) is over 2 m thick under till beds II and III. Between the gyttja deposit and till bed III there is a grey laminated silt layer, which has protected the gyttja from glacial erosion. As the sites beneath the present-day mires are always very wet, the walls of the pits collapse readily and the pits fill rapidly with water.
Photo Heikki Hirvas.

Fig. 3. Interstadial diatomite covered by till bed II at Kaulusrovat, Savukoski (locality 6 in Fig. 1). Diatomite is encountered only in a bedrock depression as an in situ deposit 10-20 cm thick. It rests immediately on weathered carbonatite bedrock at a depth of 1,1-1,3 m. Bed II, which overlies the diatomite, is loose, massive, fine sandy till with a few small clasts. The till is typical weathered bedrock till, greatly resembling the underlying weathered bedrock in appearance and properties.
Photo Heikki Hirvas.

have been made by heavy-duty excavators so that the stratigraphical position of the deposit has been verified and the samples have been representative for e.g. pollen, macrofossil and radiocarbon analyses (Fig. 2). The deepest research excavations have been 11.5 metres deep.

The following figures demonstrate the extent and the systematic nature of the soils studies of the Geological Survey of Finland: In the ice-divide zone of Central Lapland, about 15 000 till profiles have been drilled by the Geochemistry Department. The drillings have been continued to the deepest possible depth, and the samples have been taken at intervals of one metre, or when there's been a clear change in penetrability. Organic deposits have been found in 72 of the till profiles, resulting in a ratio of 1/208 in the deposits. Interestingly, organic deposits have been found in 7 of the about 1 400 excavations of till beds, meaning that the ratio in finding organic deposits in till profiles and excavations is practically the same.

About half of the soil samples consists of peat, whereas the other half consists of mud, diatomite (Fig. 3), paleosols containing old organic matter, cones and pieces of wood. In Finland, apart from the record depth in Virtasalmi, the thickness of organic deposits underlying till beds varies from a few centimetres to two and a half metres. In Central Lapland, the thickest mud deposit of 2,5 metres is found in Loukoslampi,

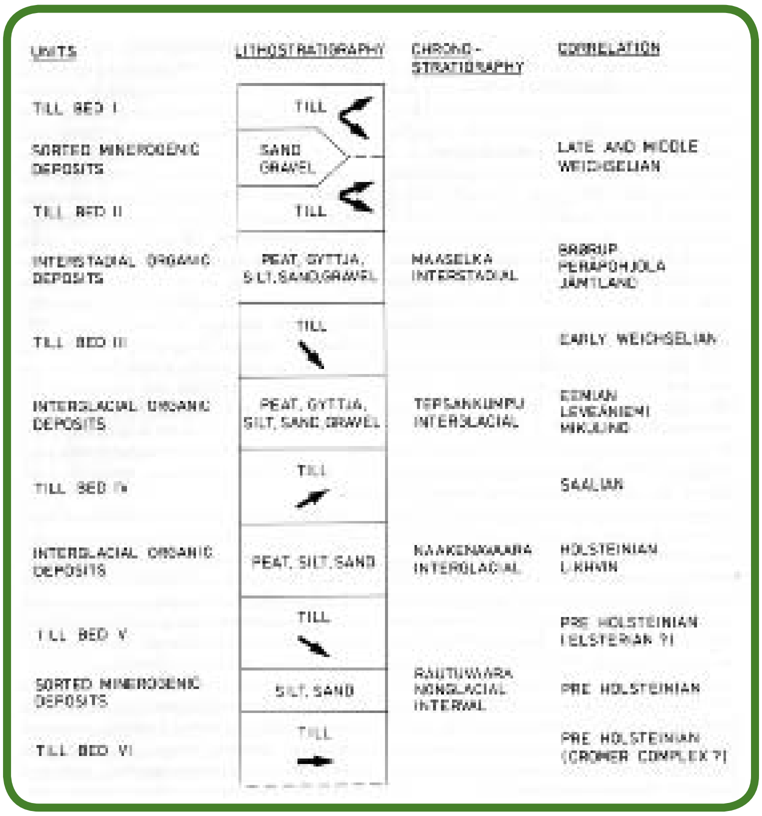
Fig. 4. Trees gnawed by beaver in the marble quarry of Ryytimaa in Poikkijoki, Vimpeli, below a 10 m thick till layer (locality 3 in Fig. 1). The thicker stick has a diameter of about 30 mm. Photo J. Väätäinen GTK.

Fig. 5. Till-covered paleosol at Penttilänkangas, Isojoki (locality 1 in Fig. 1). See text. Photo Heikki Hirvas.

in the municipality of Pelkosenniemi, whereas the thickest peat deposit of 1,5 metres is found in Naakenavaara, in the municipality of Kittilä (Fig. 1).

The most interesting findings of pieces of wood have been found in Vuotso, in the municipality of Sodankylä in Central Lapland (Locality 8 in Fig. 1), and in Vimpeli in Western Finland (Locality 3 in Fig. 1). At the construction site of the channel of Vuotso, an eight-meters-long trunk of larch (*Larix sp.*) with the diameter of 48 centimetres at the trunk base. There were 260 annual rings in the trunk (Mäkinen 1982). In the marble quarry of Ryytimaa in Poikkijoki, in the municipality of Vimpeli, an organic deposit was found underneath a 10-meters-thick layer of till. The organic layer, containing a large amount of spruce and pine cones, and pieces of wood gnawed by beavers, is deposited on the gravel soil of an ancient river bed (Aalto & al. 1989). Beavers have cut down dozens of trees, and gnawing marks are clearly visible (Fig. 4). Since all of the trees are coniferous – spruce (*Picea abies*), pine (*Pinus sylvestris*) and juniper (*Juniperus communis*) – it is likely that the beaver has built a dam in the river. The discovered pieces of wood are both from the previous warm period, the so-called Eemian interglacial, about 130 000 to 115 000 years ago.

The most representative of the till-covered organic deposits is an ancient soil, so-called paleosoil, in Penttilänkangas, in the municipality of Isojoki in Western Finland (Fig. 1) where a 0,5 metres thick typical, developed podsol soil has accumulated on an esker, formed during the last stage of the next-to-last Saale glaciation. The top-most horizon is black, consisting of organic matter and charcoal, the middle horizon is a light-coloured eluvial horizon (A) and the lowest horizon is the dark brown illuvial horizon (B), consisting of precipitated iron and manganese (Fig. 5).



UNITS	LITHOSTRATIGRAPHY	CHRONO-STRATIGRAPHY	CORRELATION
TILL BED I	TILL ←		
SORTED MINEROGENIC DEPOSITS	SAND GRAVEL		LATE AND MIDDLE WEICHSELIAN
TILL BED II	TILL ←		
INTERSTADIAL ORGANIC DEPOSITS	PEAT, GYTTJA, SILT, SAND, GRAVEL	MAASELKA INTERSTADIAL	BRØRUP PERAPOHJOLA JAMTLAND
TILL BED III	TILL ↘		EARLY WEICHSELIAN
INTERGLACIAL ORGANIC DEPOSITS	PEAT, GYTTJA, SILT, SAND, GRAVEL	TEPSANKUMPU INTERGLACIAL	EEMIAN LEVEANIEMI MIKULINO
TILL BED IV	TILL ↗		SAALIAN
INTERGLACIAL ORGANIC DEPOSITS	PEAT, SILT, SAND	NAAKENAVAARA INTERGLACIAL	HOLSTEINIAN LIKHVIN
TILL BED V	TILL ↘		PRE HOLSTEINIAN (ELSTERIAN ?)
SORTED MINEROGENIC DEPOSITS	SILT, SAND	RAUTUVAARA NONGLACIAL INTERVAL	PRE HOLSTEINIAN
TILL BED VI	TILL →		PRE HOLSTEINIAN (CROMER COMPLEX ?)

Fig. 6. The Pleistocene stratigraphy with its correlation in Finnish Lapland. The arrows indicate the average flow directions of the continental ice sheet in central Lapland during various stages.

The excavations have demonstrated that the thickest deposits of peat and mud have been preserved undisturbed, except for the compression of the glacier: the high pressure of the weight of the ice sheet has compressed pieces of trees and cones flat. In most cases layers of gravel, sand and silt of different thickness have protected the in situ deposits of peat and mud from the glacial erosion (Cf. Figs. 2, 5, 8, 9, and 11). Generally, deposits of sorted matter have been interpreted to be of proglacial origin, meaning that they have been deposited during the transgression of the glacier: in spring and summer, melting waters poured into depressions in the foreground of the ice sheet, depositing gravel, sand and silt on top of organic deposits. However, when the glacier progressed to the depressions, the organic deposits have been protected from the erosion of the glacier by the ice-dammed lakes, while the erosion has been directed to the overlying, sorted sediments. In case a protective layer has been missing, organic matter has been mixed with till completely or as large pieces of organic matter.

The in situ organic deposits, underneath or between till beds, have been of crucial importance to the diverse research of Quaternary geology in Finland. They represent undisputable evidence of the several Ice Ages and glaciations, as well as the interglacial and interstadial periods between them. Using radiocarbon and pollen analyses have has made it possible to calculate the age of the till beds relatively precisely. Pollen and different macrofossils indicate the vegetation, reflecting the climate conditions in the ice-free interglacial and interstadial periods. Diatom analyses of the mud reflect the salinity and water temperature in the earlier stages of the Baltic Sea.

Vegetation and climate in iceless Interstadial and Interglacial periods

There are six different ice flow stages with different directions of ice flow in the ice-divide zone of Central Lapland. The till beds, deposited according to the direction of the ice flow, have been numbered I-VI from the youngest to the oldest. The three youngest till beds have been interpreted to have been deposited during the last Weichselian glaciation, whereas the others are older (Fig. 6). The till beds I and II have been deposited during the same glaciation stage. The deposits were formed when the ice sheet was already retreating. In the last phases of the glaciation, the retreating ice sheet oscillated so that the ice-free areas were recurrently re-occupied

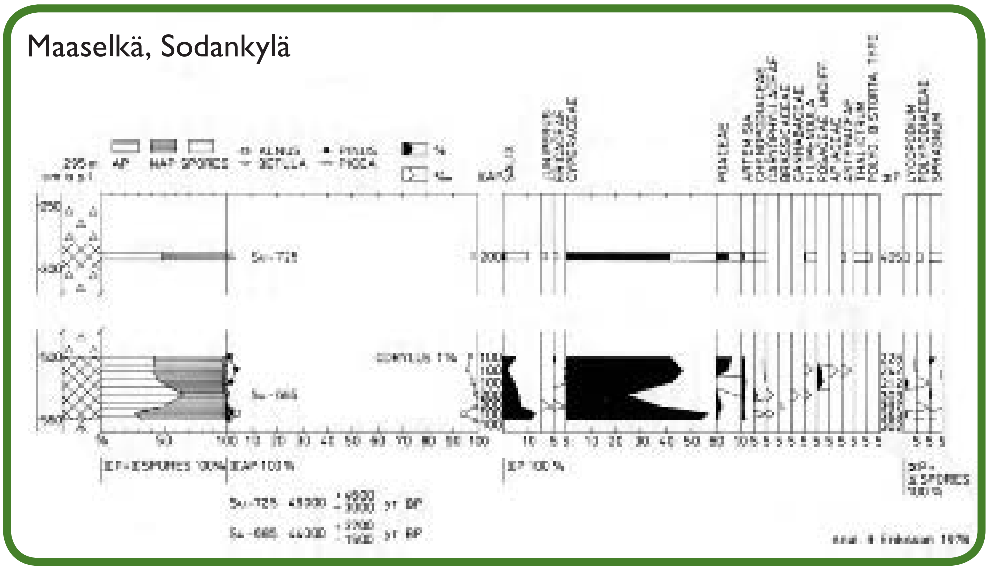


Fig. 7. Pollen diagrams of a gyttja deposit under till bed II and gyttja in the till bed at Maaselkä, Sodankylä (locality 7 in Fig. 1), correlated with the Peräpohjola Interstadial on the basis of the high *Betula* values. The gyttja deposit lies on bedrock with preglacial weathering.

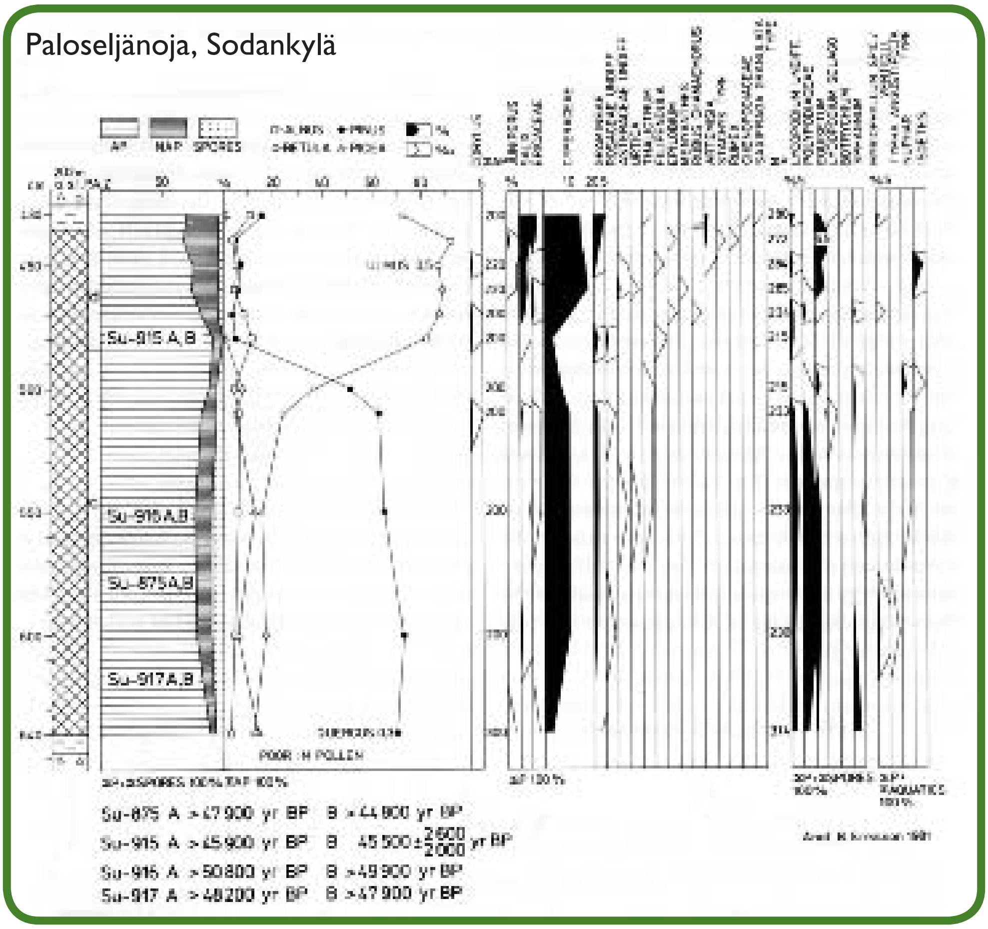


Fig. 8. Pollen diagram of a gyttja deposit over 2 m thick, overlain by silt and two till beds (II and III) at Paloseljänoja, Sodankylä (locality 4 in Fig 1). The gyttja is interpreted as interglacial on the basis of the abundance of *Pinus* and *Picea* pollen and the sporadic occurrence of *Quercus*, *Ulmus* and *Corylus* pollen. The *Betula* dominated pollen column in the upper parts of the gyttja indicate the cool end stage of the interglacial period.

by the ice sheet. The till beds III-VI have been deposited during different glaciation stages.

The till bed II covers organic deposits that have been deposited 80 000 - 100 000 BP. According to pollen analyses, Finland was experiencing a sub-arctic climate that was several degrees colder than at present. Birch and willow grew in Lapland, the area of distribution of pine reached Western Finland (Fig. 7). The result of radiocarbon dating was more than 40 000 years, which is older than can be reliably dated using the method.

This glaciation stage has been named Peräpohjola or Maaselkä interstadial in Finland, and it can be compared with the Jämtland interstadial in Sweden and the Brörud interstadial in Denmark. I personally believe that, after the iceless interstadial, Finnish Lapland remained covered by ice until the end of the glaciation around 9 000 BP.

In the time period from 100 000 to 115 000 BP, the ice sheet covered Northern Finland up to Oulu and Pudasjärvi (Sutinen 1992), whereas Southern Finland was already free from ice.

The organic deposits underlying the till bed II were deposited 115 000 - 130 000 BP. At the time, the climate was 3-4 degrees warmer than at present. Pine forests dominated in Lapland. Pollen analyses indicate that European hazel (*Corylus avellana*), hemi-boreal deciduous trees, oak (*Quercus* spp.), beech (*Fagus* spp.) and elm (*Ulmus* spp.) probably occurred as far North as Sodankylä and Kittilä in Finnish Lapland. At the time, also larch (*Larix* spp.) was growing naturally in Finland. The current western limit of the distribution of larch is to the east of Lake Onega, about 250 km from the border of Finland. Larches growing in Finland at presentaare all planted. It is possible that the tree species included also hemlock (*Tsuga* spp.) and silver fir (*Abies alba*) since the species have been found in the pollen analyses of the corresponding deposits (Fig. 8). The glaciation is named Tepsankumpu glaciation in Finland, and it can be compared to the Leveäniemi interglacial in Sweden, Mikulino interglacial in Russia and Eemian interglacial in the rest of Europe.

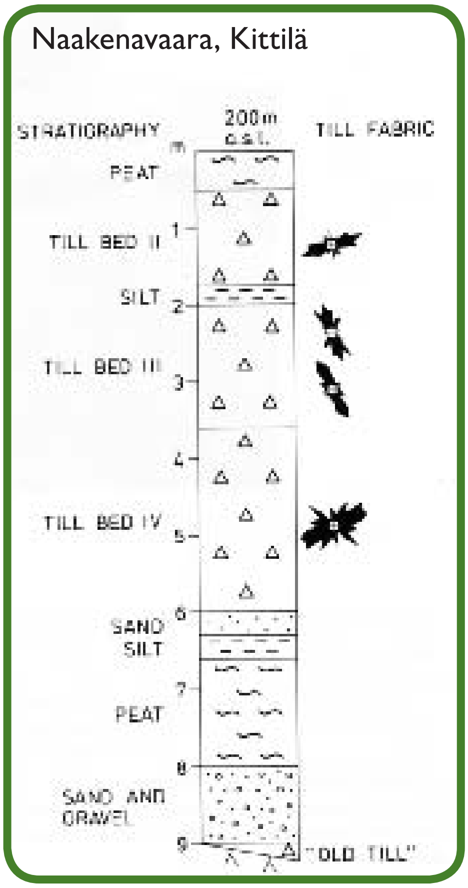

Naakenavaara, Kittilä

Fig. 9. Stratigraphy and fabric analyses of the Naakenavaara interglacial peat deposit at Kittilä (cf. Fig. 6, locality 5 in Fig. 1).

While pine forests were dominating in Lapland, birch (*Betula* spp.), alder (*Alnus* spp.), oak (*Quercus robur*) and European hazel (*Cornus avellana*) dominated the forests in Eastern Finland (Nenonen 1995). In River Poikkijoki, in the municipality of Vimpeli in Eastern Finland, pollen of *Sambucus nigra* and *Thalictrum lucidum*, growing in the nature currently only to the south of the Gulf of Finland (Aalto & al. 1989), was found. At the same time, in the same place, the beaver was constructing it's dams in River Poikkijoki. The Eemian interglacial was preceded by the so-called Saalian glaciation about 130 000 - 235 000 BP.

Oldest peat deposit in Finland

The only reliable finding of organic deposits from the ice-free periods before the Eemian interglacial is in Naakenavaara, in the municipality of Kittilä (Locality 5 in Fig. 1), 160 km north of the Arctic Circle in Western Lapland. The organic deposit is 1,5 m thick and it is under three till beds, in the depth of 6,5 m (Fig. 9). The site is

Fig. 10. The subtill peat at Naakenavaara was so tightly compressed and hard that it had to be cut with a chain saw. Photo: Heikki Hirvas.

currently occupied by a forested mire with a thin layer of peat. The organic layer is so compressed under the till that the sampling needed to be carried out with the help of a saw (Fig. 10).

The pollen analyses show that the past and present tree species in Naakenavaara are the same: also during the deposition of the peat the forests were predominantly mixed forests dominated by pine, also growing spruce and birch (Fig. 11). The most distinctive difference between the past and present vegetation is the occurrence of larch in the pollen diagrams and as pieces of trunks and cones in the deposits. In addition to the larch pollens, there are pollens of other coniferous trees that have not occurred in the area in the postglacial period. The pollen curve of the pine contains individual pollen grains other than *Pinus sylvestris*, and some pollen of *Pinus haploxylon* was found, too. The pollen curve of spruce contains some pollen of *Picea omorica*. However, their abundance is less than 1 %. Some pollen grains of conifers, such as Podocarpidites, Abiespollenites and Zonalapollenites, are considered pre-Quaternary.

The occurrence of shrub pollen is infrequent. The only species that has an abundance worth mentioning is *Myrica gale* that can be found in the upper part of the sample.

The occurrence of dwarf shrub pollen is also infrequent in the sample sequence, although pollen of the Bruckenthalia type occur in almost all the samples. The abundance of this pollen is less than 1 %, except for the lowermost part of the sample where their occurrence amounts to 4 %. At present, *Bruckenthalia spiculifolia* grows in the Balkan Peninsula and in the mountains of Rumania (Tutin 1972).

According to the pollen composition, the climate during the deposition of the peat was about 1-2 degrees warmer than at present.

The study of the Naakenavaara peat deposit has revealed some interesting facts about other vascular plants: there is a large amount of seeds of the plant species *Aracites interglacialis* in the peat deposit, most of which is composed of remains of this plant (Hirvas 1991). Seeds of the plant in question has not been found in any other interglacial or interstadial deposits in Northern Finland (Aalto & Hirvas 1987, Aalto & al. 1992). In Europe, the species has been encountered only in deposits of the Holstein-Likhvin interglacial, older glacial deposits and Pliocene deposits (Кац & al. 1965, Sobolewska 1977) - meaning that after the Holstein-interglacial the species has become extinct everywhere in the world! The exact reason for the extinction of the species is not clear. *Aracites interglacialis* was about 20-30 cm high peat-forming mire species, resembling *Menyanthes.*

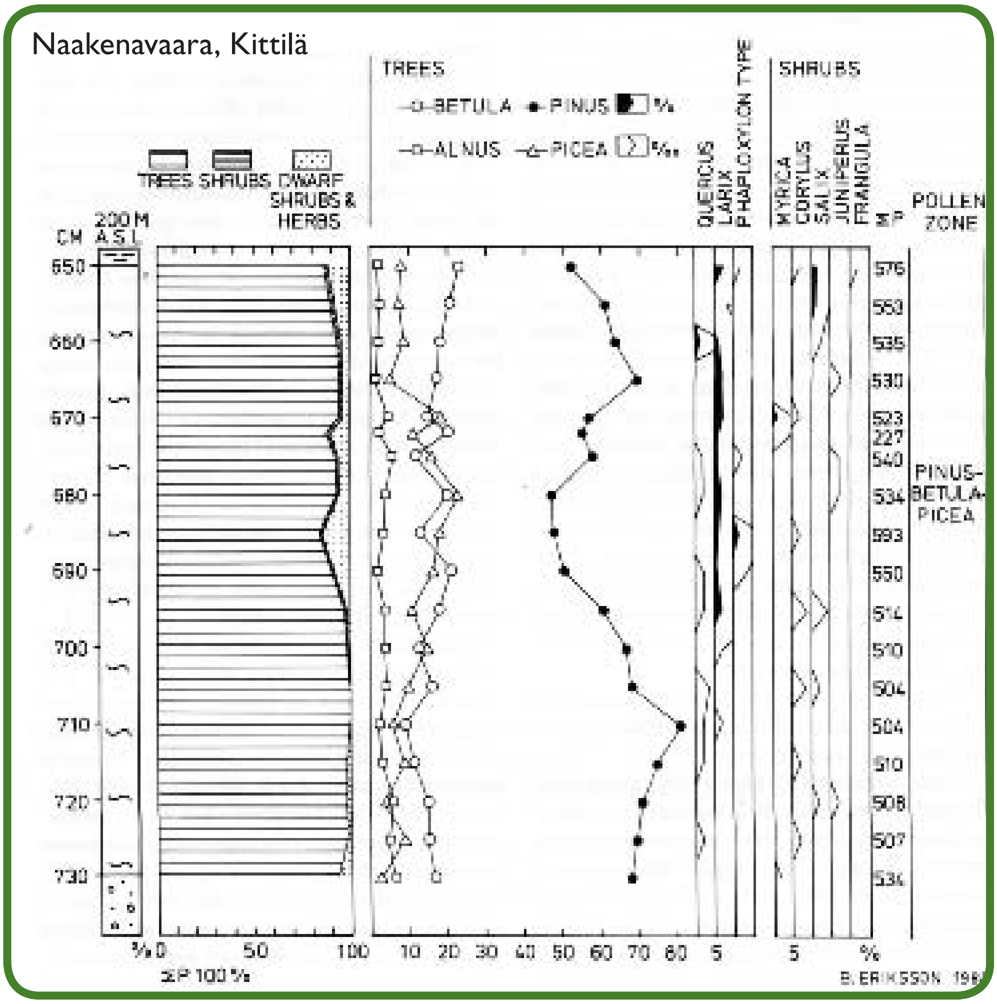


Fig. 11. Pollen diagram of peat overlain by till beds II, III and IV at Naakenavaara, Kittilä.

This ice-free period has been named the Naakenavaara interglacial, due to the large amount of the seeds of *Aracites interglacialis*. The Naakenavaara interglacial is parallel to the Holstein interglacial which is supported by the stratigraphical peat depositions under the till bed IV. The Holstein interglacial has been dated to 235 000 - 250 000 BP. The Naakenavaara peat deposition is the oldest peat deposition not only in Finland, but in whole Scandinavia.

The Naakenavaara peat deposition is a good example of the cyclicality of nature. About 250 000 years ago the site was occupied by a mire, just as it is today, meaning that the present depressions have been in existence for long. The main topographic features of Lapland and the rest of Finland have not changed considerably during the Ice Ages. The ice sheet had a surprisingly weak effect on the terrain despite the thickness of of the ice, 2 -3 km. Naturally, elevations have been eroded and worn down to some extent, but in many places old depositions have been well-preserved in depressions where also the material eroded from the elevations has been deposited. Thus, contrary to popular belief, the ice sheet had a smoothening effect on the landscape.

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Mire development history in Finland

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Forms of mire initiation

For a mire to be formed in Finland a water surplus is needed – either climatically induced or caused by local hydrological setting. Hygric component of the climate as such is not marked enough to allow rain-fed mires to initiate as a first genetic mire form ("wurzelechte Hochmoortorfe"). The types of mire formation and their significance in Finland have been dealt with during a longer period than one century. The matter was discussed focusing either more to a certain region or specifically to initiation form. Primary mire formation, paludification and terrestrialisation (infilling) were perceived in early stages as principal forms of mire initiation, although with variation in studies of different times about their proportional significance. Mire formation as a consequence of river flooding proved to have a more local significance (Auer 1921, Lappalainen 1970). Unknown is the extent of paludifying effects of the past floods caused by beavers.

In **primary mire formation** wetland vegetation occupies the soil either emerged from water or released from ice. This kind of mire formation was known already by Häyrén (1902) and Leiviskä (1902). Oldest sites, in which peat formation could start after ice retreat in many cases during the Preboreal chronozone, some 10 000-9000 conv BP, are restricted to SE-, E- and N-Finland, where they were not covered by the early stages of the Baltic Sea (Ruuhijärvi 1963, Tolonen 1967, Lappalainen 1970). Primary mire formation has been and is still of special importance in the western Finnish coast, which is rather flat and emerging rapidly (still 5 to 8 mm annually) from the sea.

Aquatic vegetation, e.g. reed stands in seawater or in regressive lake shores, may turn to open swamp mires, or small depressions in wet shore meadow may act as mire nuclei. Some depressions may have a longer life as lagoons or glo-ponds, which in turn may be occupied by mire vegetation. Among pioneer mosses in such swamp mires are e.g. *Warnstorfia exannulata* and *Drepanocladus aduncus*. Sphagna, often *Sphagnum squarrosum*, invade somewhat later. Types of mire formation on elevated shores are often combined, thus it is not always too easy to determine - especially in peat cores - whether the initiation form was primary or a result of an early terrestrialisation.

A classical work on primary mire formation of Huikari (1956) was much based on analyses of fungal remains in the very basal peats. His results revealed that majority of mires, once covered by the ancient Baltic Sea, was initiated by this primary form. A rule "The higher elevation – the older mire" is commonly valid in regions where primary mire formation has been the dominant form (Aario 1932, Aartolahti 1965). Series of such mire complexes on gently sloping western coast of Finland – even where the maximum land upheaval is against the discharge direction – thus form a genuine frame for actual and past correspondences (Fig. 1).

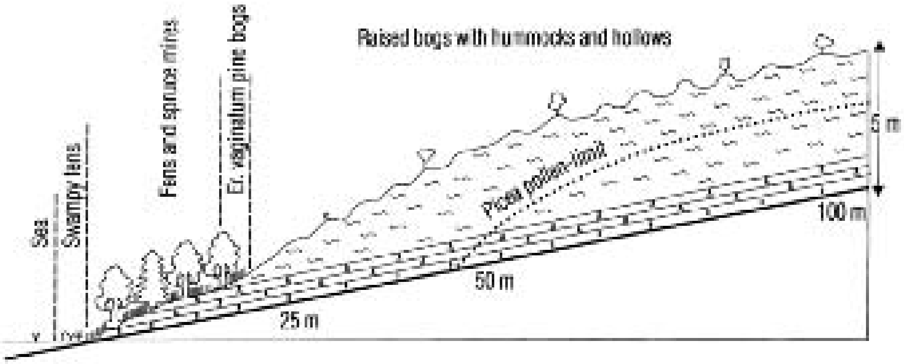

Fig. 1. Mire succession from Bothnian Bay to inland near the latitude of 62° N (modified from Aario 1932).

Paludification is a successional process from forest on mineral soil to a mire ecosystem. It is preceded by a rise in soil water level, which in turn may be result of reduced evapotranspiration, reduced soil permeability or transgressive growth of neighbouring mire. When paludification process is starting, the flora – including microbes (Mannerkoski 1972) – is changing. Pioneer mire plants e.g. *Sphagnum capillifolium, S. girgensohnii, Polytrichum commune, Carex globularis and Eriophorum vaginatum* together with mire dwarf shrubs invade to moistened heath forest vegetation.

An essential factor causing paludification is rise in water level. In *primary paludification* an independent forest site on mineral soil is getting mire vegetation cover; *secondary paludification* means enlargement of previous mire to forest land. Water level rise may be a consequence of reduced evapotranspiration after forest fire (reason in about 2/3 of the paludified area), clear cutting and transgression of former mire and of climatic period with increased effective humidity. Paludification is sometimes connected with preceding pedogenic processes: top soil impoverishment caused by leaching, and moistening by decreased permeability due to hardpan formation.

Among forms of mire formation paludification is closely related to past climatic changes. Extensive paludification in northern Finland started already near the beginning of the Boreal chronozone, some 9000 conv BP (Vasari 1962, Lappalainen 1970). According to the extensive studies of Lukkala (1933) paludification appeared to have been most pronounced during early Holocene, much ceased in Mid-Holocene (6500-4800 conv BP), and again pronounced later. According to a more recent study (Korhola 1995a) the most intensive episodes of paludification occurred c. 8000-7000 cal BP and from c. 4500 cal BP onwards in southern Finland (Fig. 2). Paludification is still going on in some extent (Lukkala 1933). More recently it has decreased to minimum due to effective protection against fires, forest drainage and e.g. due to deep ploughing after clear cuttings.

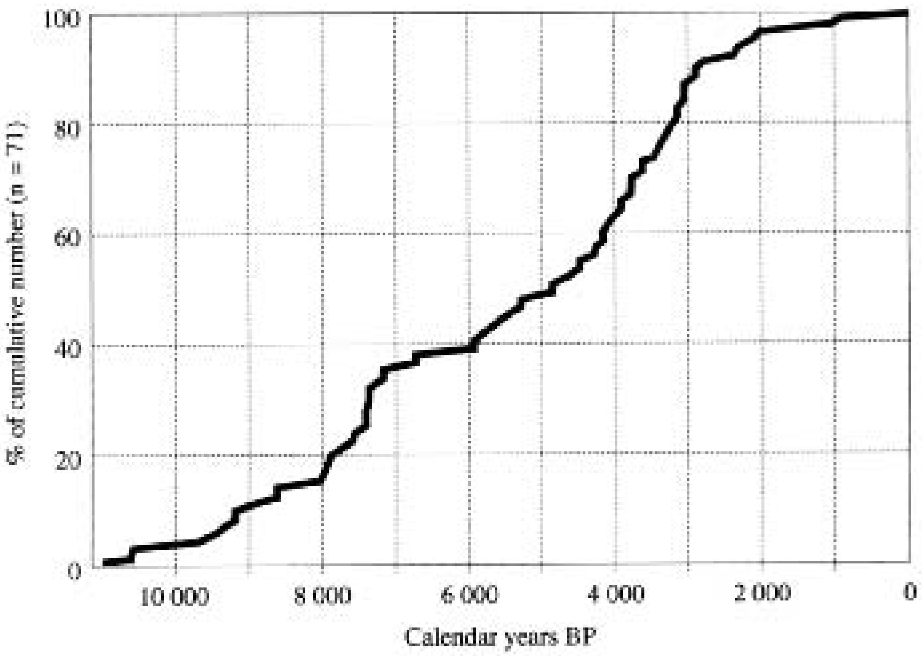

Fig. 2. Cumulative ^{14}C-ages of basal peats of paludified sites in S Finland (adapted from Korhola 1995a).

Terrestrialisation (infilling) is a hydroseral succession from open water to mire vegetation, having been and still being a common natural phenomenon. This mode of mire initiation is combined by sedimentological and biological processes. The main modes of infilling are: i) along bottom (usually with marginal helophytes), ii) intra-aquatic (by submerged plants like *Potamogeton* spp. and *Myriophyllum* spp., see Korhola 1995b), iii) along surface (often forming so called quagmires by e.g. floating Sphagna). Less studied is the mechanical mode (Auer 1952), in which the lake ice breaks down peat-bank shores causing shallowing water and succeeding mire vegetation.

It is noticeable that oldest basal peat formation is commonly found just outside the former water basin (Korhola 1992). Overgrowth thus may act as a prime in formation of peatlands as integral part in natural life span of lake basins. Infilling processes were active during drier climatic, i.e. during low water periods. Such episode was between moister and paludifying periods, i.e. during c. 7000-4500 cal BP (Korhola 1995a).

Concepts of proportional significance of different mire initiation forms varied with time to be stabilized since 1950s much as "tabula classica" (expressed as a percentage of the present mire area prior to drainage):

Geological location	Old area	Young area
Primary mire formation	40	60
Paludification	50	35
Terrestrialisation	5	10

In this output the geologically young area means the broad coastal zone (some 200 km in the west) of Finland.

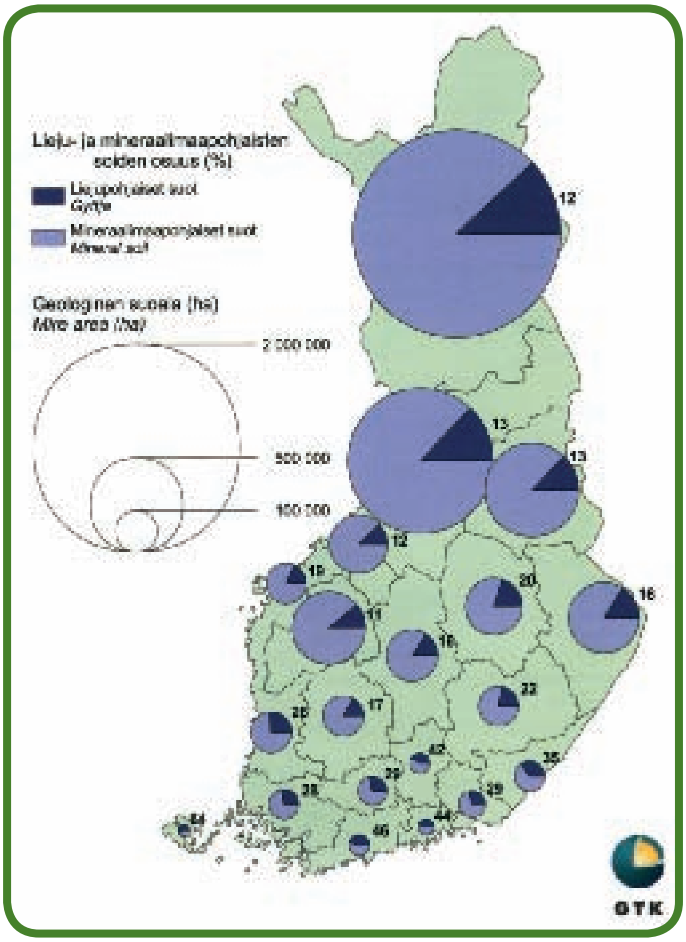

Fig. 3. Occurrence of gyttja (%) in mire bottoms by province (Virtanen & al. 2003).

An extensive investigation of the Geological Survey of Finland (Virtanen & al. 2003) revealed a higher proportion for terrestrialisation than presented in many earlier papers. The material of about one million study points and 12 000 mire basins revealed e.g. that limnic sediment can be found in 14 % of the coring points, with clearly decreasing values towards the north (Fig. 3). There are facts that indicate even higher importance of terrestrialisation. First, the above mentioned study considered at least 10 cm thick limnogenic layers only. Secondly, sapropel (gyttja and lake mud) is not deposited on erosional zones of a water basin. However, the geological survey included here only mire sites with at least 30 cm peat depth and over 20 ha size. Thin-peated forested marginal parts of mires, mire stripes, small mire basins and majority of slope mires are thus out of the inventory. This must, on the other hand, increase the proportion of paludified sites if the total mire area were considered.

Growth phases

Developmental trends of mire complexes often tend to have convergent analogy by smoothing form and causation of initiation. Peat formation in case of terrestrialisation is centripetal, while in the same time the same mire basin may enlarge by paludification centrifugally (Korhola 1995b). In some cases both these processes were rapid, exceeding even metres annually (Korhola 1992). Local topography played an important role in guiding speed and direction of lateral peat formation. In some raised bog complexes the lateral growth has practically ceased, and the present growth is more or less vertical only. To demonstrate initiation and lateral growth of a raised bog, a 3-D reconstruction (Alm & al. 2004) is shown (Fig. 4). The Kontolanrahka Bog has now its centre rising some 6 metres above the margins in places, and size about 880 ha.

First peat deposits may hide – and conserve – interesting macrosubfossils, especially in limnotelmatic, often eutrophic deposits. Such finds from extensive study series even from times of Andersson (1898), Lindberg (1910) and Backman (1919) include demanding taxa like *Trapa natans, Corylus avellana* and *Carex pseudocyperus*, which now have clearly more southern distribution. The observed trend reflect not only deteriorating climatic but poorer edaphic conditions. Also features of the periglacial nature were revealed by macroremains of e.g. arctic-alpine heath plants like *Dryas octopetala, Salix herbacea* and *S. polaris* (Bondestam & al. 1994).

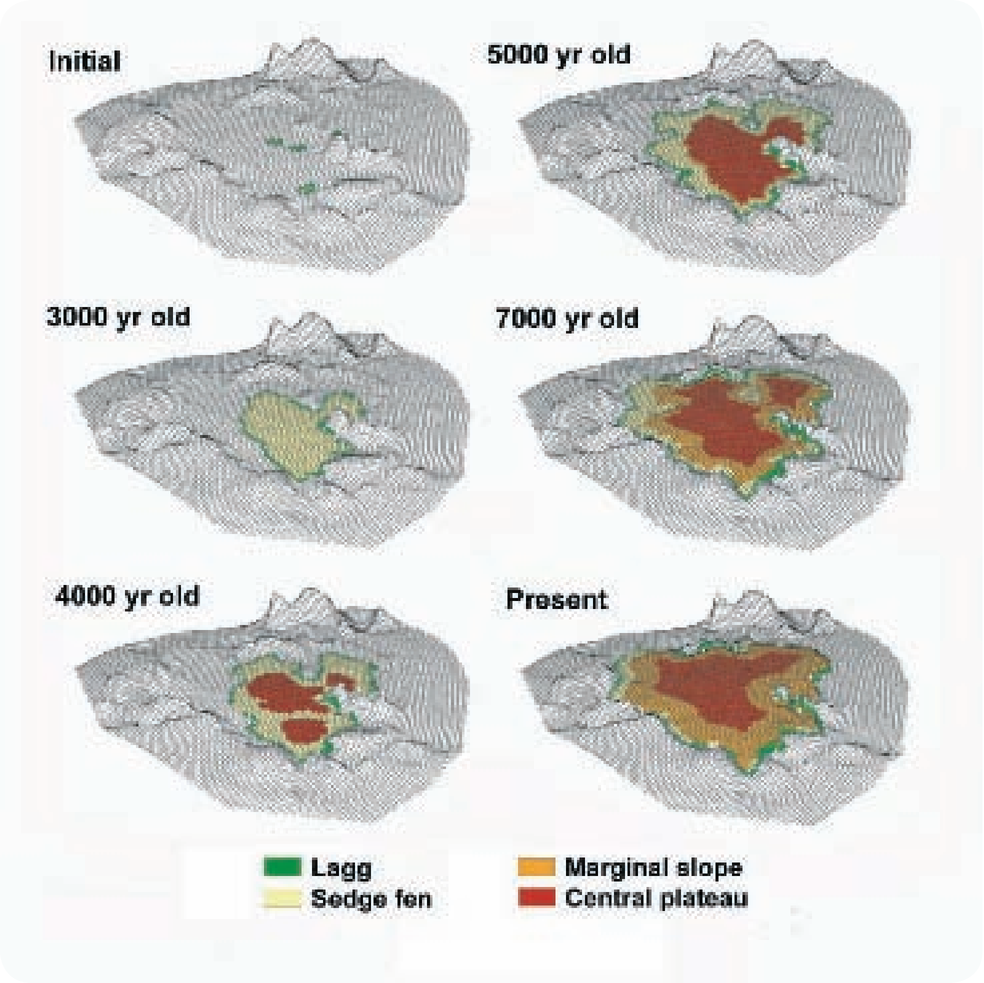

Fig. 4. Reconstruction of the initiation, secondary paludification and gross form development of Kontolanrahka Bog in SW Finland during the Holocene. Diameter of the mire at present is 3.8 km (adapted from Alm & al. 2004).

In many cases natural succession, especially in sites of terrestrialisation of eutrophic water basins or sheltered sea bays, lead to swamp mires and herb-rich forest mires. Also paludified sites carried often fertile treed fen vegetation at their early stages (e.g. Aartolahti 1965, Korhola 1992).

If the exogenic influence was not too marked, mires further tend to develop towards poorer habitats. Although each mire is its own story, these mires – when ecologically self-sufficient – tend to develop via e.g. poor sedge fens, cotton-grass pine mires or via *Sphagnum magellanicum* (Aartolahti 1965, Tolonen 1987) stages finally to ombrotrophy in bog zones.

These changes up to ombrotrophic climax are reflected, and thus can be detected also in the nutrient contents of deposits as shown already by Warén (1924), and later e.g. by Huttunen (1990). A useful method to determine minero-ombro boundary has been based on changes in the ratio of atmospheric vs. geogenic elements in peat.

The change from minerogenic (aapa) phase to ombrotrophic (raised bog) phase was time-transgressive from south to north. Earliest transition to ombrotrophic bog was in southern Finland about 8000 cal BP and in central Finland commonly about 3000 cal BP as summarised in Tolonen (1987) and Korhola & Tolonen (1996). Raised bogs can be found here and there also in Lapland inside the aapa-mire zone (Rancken 1911, Cajander 1913). They may have developed in bi- or polyfurcation sites inside an aapa complex or as an eccentric massif in shelter of minerotrophic water flows (Ruuhijärvi 1963). These bogs are not older than 2000 years.

If the local environmental factors permit, the change to ombrotrophy can be quick like in Kiimisuo Bog on Hailuoto Island. In thermally oceanic but hygricly continental region on sandy substratum, isolated from the Bothnian Bay c. A.D. 800 Kiimisuo is now a large unpatterned *Sphagnum fuscum* bog complex.

Development of morphological features

The gross morphology of mire complexes develop to typical forms for each climatically forced mire vegetation zone. From south to north they are presently concentric plateau bogs, concentric raised (domed) bogs, eccentric bogs, which may be patterned or hummocky *Sphagnum fuscum* pine bogs. All they have ombrotrophic peat massif of own characteristic form lying on minerotrophic basal peat.

North of raised bog zone are aapa mire complexes, which by their gross form are somewhat concave and at least slightly sloping. In Mid-Finland the southern (lawn) aapa mires prevail having no or commonly only slightly differentiated string-flark microtopography. They are dominated by lawn or carpet hydrotopographic level usually with low strings at their central parts. In their mesotopography the peripheral parts with lawn to hummock levels cover considerable proportion of mire expanse. In some cases (especially quite near the coast at their southwestern region) these mires tend to have features of transitional mires (Übergangsmoore) by their only slightly minerogenic general appearance.

Also in the main aapa mire zone peatlands smoothen the landscape, here with flark level dominance with high strings. Unpatterned peripheral parts of massifs are restricted to somewhat higher fringes near mire margins. Slope mires are well represented in the uplands of this mire zone. Profiles of such topographic variants of aapa mires show strong inclination (up to about 20 degrees) of - due to seasonal drought – quite thin peat mires as continuations of valley mires upslope, paludified sloping valleys or as saddle mires (Auer 1923). Paludification tendency in these uplands is big enough to enable wet heath formation with a thick raw humus layer thus resembling climatic peat, blanket mire formation.

In the northern aapa mire zone peatlands are not that clearly and regularly patterned than in the previous one. In their thin peated marginal parts mires may have pounus, frozen peat hummocks forming steeply undulating relief. In the most northern palsa mire zone peatlands resemble mires of the previous zone or have even less uniform string formation, and in some cases have also frozen peat mounds, palsas. Typical for this mountainous part of Lapland are the orohemiarctic mires. These snow-melt and spring effected mires have a huge variance in gross morphology existing both on valleys and slopes, but always having a rather thin to extremely thin peat layer.

Peat stratigraphies of any region are depending on the initiation form of mires, trophy, topography etc. to be equalized later, especially if ombrotrophy is reached like in an example from 11 raised bogs (Aartolahti 1965) in southern Finland (Fig. 5). In aapa mires peat strata are usually much simpler, often woody or Bryales peats near bottom and sedge peats mixed with Sphagna forming the main body of the massif.

In stratigraphies of many mires especially in the geologically old part of Finland, a rather thick well-decomposed peat layer is commonly present between less decomposed peats. The well decomposed peat is connected to the warm period of the Holocene. However, the rather distinct black peat/white peat contact in Finland varies by age in a broad scale of 5000-2000 BP. This recurrence horizon varies by age already in nearby mires (Tolonen 1967) and even inside same mire complex (Aartolahti 1965, see also Seppä 2002). In aapa mires such changes in decomposition are normally not that conspicuous. The basal peats, however, may sometimes be so undecomposed that

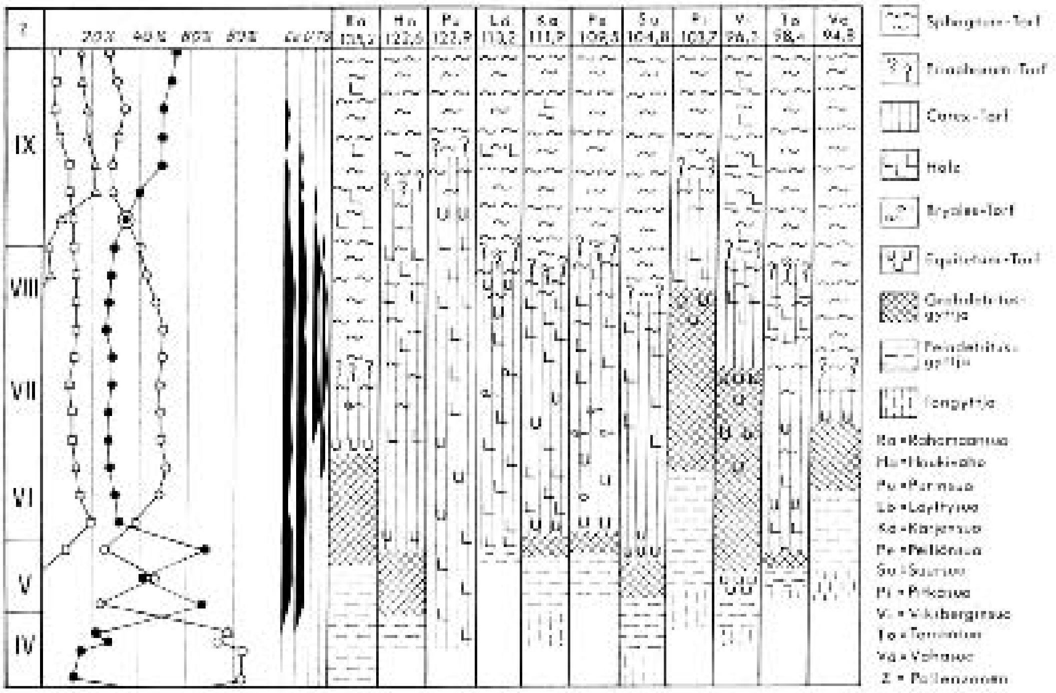

Fig. 5. Stratigraphical columns of 11 raised bogs from SW-Häme, southern Finland (from Aartolahti 1965). First column shows the biostratigraphical zones through the Holocene. Second column refers to main tree pollen percentages (white circle: *Betula*, Black circle: *Pinus*, square: *Alnus*, triangle: *Picea*. Letters Co to Q refer to *Corylus*, *Ulmus*, *Tilia* and *Quercus*). Next 11 columns show the mire complexes by name abbreviations and their altitude (m a.s.l.).

mosses can be identified into species (commonly *Scorpidium scorpioides* and *Pseudocalliergon trifarium)* level in the field. Such peat strata are most probably not reflection of any general climatic factor but result of short life-span in the oxic acrotelm.

In bog peat, several sudden humified layers or stripes have been found in a large geographical area. Such recurrence surfaces varied in number and in age within a same region (Aartolahti 1965). They do not prove any cyclic regeneration of succeeding hollow and hummock phases, but as Tolonen (1971) showed from an open peat profile, the small-scale fuscum regeneration. That means alteration of *Sphagnum fuscum* cover with occasional growth stopping lichen layers, which appear as darker stripes in peat stratigraphy.

As **microtopographic formations,** hollows in raised bogs are secondary in origin, and as shown in western Finland (Aartolahti 1965) formed after wetting of formerly dry raised bogs. Both hummocks and hollows are rather permanent microtopographic forms as shown by Aartolahti (1965) by *Sphagnum* leaf stratigraphy. Although the origin of any microtopographic formation cannot be strictly synchronous, quite a large data set suggests that the initiation of microforms in raised bogs took place about 3000-2000 BP. The period of intensive hollow formation 3200-2800 BP was detected also in Estonia (Karofeld 1998) suggesting a more general boosting by past climate.

Strings in aapa mires as primary in origin are also permanent formations, but can slightly change their position. Within the main aapa mire zone measurements of strings showed movements of few centimetres annually, sometimes even several decimetres (Seppälä & Koutaniemi 1986). Hydrostatic pressure, and ice and frost related processes are important in causing the movements. The string pool topography there appeared to have originated 3000-2000 BP.

Palsamire from Lapland. The High mounds are palsas and the low flat area minerogenic fen. Photo Pekka Salminen.

Palsas as frozen peat mounds in flarks are also secondary in origin and relatively unstable. Active permafrost formation took place in Fennoscandia 2500-1900 BP and again during the Little Ice Age 700-100 BP. Most of the modern palsas are from time 600-100 BP, and since the Little Ice Age there has been more melting than initiation of palsas (Oksanen 2005).

Recently, when large forest fires are nearly ceased, no charcoal horizons are formed in the marginal parts of mire complexes. Instead, marker horizons – having no effect on morphology – have subrecently been formed by human impact. After careful consideration they, e.g. heavy metals, can be used in future timing procedures. Ongoing processes, like restoration of drained peatlands and rewetting of cutover peatlands, similarly form usable key sites when studying mire development history and mires as temporal archives in the future.

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Regional distribution of peat increment in Finland

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Introduction

The average vertical peat increment rate has been determined to be about 0.5 mm yr^{-1}. However, most of the information used in these calculations is derived from deep basins and shallower mires have consequently been underrepresented. The data does not represent the mean depth of mires, which is 1.4 m in Finland (Virtanen & al. 2003). Total Finnish peat reserves are account for 69.3 billion m^3 in situ (Virtanen & al. 2003). A large number of data from inventories and radiocarbon datings has been stored in data registers of the Geological Survey of Finland. They offer excellent data for studying peat increment rates in different parts of Finland.

The surface patterns (hollows and hummocks) of a raised bog in Petkelsuo mire in Hyvinkää, southern Finland. Photo Markku Mäkilä.

Material and methods

The long-term rate of peat increment in Finnish mires was calculated on the basis of 520 dated peat columns (Mäkilä & Toivonen 2004a). The areas of the depth zones of different mire complex types in the study material were derived by substituting their proportions in this study material with the proportion from the inventory material. The dating results for basal peat were sorted according to the depth zone, and the averages from these were used to calculate the peat increment rates in separate depth zones of different mire complex types (Fig. 1). Finally, the increment rate and age of peat were sorted according to the depth zone in the raised bog and aapa mire areas. The basal peat samples were taken just above the mineral soil or gyttja. The ^{14}C samples generally represented a vertical thickness of 3-6 cm. The dated mires are marked with a point in Figure 1. Several datings have been performed from different depth zones of some mires (Mäkilä 1997, Mäkilä & al. 2001, Mäkilä & Toivonen 2004b).

The vertical peat increment rate was determined from different levels of 39 dated peat profiles, mainly representing the thickest peat layers of mires. Peat samples were mainly taken in pristine areas. Radiocarbon ages were determined at the ^{14}C laboratory (Su) of the Geological Survey of Finland and were calibrated after Stuiver & Reimer (1993). The determined ages correspond to the present time, as 50 years were added to them.

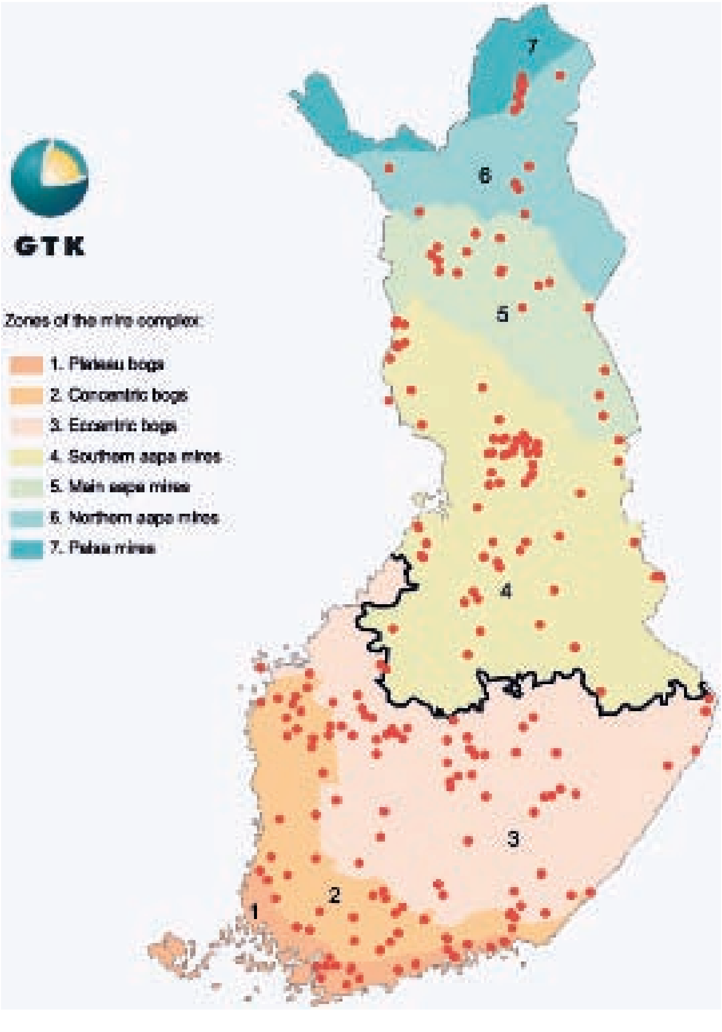

Fig I. Zones of mire complex types according to Ruuhijärvi and Hosiaisluoma (1988) and the dating points of mires.

Results

The retreat of the last glacier and in some areas the subsequent aquatic stages have determined the maximum age of Finnish mires. The oldest basal peat, dated to 10 770 cal BP, has been found in Kuhmo in eastern Finland. The thickest peat layer, 12.3 m, has been recorded in the highlands of Tammela in southern Finland, where the age of the basal peat is 10 530 cal BP (Sten 1988).

The highest recorded peat increment rates are 2-3 mm yr^{-1} in young coastal bogs (Mäkilä & Toivonen 2004b), while the lowest rates of under 0.1 mm yr^{-1} are found in the uplands of northern and eastern Finland. The average peat increment rate for the whole investigated area is 0.32 mm yr^{-1}, while in the raised bog area it is 0.59 mm yr^{-1} and in the aapa mire area 0.25 mm yr^{-1}. The rate in areas deeper than 2 metres, when northern aapa and palsa areas are excluded, is 0.40 mm yr^{-1}.

The vertical peat increment rates continuously declined between the years 10 000–5000 cal BP (Fig. 2). Thereafter there has been an increase up to the present day. During the last 5000 years the long-term peat increment rates have grown more clearly in raised bog than aapa mire areas (Fig. 2). The increase in peat increment rates in raised bogs may indicate not only the development of *Sphagnum* dominated plant communities but also the change towards a cooler and moister climate. The highest vertical peat increment rates were characteristic of mires during the last 1000 years when the average rate was about 0.8 mm yr^{-1} in raised bogs, 1,8 mm yr^{-1} in young raised bogs and 0.5 mm yr^{-1} in aapa mires (Fig. 2).

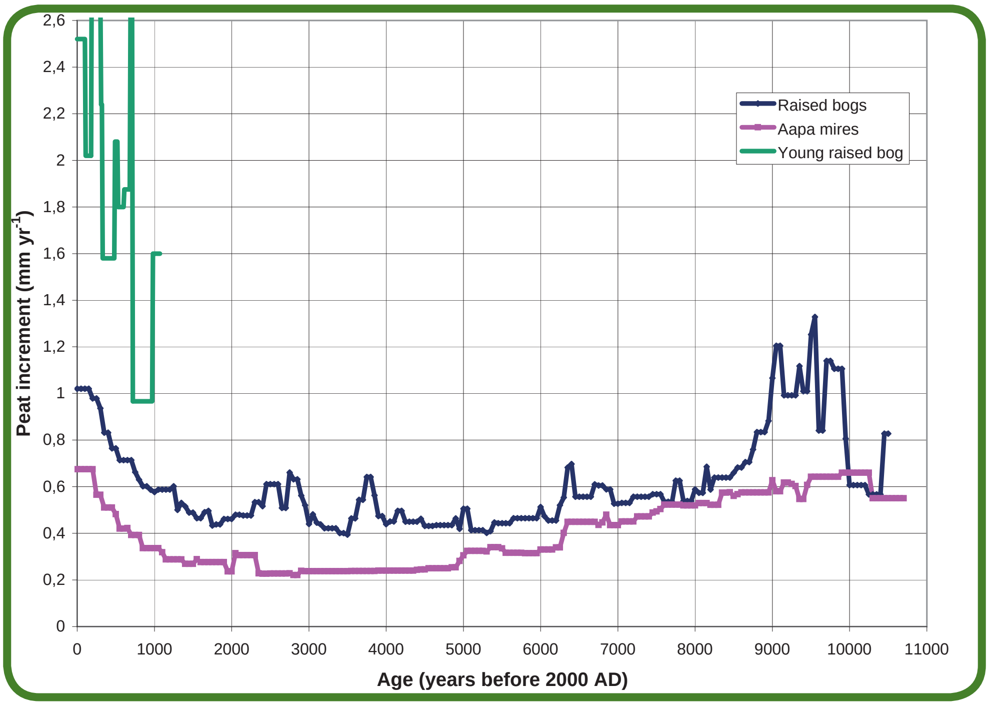

Fig 2. Rate of vertical peat increment in raised bogs, in a young raised bog and in aapa mires according to 39 dated peat profiles.

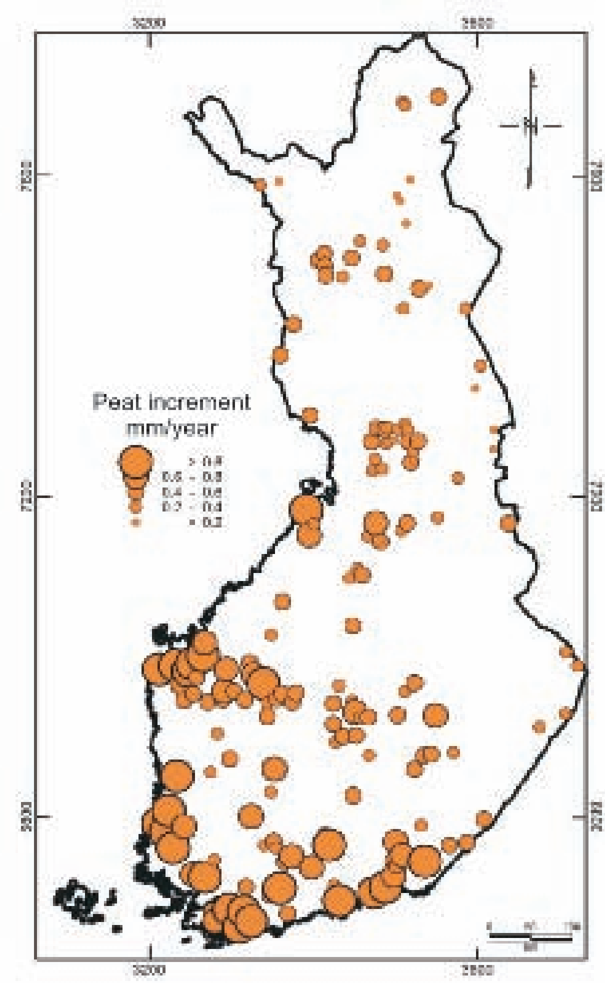

Fig. 3. The variability of the long-term peat increment in various parts of Finland.

Discussion and conclusions

Peat increment depends on various factors, including the paludification mode, water permeability, bottom soil nutrient content, the topography of the area determining runoff conditions, plant ecology (species composition, diversity), changes in the water balance of the mire, the number of fires, the age of the deposits, the decay properties of the plant species and the climate (e.g. Tolonen 1973, Aaby & Tauber 1975, Johnson & Damman 1991, Korhola 1992, Mäkilä 1997). The highest recorded rates are found in young coastal bogs with clayey nutrient-rich bottom soil. The humid climate near the sea is favourable to *Sphagnum* peat increment and the growing season is long because of early, mild and snowless springs. High peat increment rates are also found in places where the mire basin is characterized by filled in water bodies and/or depressions in the bottom soil topography. The lowest rates are found in northern Finland in basins with a sloping well permeable bottom soil topography. The short growing season in northern Finland and severe winters with strong frost action have resulted in slower peat increment and higher compression compared to southern raised bogs. Mire fires have also slowed down the progress of vertical peat increment in eastern Finland (Mäkilä 1997, Pitkänen & al. 1999). Peat increment is greater in bogs than in fens, because of efficient aerobic decay in minerotrophic fens receiving oxygenated water from the adjacent mineral soils, while ombrotrophic bogs are fed only by rain water (e.g. Damman 1996, Mäkilä & al. 2001).

The long-term peat increment in Finnish mires varies considerably, depending on many factors. For example, the peat increment rate is higher in geologically young mires than in old ones (Fig. 2), higher in southern and western than in eastern and northern Finland, and higher in ombrotrophic bogs than in minerotrophic mires (Fig. 3). In addition, the rate has varied greatly during the Holocene (Fig. 2). Variations in peat increment rates can mainly be explained by the vegetation composition and decomposition rates due to natural mire succession and variations in local conditions, but the role of climate cannot be ignored.

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Geobotany of Finnish forests and mires: the Finnish approach

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Short history of geobotany in Finland

In Finland, between Scandinavian and Russian schools of geobotany, the tradition has been different from both neighbouring traditions. It differs also from the central European and British tradition. According to nature the conservationist and teacher of Finnish geobotany Reino Kalliola (1973), the basement for Finnish geobotany was Johan Petter Norrlin (1842-1917). His ideas (e.g. Norrlin 1870, 1871) can be seen in Aimo Kaarlo Cajander´s (1879-1943) Finnish forest site type system (Cajander 1909) and in his mire site type system also (Cajander 1913). The work has later been continued by many geobotanists of following generations. Rauno Ruuhijärvi (1960) and Seppo Eurola (1962) have worked with the geobotany of mires. The work with forest vegetation zones continued in whole Finland (Kalela 1961) and in Lapland (Hämet-Ahti 1963) A general synthesis of geobotanical zones has stretched also outside the Finnish boundaries in northwesten Europe (Ahti & al. 1968). The corresponding mire vegetation zones have also been studied (Eurola 1968). Finally the geobotanical studies in Finland were widened for the whole circumboreal zone (Tuhkanen 1984). In the Finnish approach mires and forests have been understood to form a continuum. In botanical sense, the marginal habitats are classified as mires if the vegetation is dominated by mire species and there is a peat layer, even though in forestry they are classified as forests on the basis of the density, size and growth of tree layer.

Geobotany of Finland in general

Finland is a strip of the circumboreal vegetation zone, which covers an over 1000 km broad zone. Even the northernmost parts of Finland do not reach the arctic zone, but in northern Lapland, due to the high elevation in fells, there are alpine orohemiarctic and oroarctic areas (Hämet-Ahti 1963) South of Finland there is the temperate zone, but it does not reach further north than southern Sweden. Between the temperate zone and the boreal zone there is a hemiboreal or boreonemoral zone. The hemiboreal zone reaches Finland only as a narrow strip in the southern coast of the country (Tuhkanen 1984).

The boreal zone is a vegetation zone of coniferous forests. Sometimes it has been called according to Russian tradition also as Taiga. In Finland there are only three taxa of conifer trees: *Pinus sylvestris*, *Picea abies* ssp. *abies* (southern Finland) and *Picea abies* ssp. *obovata* (northern Finland). Between them there is wide gradient population of these two spruce taxa (Hämet-Ahti & al. 1998).

Forest fires have rather much determined the structure of forest vegetation and tree species. After the forest fire deciduous trees *Betula pendula* and *Populus tremula* together with pine dominate. Spruce has then rescued to wet sites, from where it comes back to drier sites (e.g. Pöntynen 1929). Pine originally was in principle dominating in more dry and poor habitats of mineral soils and spruce dominated more mesic and fertile sites. Due to the heavy forestry, however, pine has during about last 5 decades, due to planting of seedlings, conquered also habitats originally covered by spruce dominated forests. Also the large scale drainage of all kinds of mires has resulted in pine stands growing in those habitats (Hökka & al. 2002). So pine has become rather dominating in Finnish forest landscape.

The deciduous tree species are however rather common in Finnish forests: silver birch (*Betula pendula*) in mineral soils, downy birch (*Betula pubescens*) mainly on peat soils, but also in many cases in mineral soils. In northern fell area grows fell birch (*Betula pubescens* ssp. *czerepanovii*). In Finland we have also two species of alder, black alder (*Alnus glutinosa*) on shores of lakes and Baltic sea, growing also in rich mires on spring-fed and alluvial sites. Grey alder (*Alnus incana*) grows in poorer mires, mineral soils, and also in cultural habitats. Aspen (*Populus tremula*) grows usually only in mineral soils like also rowan (*Sorbus aucuparia*) and goat willow (*Salix caprea*). Bird cherry (*Prunus padus*) grows commonly along rivers and brooks. In southern Finland grow, mainly on rich mineral soil sites, also several other species: *Tilia cordata, Acer platanoides, Ulmus glabra, U. laevis, Corylus avellana, Fraxinus excelsior* and *Quercus robur*. These species are not common in nature due to the scarcity of suitable habitats, but they are rather popular in parks and gardens.

Forest vegetation and vegetation zones

In Finnish botanical, geobotanical and forest ecological as well as in mire ecological thinking, all is based on the Norrlin-Cajander school of site types. The basic definition of forest site type by Cajander (1909, 1949) is: *"All those stands are to be included in the same forest site type, which, when the stand is normally dense and ready to be cut or close to that, are more or less similar in plant species composition. Also similarly all those forest stands, whose vegetation differs temporarily, not permanently, from the basic type defined above only due to reasons, which e.g. can be derived from the age of the stand, thinning or selective cuttings or the change of the dominant tree species etc. – are included in the site types. Permanent differences result in a new forest site type, if the differences are remarkable, and if not so essential, in a subtype of forest site."*

The Finnish forest site type system is based on the assumption that the presence of different plant species is determined by the ecology of the habitat. The forest habitat is constant, but the vegetation can change for instance due to forest fire, or by cuttings. The primary vegetation can to some extent vary but in the succession the *primary habitat factors* determine the final structure of vegetation. These factors do not change. The secondary factors are the state of tree stand, tree species, amount of light etc., and they can affect the vegetation, but they do not change the site itself. The habitat characterized by certain vegetation reflects also the potential productivity of the site. In practice the identification of a forest site type is easier in mature forest, where the effect of secondary factors is most stable.

Thus, all those plant communities, which reflect the same productivity and which are in or are developing to a more or less stable state, so called "*normal stage*" can be counted in the same forest site type

The forest site types were in the beginning described in southern Finland, but soon it became evident that the forest vegetation and the productivity of forests is different in northern Finland. So the Finnish forest site systems became also a geobotanical system. The work of Kujala (1936) was the start of the regionalization of the system. The son of A.K. Cajander, Aarno Kalela (1961) finally developed the regionality of forest vegetation zones, developed further by Ahti et al. (1968) and Hämet-Ahti 1988 (Fig. 1.). The presently accepted regional forest site types were published by Kalliola (1973) (Table 1.). The other line of Cajander's site type system, mire sites, were not considered to be regional, although some regional characters can be found also on site type level. Instead, mire massifs (complexes) were the basis of the regional approach (Ruuhijärvi 1960, Eurola 1962)

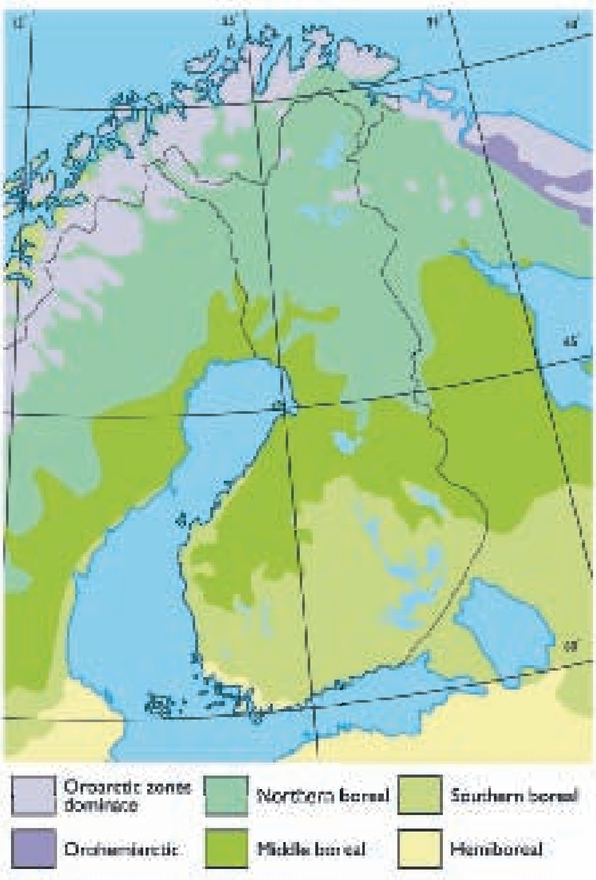

Fig. 1. Forest vegetation zones in Finland and adjacent areas (modified from Hämet-Ahti 1988).

Table 1. The basic series of forest site types in different vegetation zones (Modified after Kalliola 1973).

Zone	**Hemiboreal and Southern boreal**	**Middle boreal**	**Northern boreal Southern subzone**	**Northern boreal Middle subzone**	**Northern boreal Subalpine subzone**
Forest site type group					
Poor dry	Cladina type ClT	Cladina type ClT	Cladina type ClT	Cladina type ClT	Subalpine Empetrum Lichenes type sELiT
Dry	Calluna type CT	Empetrum-Calluna type ECT	Vaccinium myrtillus-Calluna-Cladina type MCClT	Vaccinium uliginosum-V. vitis-idaea-Empetrum type UVET	Subalpine Empetrum-Lichenes-Pleurozium type sELiPlT
Semi dry	Vaccinium vitis-idaea type VT	Empetrum-Vaccinium vitis-idaea type EVT	Empetrum-Vaccinium myrtillus type EMT	Vaccinium uliginosum-Empetrum-V. myrtillus type UEMT	Subalpine Empetrum-Vaccinium myrtillus type sEMT
Mesic	Vaccinium myrtillus type MT	Vaccinium vitis-idaea-V. myrtillus type VMT	Hylocomium-Vaccinium myrtillus type HMT	Ledum-Vaccinium myrtillus type LMT	Not typified
Semi herb rich	Oxalis-Vaccinium myrtillus type OMT	Geranium sylvaticum-Oxalis-Vaccinium myrtillus type GOMT	Geranium sylvaticum-Vaccinium myrtillus type GMT	Not typified	Not typified
Herb rich	Oxalis-Maianthemum type OMaT and others	Geranium sylvaticum-Oxalis-Maianthemum type GOMaT and others	Geranium sylvaticum-Dryopteris type GDT and others	Not typified	Not typified

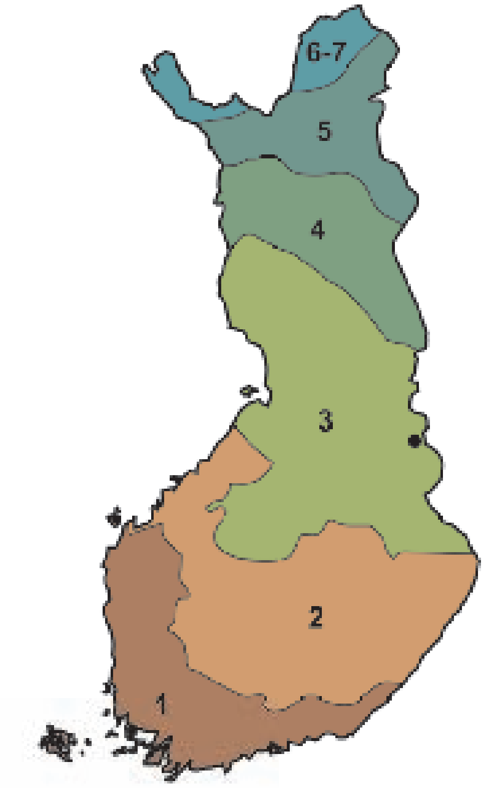

Fig. 2. The zonation of mire massifs in Finland (Ruuhijärvi 1988). 1. Concentric and plateau bogs, 2. Eccentric bogs, 3. Sedge aapamires, 4. Flark aapamires, 5. Pounikko aapamires, 6-7. Palsamires and orohemiarctic mires.

Mire zones

Mire massif types have basically been defined by Cajander (1913), and the system was developed further by Aario (1932), Paasio (1933), Ruuhijärvi (1960) and Eurola (1962). When good aerial photographs became available, covering the whole country in the late 1970s, the zonation was re-evaluated (Ruuhijärvi 1983, 1988) (Fig. 2).

Bog massifs

Bog massifs are divided into three main climatic zones. In addition, there are also azonal bog massifs, which occur over the whole country in suitable places, *Sphagnum fuscum* bogs and Pine forest bogs. In the southern coast, close the Baltic Sea, where the climate is relatively humid, especially in the autumn, bog vegetation is formed on rocky outcrops. In bedrock depressions there are numerous small bogs and pine mires and in open cliffs there are typically *Sphagnum capillifolium* pillows. Sometimes also *S. compactum* forms pillows of a few square metres on rock cliffs. Similar vegetation can be found also in some hill regions, which have a humid local climate. These mires cannot really be called mire massifs, but they are independent entities, which cannot be included in any mire massif type.

The central parts of *Sphagnum fuscum* bogs are open *Sphagnum fuscum* bogs or *S. fuscum* pine bogs. There may be small hollows dominated by *S. balticum, S. rubellum* or *S. angustifolium*. Regular pattern of hummock ridges and hollows is lacking. There is no morphological margin slope, but the zone can be seen in vegetation as a belt of dwarf shrub pine bog or *Eriophorum vaginatum* pine bog. Usually the lagg is not well developed.

Pine forest bogs are relatively small and characterized by hummock or lawn level vegetation, and a rather dense tree layer, consisting of *Pinus sylvestris*. The trees are typically 4-6 metres high, 1-2 m taller than in other bog types. The central part is dwarf shrub pine bog or *Eriophorum vaginatum* pine bog, and in the first case marginal belt cannot be separated from the centre. The lagg is lacking or is unclear.

Especially in the southwestern coast pine forest bogs are sometimes clearly raised bogs, but further north and east their surface is even. They are most common in Lake Finland, but do not cover wide areas anywhere. In the east they are characterized by the abundance of *Chamaedaphne calyculata*, in the north *Betula nana* and in the west *Ledum palustre*.

Plateau bogs

Plateau bogs are typical in southwestern Finland. The weakly developed low hummock ridges and hollows are not clearly oriented in the plain centre of the massif. There is no concentric structure. In the largest plateau bogs there are bog pools. In the margins of the central plateau there is more clear orientation of the hummock ridges and hollows. The marginal slope is steep, and it can be divided into two parts: in the upper part the vegetation is *Calluna – Sphagnum fuscum* pine bog, and in the lower part dwarf shrub pine bog. In the lagg there are wet sedge fens and spruce fens. The hollow vegetation is dominated by *Sphagnum cuspidatum, S. magellanicum, S. tenellum, S. rubellum* and *S. balticum*. On the hummocks *Calluna – Sphagnum fuscum* pine bog is typical. Hepatics are often abundant on hummocks and especially in *Sphagnum tenellum* patches. Small plateau bogs are heath-like in their centres. Hollows are very small, and hummock surface dominates.

Concentric bogs

Concentric bogs are concave mire massifs, developed on plain or very gently sloping terrain. Their hummock ridges and hollows form circles around the highest point of the mire. The length of hummock ridges can be hundreds of metres and height up to one metre. In the most even parts of concentric bogs the hollows are wide, but in more sloping parts the hollows are narrow and elongated along contours. Typical mosses in hollows are *Sphagnum cuspidatum, S. majus, S. balticum, S. tenellum, S. rubellum* and *S. magellanicum*. In the hollows, *Rhynchospora alba* is common along with *Scheuchzeria palustris* and *Carex limosa*. Bog pools are common, and especially in the northern part of the concentric bog zone they are abundant and large, up to 200 metres long. The marginal slope consists of dwarf shrub pine bog. Minerotrophic lagg is usually clearly formed, but in some cases it can be lacking.

The zone of concentric bogs can be divided into two parts: 1) Southern Finland and 2) North Satakunta and Southern Ostrobothnia. In southern Finland the centres of concentric bogs rise up to 5 metres above the margins, in the north clearly less. For example the centre of the large concentric bog in the eastern part of Kauhaneva mire rises only some 30 cm above the margins (Heikkilä & al. 2001). In the north the hummock ridges are high, hollows wide and often mud-bottom hollows, obviously due to strong ground frost influence. In the south the hollows and bog pools are small, the diameter typically not more than 50 metres. The marginal slope is steep and easy to distinguish in southern Finland, but in the northern part of the zone it can often be noticed only on the basis of the vegetation. Reindeer lichens (*Cladina* spp.) are very common and abundant in the hummock ridges of northern concentric bogs. In the south they grow only in small patches.

Eccentric bogs

Eccentric bogs are gently sloping bogs, which follow the forms of mineral soil. Their centres do not rise above the margins. Hummock ridges and hollows are perpendicular to the slope of the mire. There is no morphological marginal slope, but typically there is a belt of non-patterned *Sphagnum fuscum* pine bogs or dwarf shrub pine bogs in the marginal parts of the bogs. The lagg is dry, formed of pine mires and spruce mires in the upper margins of the bogs, or completely lacking. In the lower margins there is a wet lagg with sedge fens. In the central parts, the hollows are more dry than in concentric bogs. On the hummock ridges, *Empetrum – Sphagnum fuscum* pine bog dominates. In eastern Finland *Chamaedaphne calyculata* is the dominant dwarf shrub. In hollows, *Sphagnum balticum* dominates together with *Eriophorum vaginatum* and *Scheuchzeria palustris*. Mud bottom hollows and bog pools are common only in the bog parts of aapamire systems.

Aapamires

Aapamires (Cajander 1913) are mire massifs which are minerotropic in the central parts, and mainly have a thick peat layer. The water in aapamires is rainwater flowing to the mire from the surrounding mineral soil areas. Aapamires can preserve their minerotropic state despite peat accumulation, because abundant snowmelt waters wash humic acids from the mires in springtime (see Tahvanainen 2005). Quickly rising spring flood flows into watercourses through mires, and partly remains in mires. When the water table sinks in the summertime due to evapotranspiration, the mire surface consolidates and follows the water table preserving moisture, which hinders the growth of hummock sphagna. In the mire massifs there are also ombrotrophic parts, which do not receive flood waters (Laitinen & al. 2005, 2006).

The surface of aapamires is even or gently sloping. In the open parts of mires wet flarks and strings representing hummock or lawn level form a structure where strings are perpendicular to water flow. In the southern parts of aapamire zone the whole minerotrophic mire can be unpatterned lawn or carpet level fen. In the north the flarks are partly open water pools (Fig. 3.). There is ground frost in peat in wintertime, but it melts in the summer. It has a strong influence on the structure of strings and flarks (Seppälä & Koutaniemi 1986). The structures are more pronounced in the north where the winter is long and ground frost penetrates deep in the peat. In central Finland the winter is shorter and snow layer often more thick, which isolates the peat from cold air, preventing a deep ground frost to form.

In addition to the central parts also marginal parts characterized by pine mires and often ombrotrophic pine bogs. In the margins to mineral soil and along streams there are often also forest mires. Between the margins and open central part there is typically a zone of site types, which are mosaics of fen surfaces and pine mires or forest mires on hummocks.

Percolation mires are defines to be mires, where the water supply is based on the constant flow of water. In Finland that is normally connected with glaciofluvial formations. The structure and vegetation of percolation mires are different from that of true aapamires. It seems that there are percolation mires in the aapa mire zone, and also in southern Finland. Most of the southern aapamires exist due to the percolation.

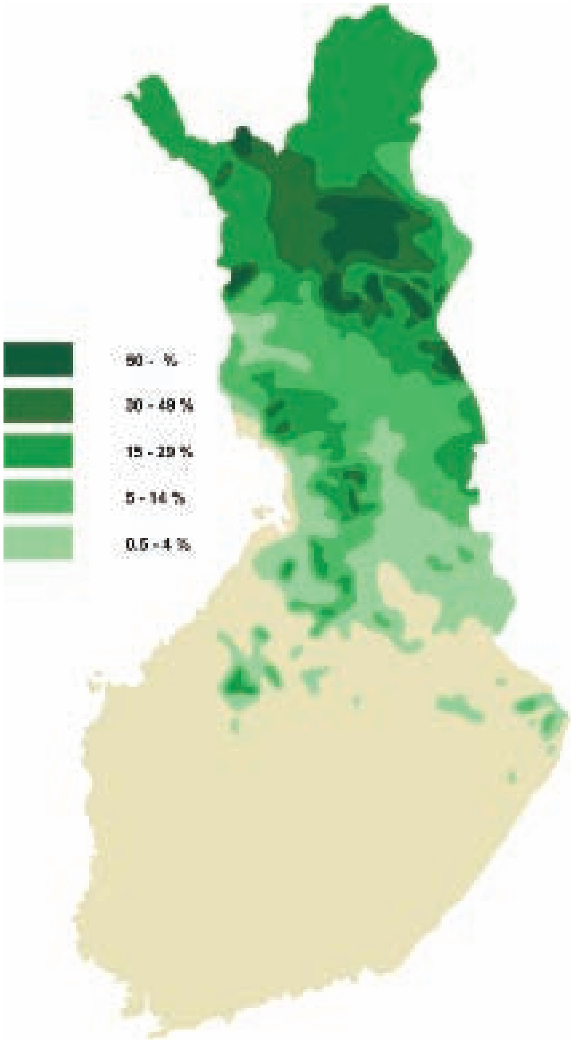

Fig. 3. The proportion of patterned fens of the mire area in Finland. Redrawn after an unpublished map compiled by Rauno Ruuhijärvi and Väinö Hosiaisluoma.

Sedge aapamires

In middle boreal sedge aapamires relatively dry minerotrophic lawn surfaces dominate, especially in the southern part of the zone. Typically the strings are very low or they are lacking. In largest mires and especially in Northern Ostrobothnia there are wide flark fens with clear string pattern. Typical for the vegetation is the abundance of short-sedge *Sphagnum papillosum* fens.

Flark aapamires

The southern part of the northern boreal aapamires are the most typical aapamires with wet flark fens and a regular string-flark pattern. Typical mire site types are intermediate *Warnstorfia* fens and flark fens, *Revolvens* flark fens, *Scorpidium* flark fens and wet rich birch fens.

In northern aapamires the strings are high and the flarks very wet, often open water pools. Ristivuoma mire in Ylitornio, western Lapland. Photo Pekka Salminen.

Northern aapamires or pounikko aapamires

It is characteristic for the northernmost northern boreal aapamires in Forest Lapland that the flarks are large and wet, and the strings form a net-like pattern, which is not uniform. In small mires lawn level dominates. Northernmost aapamires are more poor than the more southern aapamires in average. Typically the strings are wide, and dominated by *Sphagnum fuscum* and dense stands of *Ledum palustre* and *Betula nana*. In the margins of mires there are also *Sphagnum fuscum* bogs with pounu hummocks formed by ground frost, which does not melt completely during every summer. The reason for the abundance of *Sphagnum fuscum* is less abundant spring flood and more strong ground frost activity than further to the south. Typical species are e.g. *Sphagnum lindbergii, Eriophorum russeolum, Carex rotundata* and *C. aquatilis*.

Sloping fens

Sloping fens occur typically as parts of aapamire massifs, and sometimes as independent entities in hill and fell areas, where local climate is moist and cool, and precipitation is abundant. The peat layer of sloping fens in thin, usually not more than 1 metre. The more steep is the slope, the more thin the peat layer. Typically sloping fens are narrow strips in slopes, and below the slope they join in the valley aapamires. Sloping fens are most common in Kainuu and Kuusamo areas and some hilly parts of Lapland.

Ground water influence and margin effect in general is more common than in other aapamires. Sloping fens are commonly intermediate or rich fens. Flarks are abundant, if the drainage basin of the mire is large and the slope is not very steep.

During dry periods in the summer sloping fens often dry out, and the peat is usually well humified.

The vegetation of sloping fens is highly variable, depending on the gradient, peat thickness, width of the mire strips, the quality of bedrock and soil as well as variation in ground water and surface water influence. Lawn-level fens with a highly variable water table are common. They are typically *Sphagnum papillosum* fens or *S. compactum* fens, dominated by *Molinia caerulea*, or lawn level rich fens and intermediate fens. Mosaics of fens and pine mire or spruce mire hummocks are common.

Orohemiarctic mires

The concept orohemiarctic mires covers all mires above the forest limit in fells. They are characterized by a thin peat layer, constant influence of groundwater and meltwaters, lawn and flark level vegetation and trophic status from poor to rich fens. The differentiation from forest zone mires is gradual, and especially in the lower parts of treeless zone there are often also bogs and fens typical of forest zone. Pounu hummocks are common in mire margins.

Several plants species demanding spring influence are typical for orohemiarctic mires: *Angelica archangelica, Carex atrofusca, C. parallela, C. saxatilis, Juncus biglumis, Pinguicula alpina, Ranunculus hyperboreus, Salix reticulata, Saxifraga aizoides, S. stellaris, Oncophorus* spp. and *Pohlia wahlenbergii*. These species occur also in springs and rich fens in the northern boreal zone. Also many fell species grow in paljakka mires: *Salix lanata, Arctostaphylos alpina, Carex bigelowii, C. lachenalii* and *Pedicularis lapponica*. In the landscape of orohemiarctic mires, *Betula nana, Eriophorum angustifolium, Trichophorum cespitosum, Carex aquatilis, C. lasiocarpa, C. rostrata* and *Salix phylicifolia* are characteristic and common

Palsamires

Palsamires are a hemiarctic mire massif type (Seppälä 2006). Palsas are formed in a continental climate with cold winters and mean annual temperature ≤ -1° and short growing season. Precipitation is low and due to strong winds the snow cover is unevenly distributed. Palsamires are named after the giant hummocks, palsas, with a permafrost core. Another typical microform for palsamires are pounu hummocks in thin-peated marginal parts of mires. Pounus are hummocks formed by ground frost, which does not melt completely during every summer. Their surface is covered by thickets of *Betula nana* and *Ledum palustre*. The vegetation resembles that of pine bogs in the south. Due to the long-lasting ground frost they are treeless. During cold summers ground frost does not melt in pounus.

The characteristic uniform structure of strings and flarks, typical for main aapamires is lacing in palsa mires. Instead, there is a network of strings, which are not uniform. Snow melt and flood waters flow over the mires through soaks or in the form of streams.

The plant communities of palsamires in general resemble those of northern aapamires. On palsas there are palsa bogs and in pounikkos Sphagnum fuscum bogs or dwarf shrub bogs. Spruce mires are lacking, but along streams and rivers there are forest mires growing willows and birches. Their vegetation varies from sedge fen forest mires to herb-grass forest mires and rich forest fens. In some areas willow swamps are wide. In open mires, poor, intermediate and rich fens dominate. Typical mosses are e.g. *Sphagnum lindbergii, Warnstorfia* spp. and *Scorpidium scorpioides*. In the field layer, *Carex aquatilis, C. rostrata* and *C. rotundata* are most common.

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Mire ecohydrology in Finland

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Introduction

A mire ecosystem is a product of its water sources. Water is needed already in the initiation of paludification. Hydrology becomes increasingly important in the course of mire development, when accumulated organic matter gradually cuts off the connection of plant roots to the underlying mineral soil, and the mire starts to control its own hydrology.

However, the properties of the mire catchment are the foundation of mire ecohydrology. The physical, climate-driven hydrology of Finnish mires is discussed in this volume by Solantie and hydrology in general by Kuusisto. The role of bedrock properties for the vegetation is discussed by Husa & Kontula. Some specific features affecting mire ecohydrology are brought up here again.

Hydrogeological properties of Finnish catchments

One of the hydrologically important aspects of bedrock properties is the fact that it is practically impermeable to water. This impermeable bedrock is overlain by a sedimentary cover of 7 m average thickness, but only about 3-4 m median thickness. Both the thickness and the properties of the deposits overlying the bedrock have profound impacts on the hydrological behaviour of catchments.

Of the mineral deposits, till soils are dominant, especially basal tills. These are compact and dense, with a high proportion of fine matter, and, therefore, poorly permeable. Due to various processes, the permeability is highest close to soil surface and it rapidly diminishes deeper in the solum (e.g. Lundin 1982). Therefore, the water table level of till soils is not very deep down and follows the landforms. In the spring, when the snow melts, or during other wet periods, the water table rises close to the soil surface creating surface layer runoff. Rock outcrops, being most common in the southernmost and northernmost parts of Finland, advance surface runoff further. The water permeability of clay soils is scarce, too, and these soils are often paludified. Today clay soils, covering about 10 % of the land area, are mainly in agricultural use. Anyhow, poorly permeable soils, including peat soils, dominate in Finland. Peat soils (peat depth over 30 cm) cover 22 % of the land area of Finland (Hökkä & al. 2002).

Snow melting flood in the river Kyrönjoki, western Finland, in spring 1984. During snow melt period the water table may rise up to 6,5 metres above the mean level in the rivers flowing in the clay plain. Photo Raimo Heikkilä.

In late spring and in early summer evaporation is much greater than precipitation. Water levels in the soils are rapidly declining to poorly permeable layers and runoff diminishes to low values. Fluctuations in runoff and river discharges in basins poor in lakes are, therefore, typically very large in Finnish conditions (cf. Kuusisto, this volume).

Glaciofluvial and ice marginal formations, as well as littoral deposits, are mainly sorted coarse material and have therefore high permeability. Littoral deposits are shallow formations, but eskers and ice marginal formations are often thick, and have a totally different hydrology from e.g. till deposits. Practically all the precipitation infiltrates, and steady groundwater outflow from springs or larger seepage areas is the main form of runoff. These formations with high permeability cover 8,1 % of the area of Finland. They are scattered all over the country, and, therefore, have great local influence, but do not affect the discharges of larger river basins so clearly.

Ablation tills are somewhat more sorted and less compact soils than basal tills and have an intermediate hydrology between these and coarse sorted deposits. Ablation tills are less abundant than eskers.

Water regimes

When the runoff regimes in the south, in bog Finland and in the north, in the zone of aapa-mires are compared, the differences are logical, but not very big, if mean values are compared. Precipitation is, on an average, greater in the south, which compensates for the higher evaporation rates. Thus, variations in mean annual runoff are relatively small in different parts of the country. In 90 % of the catchments studied by Hyvärinen & al. (1995) the range was approximately from 240 to 400 mm/a. The studied catchments cover most of the land area in Finland. In Sweden and in Norway, for example, the total variation range is about 5 times larger (Henriksen & al. 1998). Annual runoff is slightly less in bog Finland than in the zone of aapa mires.

To a great extent the small range in annual runoff is due to the fact that Finland is a relatively flat country. The orographic effect increases precipitation from October to April by 86 mm/100 m (Hyvärinen & al. 1995). Altitude decreases the temperature sum of the growing season by 80 day-degrees/100m. The greatest part of southern Finland is less than 200 m a.s.l, and altitude, on average, increases rather slowly towards north and east. Increase in humidity and runoff with altitude can be seen in mire ecosystems, e.g in the occurrence of sloping mires in the relatively high altitude hill slopes of eastern Finland. Southern aapa mires are also rather common in the upland area Suomenselkä extending to the south to about 62 °N with altitudes locally around 200 m a.s.l. Examples are some mires of Seitseminen, Lauhanvuori, and the extensive mire Kauhaneva with large aapa mire parts together with raised bogs (Heikkilä R. & al. 2001).

In bog Finland, the maximum water equivalent of snow cover is about 100 - 140 mm on the average, in aapa mire Finland typically 140 - 200 mm. As a consequence, a considerable part of annual runoff takes place in spring; in southern Finland around 50 % or slightly less, in the north usually more. The snow melting period varies in the south. Especially on the southern coast, in the zone of plateau bogs, wintertime runoff peaks are common, but on the average, there is a runoff peak in early April, which is more than one month earlier than in the northern part of sedge aapa zone near the Arctic Circle. As a rough approximation, the spring maximum runoff takes place on an average in April in bog Finland, in the aapa region in May, and in the zone of pounikko aapas and palsa mires as late as in early June.

Mean maximum runoff is larger in the north than in the south. In the north, snow melts more rapidly than in the south, and in mild winters spring peaks may be minute in the south. However, in the spring maximum with a return period of 10 years, the differences are not so large (Seuna 1983). Furthermore, large runoff peaks may occur in the south also in autumns, in the wintertime, or al-most in any time of the year.

For these and various other reasons, the differences in runoff regimes are not easily demonstrated. The monthly mean values in small basins clearly show that April is the month of greatest runoff in the south, May in the north (Fig 1). Relative differences are large also in wintertime, but otherwise the regimes look rather similar.

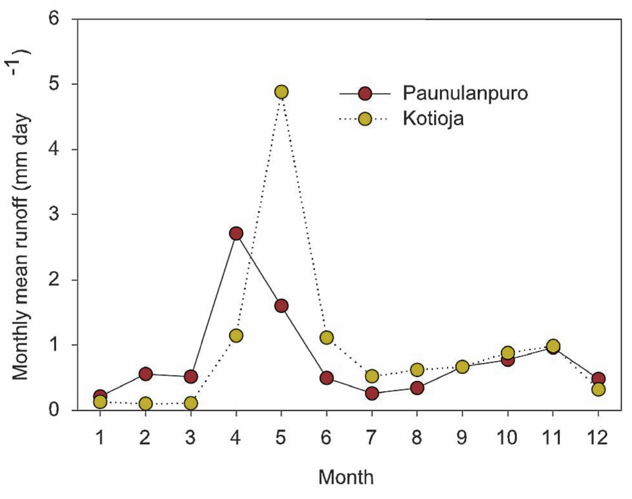

Fig. 1. Monthly mean values of runoff in two areas belonging to the network of small basins (Seuna 1983); Paunulanpuro in Orivesi, near Lakkasuo (Laine & al. 2004), situated in the mire zone characterized by eccentric bogs and *Sphagnum fuscum* bogs, and Kotioja, Ranua, in the northern part of southern aapa mires (sedge aapas, Pohjanmaa type). Paunulanpuro is characterized by spruce forests growing on till soils, Kotioja by aapa mires, partly forestry drained, surrounded by pine growing hills.

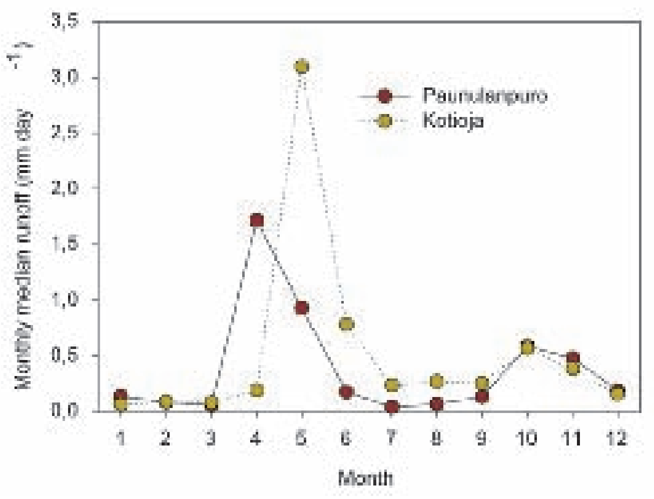

Fig. 2. Monthly median values of runoff in two small basins (See Fig 1.).

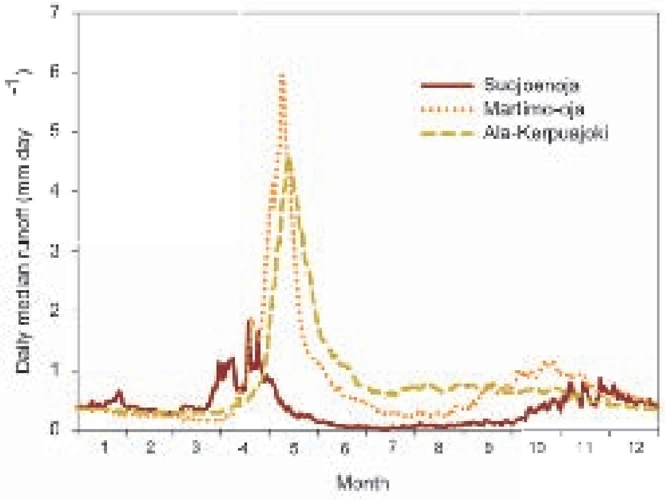

Fig. 3. Daily median values of runoff (modelled values, Finnish Environment Institute) in three river catchments, poor in agricultural land and lakes, 40 – 130 km^2 in area. Suojoenoja (31.008) in Mynämäki, in the border of the zones of plateau bogs and concentric bogs; Martimo-oja (64.015), draining Martimoaapa in Simo, the zone of sedge aapa mires, and Ala-Kerpuajoki (65.535) in Kittilä, Lapland, the zone of flark aapa mires, Peräpohjola type.

In the monthly medians, the earlier and slightly smaller spring runoff in the south can be seen equally as in the mean values, but the drier summers of bog Finland show much more clearly (Fig 2). The relative differences are actually very big.

In the daily medians of somewhat larger basins, the unpredictability of runoff peaks in southern Finland is obvious, as well as the substantial increase in runoff during the growing season towards the north (Fig. 3). In the mires of southern Finland, runoff ceases in most years completely, in northern Finland watersheds supply the mires with a constant through-flow .

The different hydrological conditions are shown in the properties of mire vegetation as well, as discussed by e.g. Ruuhijärvi & Lindholm (this volume), Lindholm & Heikkilä (this volume) and Solantie (this volume). The relatively dry summers of southern Finland facilitate the takeover of bog vegetation in paludified areas, and the cool climate, a short growing season and the supply of water through the growing season both from the watershed and from surplus of precipitation over evaporation, favour fen vegetation, as demonstrated by Solantie (this volume). The role of spring floods is also of utmost importance.

Water chemistry

Regional data bases

In addition to water availability and water flows, mire ecosystems are affected by the quality of waters. No large scale inventories are available concerning the quality of water in Finnish mires. Mires are, however, rather evenly spread elements of the Finnish landscape. In Finnish conditions mires are usually a lower topographic unit, when e.g. in Scotland mires concentrate on uplands, often on water divides (Bragg 2001). Since mires have been formed in water discharge areas in a basin scale, the majority of water in our watercourses is "mire water", or at least this was the case before large scale mire drainage. Therefore, lake water and brook water inventories give indications of the distribution of water chemistry in mires as well.

Two systematic extensive lake water inventories have been conducted in Finland, in the autumn of 1987 and 1995, when 1172 and 873 lakes, respectively, were sampled throughout the country (Kämäri & al. 1991, Henriksen & al. 1997, 1998, Mannio & al. 2000). The 1995 inventory covered 3 % of lakes greater than 4 ha, but the first inventory also included smaller lakes. In late summer 1990 a total number of 1165 brook water samples were collected, the watersheds covered evenly 10 % of the land area of Finland (Lahermo & al. 1995).

Following the long traditions of small basin research in Finland (Seuna 1983), there are also many studies dealing with the role of catchment characteristics on water quality. There are studies both dealing with anthropogenic impacts on water quality (e.g. Kortelainen & Saukkonen 1998) and studies working in a pristine landscape (Mattsson & al. 2003, Finér & al. 2004, Kortelainen & al. 2006). In these studies sampling usually omits the growing season, because of low discharge and the emphasis on water quality effects in the watercourses. Yet, these studies give useful information about mire waters, too. These studies include water quality data from scientifically very important sites as well: for example, Kauhaneva, studied among others by Heikkilä R. & al. (2001), and Joutensuo, made well known by Tahvanainen (2005) (cf. Table 1 & 2).

Table 1 . Medians of the main water quality variables in some Finnish mire catchments. Lakkasuo 7, an ombrotrophic catchment (Sallantaus & Kaipainen 1996a); Kauhaneva draining south (Kruunuoja), poor aapa fens and raised bogs (Heikkilä R. & al. 2001, Kortelainen & al. 2006); Joutensuo, poor fens and open bogs (Tahvanainen & al. 2002, Mattsson & al. 2003); Lakkasuo 2, mainly tall sedge fens and herb rich fens, marginal spruce mires (Laine & al. 2004), some road salt influence; Runkaus, Kuivasoja, draining herb rich aapa mires, e.g. Ahma-aapa (Mattsson & al. 2003, Finér & al. 2004), strict Nature reserve in Simo.

Catchment	pH	Alkalinity mmol/l	TOC mg/l	Total P µg/l	Total N µg/l
Lakkasuo 7	3,9	-0,161	34	6	400
Kauhaneva	4,5	-0,03	21	13	380
Joutensuo	5,0	0,03	12	13	270
Lakkasuo 2	5,5	0,03	13	6	260
Runkaus	6,7	0,33	10	8	410

Table 2. Some median metal concentrations in the catchments of Table 1. There is some road salt influence in Lakkasuo 2 (about 5 mg/l chloride; less than 1 mg/l in those areas, which do not receive road salt).

Catchment	Ca mg/l	Mg mg/l	K mg/l	Na mg/l	Fe µg/l	Al µg/l	Sulphate mg/l
Lakkasuo 7	0,2	0,1	0,1	0,4	119	36	0,6
Kauhaneva	0,5	0,2	0,2	0,7	880	-	0,8
Joutensuo	1,6	0,4	0,2	1,1	540	63	0,9
Lakkasuo 2	2,2	0,7	0,4	2,2	425	28	2,4
Runkaus	3,8	1,4	0,2	1,1	2600	38	0,6

General chemical properties of waters

Alkalinity is a good indicator of weathering in the soil. The distribution of alkalinity in the 1995 lake inventory reflects the acidic bedrock of Finland consisting mainly of Precambrian granites and metamorphic rocks, and postglacial soils (Fig. 4). Truly calcareous lakes are very rare, and in 90 % of lakes alkalinity is less than 0,28 meq/l, while the median is 0,11 meq/l (Mannio & al. 2000). The median for pH is 6,6, for the sum of base cations Ca, Mg, K, and Na 0,24 meq/l and 90 % of the lakes sampled had a base cation sum less than 0,49 meq/l. Of the anions, sulphate has a median of 0,06 meq/, chloride 0,04 meq/l and the median of organic anions probably slightly exceeds that of sulphate (TOC-median 8 mg/l), leaving nearly 0,1 meq/l for bicarbonate. The median of conductivity is 3,0 mS/m.

The 1987 inventory gave lower values for alkalinity: median 0,08 meq/l, explained by a wet year and consequent higher TOC (median 12 mg/l), organic anion (median 0,09 meq/l), sulphate (median 0,05 mq/l) and lower pH (median 6,3) (Kämäri & al. 1991).

The lake data give some indications of the chemistry of mires, but there are some obvious differences. First of all, only very few ombrotrophic lakes are included in the inventory data sets, while about 26 % of Finnish mires are ombrotrophic based on National Forest Inventories (Hökkä & al. 2002). In the truly ombrotrophic part of Lakkasuo in southern Finland (Laine & al. 2004), the annual flow-weighted mean for base cations in runoff is 0,04 meq/l (Sallantaus & Kaipainen 1996a). Only 2 % of the lakes fall into this category.

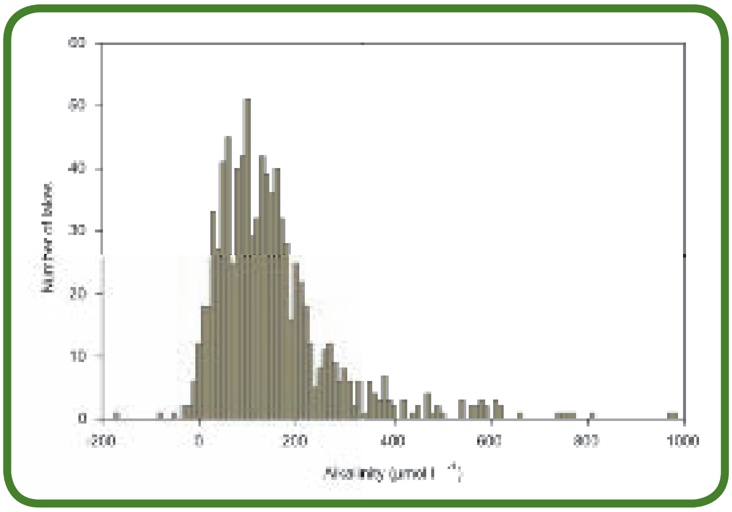

Fig. 4. Distribution of alkalinity in the 1995 lake survey (Henriksen & al. 1997, 1998, Mannio & al. 2000).

pH distribution and factors affecting it

The lack of ombrotrophy in Finnish lakes is equally obvious from pH values (Fig. 5). In ombrotrophic mires pH values around 4 are typical. These are nearly missing in the lake data set from 1995. In a lake basin, mixing is efficient and a lake water chemistry reflects the mean value of all water sources, both from the drainage basin and from precipitation, and, depending on the residence time, may reflect also longer term hydrological conditions. A mire basin, however is effectively stratified both horizontally and vertically and can therefore both create and retain diversity in water chemistry.

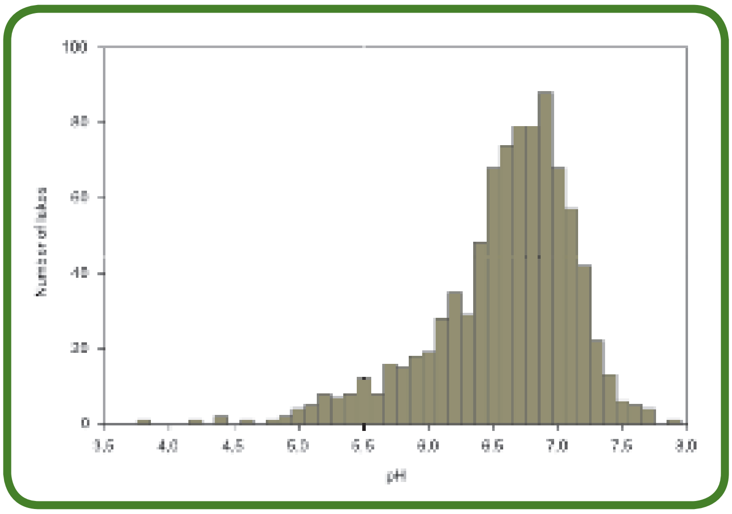

Fig. 5. Distribution of pH in the 1995 lake survey (See Fig 4).

Looking at the pH value distribution and comparing it to the alkalinity values (Figs 4 and 5), it is also obvious that lake water pH values are higher than typically met in mire waters, not only in the low pH range, but in the whole range. Sjörs & Gunnarsson (2002) compiled pH data from Swedish mire studies and the upper mode in the bimodal pH distribution was more than half a pH unit lower than the mode of 1995 lake data set, although mire studies have concentrated on rich fens. More importantly, median pH values for intermediate fens and even moderately rich fens, around 6,1 and 6,5, are both lower than the median in the lake data set, 6,6. Already intermediate fens in Finnish classification belong to the richest site type class of National Forest Inventories (Hökkä & al. 2002), based on indicator plants like *Sphagnum warnstorfii, S. teres, Scorpidium revolvens, Paludella squarrosa, Carex flava, Pinguicula vulgaris* etc. In the most recent inventory, less than 2 % of the mire area, natural or drained, belonged to this richest class (Hökkä & al. 2002). Clearly, pH in lake water reflects something else from what it shows in mire water, if two thirds of Finnish lakes have pH values comparable with the richest two percent of mires.

The reasons for higher pH values in lakes, compared with mires, are several, but the main reason is the loss of excess carbon dioxide, typical of soil waters, to the atmosphere; this increases pH values considerably, as discussed by e.g. Tahvanainen & Tuomaala (2003). Additionally, there is a loss of organic matter due to flocculation and sedimentation, biological oxidation and chemical oxidation aided by light and catalysts, e.g. iron (Miles & Brezonik 1981). In fact, the percentage of lakes in the catchment is a very good predictor of organic carbon concentrations both in lakes and in river basins (Rantakari & al. 2004, Mattsson & al. 2005), and the presence of lakes, even in a very low percentage, noticeably reduces organic carbon concentrations in the outflow.

The medians of alkalinity in 1987 and 1995, 0,08 and 0,11 meq/l respectively, or the sum of base cations, 0,24 meq/l in both cases, fall in poor mesotrophy (Table 1), if the traditional Finnish mire terminology was used (see Ruuhijärvi & Lindholm, this volume). The mire statistics suggest a clearly less fertile picture for typical mires. In the last national forest inventory, the peatland fertility classes representing ombrotrophy accounted 26 % of all mires (natural or drained) and the poorest oligotrophic class, representing mires characterized by “short sedges”, or *Vaccinium vitis-idea*, 29 %, i.e. 55 % altogether (Hökkä & al. 2002). According to my experience, these mires should have negative or negligible alkalinities, and yet show clearly different chemistry from truly ombrotrophic mires (c.f. Table 1). Mires in the upper end of oligotrophy, representing tall-sedge or *Vaccinium myrtillus* –fertility class have already usually slightly positive alkalinities, approaching the above mentioned medians.

The percentage of mires belonging to upper oligotrophy class is 28, which means that 83 % of Finnish mire area is oligotrophic or ombrotrophic, and have alkalinities below 0,1 mmol/l, approximately. Of the lake area, a much higher percentage has alkalinities exceeding this value. Reasons are partly the same as was the case with pH values, i.e. loss of organic carbon. Secondly, also hydrology of the mires has influence on the results. The most fertile mires are small, often influenced by groundwaters, they receive water from a large area, or the fertile parts of a mire are those of preferential flow paths. Vice versa, the poorest mires are fed by small catchments relative to the mire area. Thirdly, some waters entering watercourses bypass mires completely. Lake waters and mire waters reflect their watersheds in a clearly different manner.

Gradients of water chemistry in time and space

The brook data set gives a still more base-rich picture of Finnish waters than either of the lake data sets. The median of alkalinity in the brook data set is 0,2 meq/l and the sum of base cations 0,45 meq/l (Lahermo & al. 1995), nearly twice the values in 1995 lake data set and 3 times the 1987 data set median alkalinity. The sampling period, August, explains a great deal of these higher values; in many years, August is the month of a very low runoff rate. During low flows, water levels in till soils or peat soils are deep down in poorly permeable layers and hardly any runoff is formed. The origins of runoff are mainly in deep groundwaters, e.g. in eskers, but there is a deep groundwater component in till soils as well. Due to poor permeability, these waters have long residence times and are therefore rich in weathering products. The median alkalinity of 54 groundwater monitoring stations in Finland is 0,22 mmol/l, mean 0,32 mmol/l, and groundwaters in till soils have higher alkalinities than waters in coarse sorted deposits (Soveri & Ahlberg 1990).

Groundwaters enter brook channels through discharge areas that are very limited in area during low flow periods. These sites receiving constant supply of water include e.g. spring mires and seepage mires. Low flow period water chemistry may reflect mire vegetation in these areas, but does not tell much of the average in catchment.

The interpretation of water quality results from catchment outflow is often very problematic. The low flow component is often enriched in minerals (Fig. 6, Fig.7), but yet the values during peak flows are very dilute. In the spring when the snow melts, nearly all the catchments' surface area is hydrologically active, affecting runoff water quality, and therefore may reflect the average in the catchment, but ecologically these diluted waters may be of limited value. In the tables 1 and 2, medians have been chosen to represent "typical" situation, but clearly different approaches are needed in vegetation analyses, and a suitable sampling period may vary depending on the target. (c.f. Tahvanainen & Tuomaala 2003, Tahvanainen & al. 2003).

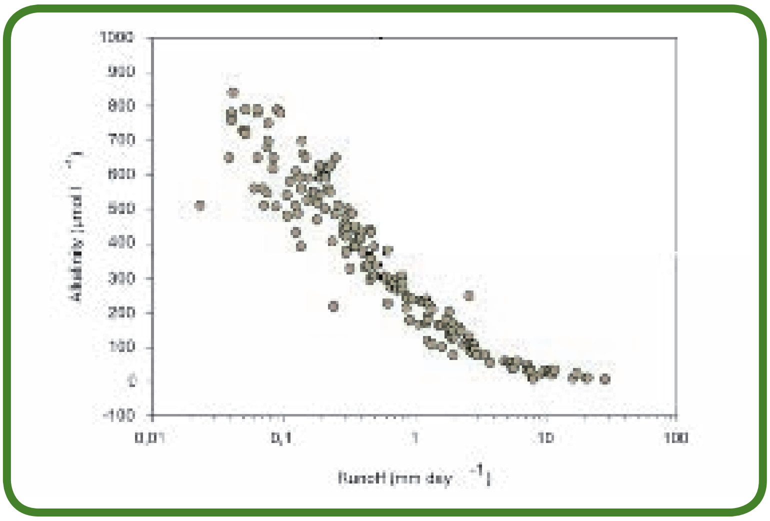

Fig. 6. The dependence of alkalinity on the runoff of the sampling period, Kotioja, Simo (See Fig. 1).

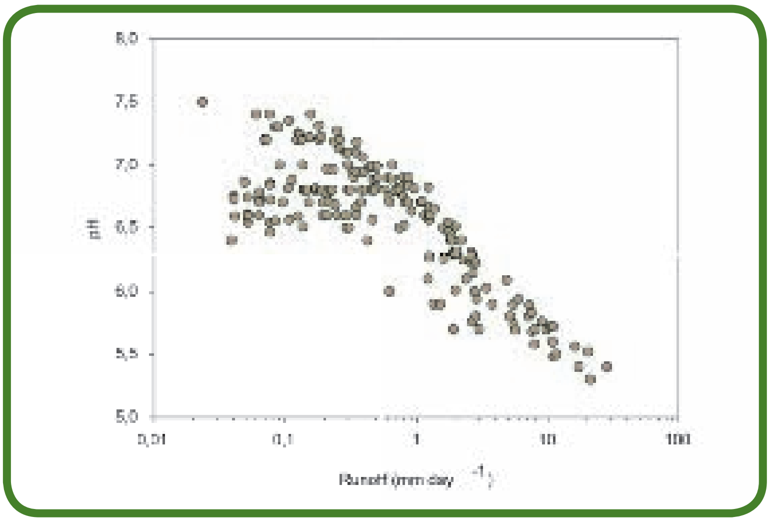

Fig. 7. The dependence of pH on the runoff of the sampling period, Kotioja, Simo (see Fig. 1).

The gradients of water chemistry from south to north or from west to east are not very clear. In lowland areas of the southern and western coasts, the anthropogenic influence is very strong and agricultural lands are abundant, and they show e.g. in the high conductivity values as well as in phosphorus and nitrogen concentrations. The "Daughter of the Baltic" effect increases the sulphate and chloride values as well. The lowlands of the strongly paludified Ostrobothnia have also waters rich in dissolved organic matter. But excluding these effects, the differences due to geochemical factors are not very strong. Median alkalinities do not differ essentially in different parts of the country (Mannio & al. 2000), but local variations are large due to bedrock and consequent soil properties (Lahermo & al. 1995). In the base cation concentrations there is a weak decreasing trend from south to north (Mannio & al. 2000, Kämäri & al. 1991, reflecting more the temperature dependence of weathering than properties of the soil. Also organic matter values are higher in the south than in the north (Kortelainen & Saukkonen 1998, Rantakari & al. 2004, Mattsson & al. 2005).

In this context it should be emphasized that there are not very big differences in the distributions of mire fertility classes between southern Finland and northern Finland either, based on the data of National Forest Inventories (Hökkä & al. 2002), although northern Finland belongs to the aapa mire zone and most of southern Finland is in the zone of raised bogs. The proportion of ombrotrophic mires (natural and drained together) in southern Finland is 29 %, and in northern Finland 24 %. Since mires are more abundant in northern Finland, ombrotrophic mires are more common in the aapa zone than in the bog zone. The richest mires are more common in the north, but otherwise the differences in the percent distribution based on fertility classes are minor between south and north. Of the minerotrophic mires, open fens are, and have been, however, very characteristic in the aapa mire zone, and spruce mires in a major part of the bog zone (Ilvessalo 1957).

Mire processes affecting water quality

A mire is a product of its water sources. Mires also change the chemistry of waters they receive, and these changes are relevant to vegetation differences e.g. in the mire margin – mire expanse gradient. The profound knowledge of the role of hydrochemistry to mire vegetation and mire ecosystems as a whole would be of great value not only scientifically, but it would be needed e.g. in mire conservation and restoration.

It has been observed in many studies that mire water pH alone explains a lot of the variation of vegetation (e.g. Tahvanainen 2005), in spite of the huge potential errors in relevant and comparable pH determination (Shotyk 1988, Tahvanainen & Tuomaala 2003). High pH means automatically that there are also inorganic nutrients from the lithosphere available, and indirectly from atmospheric sources, too, through nitrogen fixation (Waughman & Bellamy 1980). Alkalinity would theoretically be a much better explanatory variable than pH, although it is seldom used.

Alkalinity, as well as pH, is affected by all the transformations of discharged species in the waters, and, therefore, relevant process oriented studies are tedious and difficult to quantify. Of the incoming waters, precipitation water quantity and quality can be easily measured. Measuring exact outputs may cause problems, because natural ombrotrophic catchments with exact boundaries are hard to find. Measuring minerogenic inputs to mires is nearly always problematic.

Mires in general, as peat accumulating ecosystems, are sinks of inorganic elements. Mires filter inorganics and these accumulate as peat ash. There are, however, large fluctuations in the accumulation process depending on the season and on hydrological conditions. At the same time when there is a net retention of inorganics in the long term, mires release large amounts of dissolved organic matter to runoff waters. Some attempts to measure all the inputs and outputs of organic and inorganic constituents and to relate these to the amounts found in peat, have been made in Lakkasuo (c.f. Laine & al. 2004), southern Finland.

In ombrotrophic conditions, there are three major processes affecting pH and alkalinity. Lakkasuo receives large amounts of protons in deposition: 23 meq/m^{2}a (Sallantaus & Kaipainen 1996a). This acidity is more or less compensated by the transformation of sulphate into organic form due to anaerobic conditions in peat (22 meq/m^{2}a). Base cations from precipitation are retained in the peat: 50 % of Ca and 37 % of Mg, very little of Na as well as K, on annual basis. In the growing season, K is effectively taken up by the vegetation, but released in fall and in spring. Base cation retention produces very little protons, mere 4 meq/m^{2}a, because the incoming concentrations in ombrotrophic conditions are so small. The leaching of protons, 25 meq/m^{2}a, is mainly due to the leaching and deprotonation of organic acids. Leaching rate of TOC in the study period was 7 g/m^{2}a.

The same processes operate in the minerotrophic catchments as well. Absolute retention of sulphate is larger than in ombrotrophy, since also inputs are larger, due to inputs from the watershed (Sallantaus & Kaipainen 1996b). Fen peats contain higher concentrations of base cations than ombrotrophic peats, but due to the lower accumulation rates of peat, annual retention is not much higher in the fen catchment of Lakkasuo. Production of organic acids is larger than in the bog, in spite of the much lower concentrations (Table 1); the low concentrations are explained by the large diluting inputs of groundwater from the watershed. These incoming waters also bring alkalinity to the fen, and a moderate pH can be attained, although it decreases while the waters flow through the mire. Dilution mainly by precipitation, and the released organic acids are the main causes for the lowered pH, in the same way as e.g. in Härkösuo mire in Kuhmo, eastern Finland (Tahvanainen & al. 2002).

Organic acids are partly rather strong acids, producing protons and reducing alkalinity, but a part of them are also just moderate acids, reducing pH values but not affecting alkalinity. The classical study of Oliver & al. (1983) gave a rule of thumb: there are 10 µmol of acidic groups per 1 mg of dissolved organic carbon. Another rule of thumb could be that half of these are strong acids in the sense that they are dissociated at the 0-point of alkalinity. It can be demonstrated that in normal Gran alkalinity titration (e.g. titration down to 4,5 and 4,2) this zero reference level corresponds to organic acid dissociation degree at pH 4,8.

The release of organic carbon to runoff waters is the main contribution provided by mires, when the pH gradient is considered. Average leaching rate in Finland is about 6 g/m^{2}a (Kortelainen & al. 2006) and mean concentrations in runoff in the order of 20 mg/l. Concentrations of organic carbon in mire waters up to about 40 mg/l are not uncommon during the growing season. With the rules of thumb above, this kind of a concentration would consume 0,2 meq/l alkalinity; a substantial amount, when compared with e.g. the median of the sum of base cations in the lake data set from 1995, 0,24 meq/l (Mannio & al. 2000). In addition, in the positive alkalinity range, from approximately pH 4,8 to neutrality and above, there are still another 0,2 meq/l of organic acids, in our hypothetical 40 mg/l organic carbon case, consuming bicarbonate, lowering the pH, compared with DOC free water having equal alkalinity. Clearly, pH, a master explanatory variable of mire vegetation, is also strongly modified by mire vegetation, or rather by its decay by-products.

However, peatlands are not the only source of organic carbon to Finnish watercourses. Actually the dependence of TOC concentration or leaching is rather poorly explained by peatland percentage (Kortelainen & Saukkonen 1998, Mattsson & al. 2003), and surprisingly, the proportion of the watershed growing spruce was a good predictor in a subgroup of the studied basins. Poorly permeable moist podsolized till soils, providing surface layer runoff occasionally, growing spruce stands, export large amounts of organic matter as well. Runoff from e.g. eskers or other permeable soils, on the other hand, has negligible organic carbon concentrations (Laine & al. 2004).

There are large differences in the organic carbon concentrations in different kinds of mires as well. Reasons may be in physical hydrology alone, size of the watershed compared with the size of the mire, soil permeability, in vegetation type (*Sphagnum* growing mires versus *Bryidae* dominated mires with different decay products), or in the inorganic chemistry of mire waters (affecting the release of organic matter, causing flocculation or affecting the decay rates)

As a secondary product from primary production by plants, DOC is also dependent on productivity. In stagnant conditions, accumulation will result in higher concentrations than in moving waters. On the other hand, the accumulative property of DOC results in spatial gradients in sloping mires; the longer residence time of water, the more DOC. The decay rate is regulated by e.g. temperature, N:C ratio of substrate and by the fluctuation of water table. Thus, there are gradients in DOC across climatic, hydrological and vegetation gradients. Taking into account the dependence of DOC on the production-decomposition balance, as well as the importance of DOC to carbon balance and acidity, the organic chemistry of mire water should be a major topic e.g. for studies concerning responses of northern mires to the climate change.

Iron is released into soluble forms in anaerobic conditions. These conditions are created by mires, and groundwaters in peat rich areas are often rich in iron. Iron is a typical feature in aapa mire landscape, and precipites are commonly seen in the flarks (Ruuhijärvi 1960, Virtanen 1994). Iron chemistry is complicated: divalent iron is a cation, affecting alkalinity and pH. Oxidation of iron produces acidity and vice versa, both divalent and trivalent iron form complexes with solid and dissolved organic matter, affecting acid-base balances. Iron rich mires have several, characteristic, perhaps exotic plants like *Hamatocaulis lapponicus, H. vernicosus* and *Saxifraga hirculus*.

In some cases, mire waters may become crystal clear due to co-precipitation of DOC with iron. In some aapa mires, Leväsuo, in Olvassuo Natura 2000 area as an example, concentrations of organic carbon in the waters are surprisingly low, jus a few mg/l (Heikkilä H. & al. 2001), in spite of a large mire area with regular *Sphagnum* patches. The exact controls are not known. The role of iron, as a precipitating agent, or perhaps as a catalyst in the decay process, as in lakes (Miles & Brezonik 1981), should be paid attention to.

Concluding remarks

There is a long tradition of hydrological research in Finland, and in small experimental basins in particular (Seuna 1983), but the network of small basins lacks basins properly representing natural mires, and real process oriented mire hydrology research has been rare in Finland. One of the notable exceptions is the study by Virta (1966). Some early research was also conducted in connection with drainage experiments (Mustonen & Seuna 1971). Nisula & Kuittinen (1988) studied an aapa mire and the behaviour of snow melt waters. Solantie (this volume and references therein) has done pioneer theoretical work, but he never went to the field, at least not to the mires.

Research on water chemistry of mires has long traditions as well. Kivinen (1935) was one of the pioneers. Otherwise the early studies in mire water chemistry have concentrated on the impacts of utilization on water quality (Sallantaus 1988). Lakkasuo in southern Finland has been an important site since about 1991, when it was chosen to be one of the main study sites of the mire projects in the Finnish Research Programme on Climate Change (Laine & al. 2004). In the studies of Tahvanainen (2005) botany and hydrology were equal tools and these works advanced our ecohydrological understanding greatly.

Yet, there are many questions remaining open. Perhaps there is some truth in the statement of Hugh Ingram (1983), when he described gaps in our knowledge of mire hydrology. He wrote that "One must temper criticism with admiration. No one with experience of field work in mire hydrology can fail to appreciate the very great effort required to obtain any worthwhile results in an environment accessible only with difficulty, remote from power supplies and laboratory facilities, and rendered hostile by its exposure, its humidity, its insect fauna and its rough, wet and unstable ground surface".

Hamatocaulis vernicosus is a rare species of aapamires. It has a peculiar ecology, on the other hand it grows in rich birch fens and on the other hand in spring-fed mires.
Photo Teemu Tahvanainen.

One of the specialities of Finnish mire nature are the aapa mires, and studying them is our national responsibility, especially from the hydrological point of view. A lot of mire hydrological understanding comes from studies in bogs (Ingram 1983), but these can be applied for aapa mires only with difficulty; there are large differences e.g in the water conductivities of bog peats and sedge peats, especially when considering more decomposed peat (Korpijaakko 1988). Hydrological thinking is essential for mire ecologists, and there is also recent evidence that hydrology has not been forgotten, (e.g. Laitinen & al. 2005), but yet, hydrology should better serve botany than the other way round.

In northern conditions, even poor waters may grow rich vegetation (Sjörs 1950, Tahvanainen 2005). Spring floods cause a great dilution to the already poor waters, but may otherwise favour fen vegetation on the expense of bog vegetation. Seasonal changes in water chemistry are great not only in basin outflow (Fig. 6), but in the mire sites as well (Tahvanainen & al. 2003). Water movement is characteristic for aapa mires also during the growing season while in the bogs of southern Finland, stagnant periods may be long. Southern mires with aapa characters in vegetation are usually formed under the influence of ground waters from e.g. eskers. Lakkasuo is one example of this (Laine & al. 2004).

Hydrochemical diversity is the cause of plant diversity as well. In a minerotrophic mire, there are many water sources, and the vegetational gradients in the mires are determined in the mixing processes. The understanding of these issues has become increasingly important with large-scale mire restoration projects in our nature reserves. Unfortunately, very few such studies exist that could help us to reconstruct mires properly. The dangers of loosing hydrochemical diversity are not the first concerns that a restoration plan brings up, and analyzing water samples not the first tools in the planning stage, although this should be the case in problematic situations (Sallantaus 2006). Moreover, there may be some changes in water chemistry after restoration as well (Fenner & al. 2001).

Huge amounts of water chemical data have been collected from brooks draining catchments with mires or from lakes surrounded by mires. Also physical hydrology is studied by large networks. For a mire ecologist, these studies are difficult to apply. With a few exceptions, ecohydrology has been a neglected field in Finnish mire science. Yet, hydrology is the backbone of mire ecology, and much effort is still needed.

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Ecological gradients as the basis of Finnish mire site type system

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The development of Finnish mire classification

The botanical mire science is in Finland more than a hundred years old. The mire site classification was developed in the beginning of 1900s by A. K. Cajander (1906, 1910, 1911a,b, 1913, 1916). That was developed together with forest site type system (Cajander 1909). At that time, there was a need to know more about the ecology of mires for the utilization of them for agriculture and forestry. In this task, a special terminology was needed and the rich and specific terms in dialects of Finnish language was noted to be good for this purpose. The lack of corresponding terms and thinking in other languages causes difficulties in describing the variety of Finnish mires in other languages.

Cajander´s mire site types have been defined to be vegetation types characterized by similar vegetation and ecological conditions¸ (i.e. the mire site types are ecosystem types in more modern terminology; e.g. Odum 1971). Before Cajander, his professor and teacher J. P. Norrlin had in his lectures and publications (Norrlin 1870, 1871) described the four main groups of mire sites. Also the raised bog monograph by C. A. Weber (1902) was familiar to Cajander. Cajander´s personal concept of mires developed during his large expeditions in different parts of Finland, Russian Karelia and Archangel region and in Siberia. His main work of mires "Studien über die Moore Finnlands" (1913) contains a description of 75 mire site types and in a later important work "Metsänhoidon perusteet I" (The elements of silviculture, part I) (1916) the number of mire site types is 87. Later, two main groups of mires, (i.e. flooded swamps and spring mires) have been added (e.g. Eurola & al. 1994) in the system, beside the original four main groups (i. e. pine mires (including bogs) – Reisermoore - rämeet, forest (=spruce) mires –Bruchmoore - korvet, fens – Weissmoore - nevat and rich fens – Braunmoore - letot).

The system is flexible. For different purposes they can be defined in a wider or a more narrow way. The development of the Finnish mire site type classification system can be seen in different mire site guides which have been published during the last 70 years for the purposes of different inventories of agriculture, peatland forestry and biodiversity (e.g. Lukkala & Kotilainen 1945, 1951, Kivinen 1948, Heikurainen & Huikari 1960, Eurola & Kaakinen 1978, Eurola & Holappa 1985, Eurola & al. 1994, Laine & Vasander 1990, 2005). The Finnish mire site type system has also been presented in international textbooks (Ruuhijärvi 1983 and Eurola & al. 1984.)

Rubus chamaemorus spruce mires are common in the margins of mires. The peat layer may be shallow or up to 2 metres thick, and *Sphagnum girgensohnii* dominates in the ground layer. Photo Raimo Heikkilä.

The Finnish mire site classification system has not been much studied from the point of theoretical vegetation science. The almost forgotten classic of that approach is the academic dissertation of Risto Tuomikoski (1942), in which he, using forest mire (Bruchmoore) vegetation as an example, studied the character of mire margin vegetation and its systematics. Tuomikoski´s main arguments were multidimensional coordinates of forested mire vegetation and he emphasized the serial order of different plant species and species groups, which is studied by positive and negative correlations.

For Tuomikoski, classification is always based on an agreement, and needed only for the terminology and communication. By this argumentation Tuomikoski was very modern and ahead of his time. Tuomikoski linked the Finnish Cajanderian school of mire and forest site classification by its theoretical base closer to the Central-European school of vegetation science than to the Swedish Uppsala school, which was rather dominating in the beginning of the 1900´s in Nordic countries. Hugo Sjörs (1948) developed the system of Tuomikoski (1942) further, and instead of putting the lower units of vegetation into a hierarchical system, he arranged them according to "directions of variation". As suggested by Tuomikoski (1942: 74), such a coordinate system can be changed into a conventional hierarchy by using the different gradients one by one.

The most comprehensive mire vegetation datasets have been published in the regional studies of Finnish mires by Ruuhijärvi (1960) and Eurola (1962). In Finland there are also large unpublished mire vegetation datasets, which have been collected by botanists as parts of inventories for peatland agriculture and National survey of forests. The modern vegetation science of mires in Finland was started by Pekka Pakarinen (1976, 1979, 1982, 1985, Pakarinen & Ruuhijärvi 1978). At present the use of different ordination and clustering methods is usual and almost a standard (e.g. Heikkilä 1987). It is important to note that these approaches have not changed the basic character and classification of the mire site system. The idea of multidimensional continuum system has even become clearer in modern thinking.

The difficulty to create uniform international mire classification is not only because of the different scientific schools, but also the differences of mires in different areas, and the different way to separate mires from other ecosystems like forests. Also the difficulty to translate the national concepts and terms is great. So the best common understanding of mire vegetation and classification is reached by the understanding the ecological continuums in mires.

Different gradients as the basis of mire site type description

Ombrotrophy – minerotrophy

The division of mires to those fed only by precipitation and those with precipitation and waters from mineral soil became a main concepts of general mire ecology after the studies of Sjörs (1948) and Du Rietz (1954). In Finnish mire science these concepts were adopted by Ruuhijärvi (1960) and Eurola (1962); they used this main division both in mire site and in hydrotopographical mire classification (Fig.1). Plants are the most reliable way to measure this bog – fen gradient. In the climate of Finland, this measurement is rather easy and the progressive development of mires even makes that more clear. We would lose a lot of regional information of mires, if we would abandon these concepts like Wheeler & Proctor (2000) have proposed. Ombro- and minerotrophy cannot be separated solely by chemical characteristics (Sjörs & Gunnarsson 2002, Tahvanainen 2005).

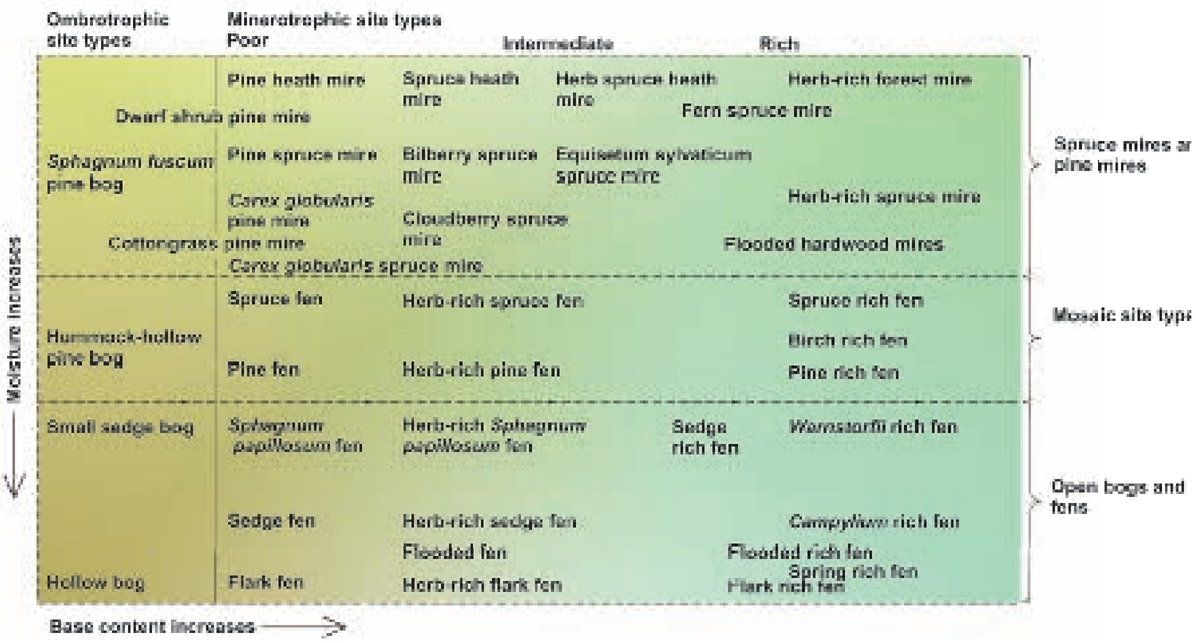

Fig. 1. Finnish main mire site types along the moisture and base content gradients. Note that the site type names are different from Eurola & Huttunen in this volume.

Poor - rich gradient

The differentiation between bog (ombrotrophic) and fen (minerotrophic=geotrophic) vegetation is a major limit. The bog vegetation only receives atmospheric (=ombrogenous) water, but fens, in addition, receive water from the mineral soil. The fens are further separated in poor, intermediate and rich (sometimes separated in moderately rich and extremely rich) fens. In Finnish mire literature concepts of oligotrophy, mesotrophy and eutrophy are traditionally generally used instead the concepts poor, intermediate and rich, even though the oligotrophy-eutrophy gradient is often also used for productivity; i.e. mainly reflecting the content of N and P (and perhaps K). The best explainer of the gradient is pH, the strongest of the chemical parameters in mire water (Tahvanainen 2005). In rich mires also carbonate ions have a great role. Most of the poor fen vegetation can be found in the central parts of mires, and rich fens can be found mostly on the margins of the mires.

Rich pine fen in Oulanka national park in Kuusamo, eastern Finland. The vegetation is a mosaic of rich fen surfaces and *Sphagnum fuscum* hummocks. *Eriophorum latifolium* is a visible indicator of the site type. Photo Raimo Heikkilä

Mire margin - mire expanse gradient

Mire margin

Mire margin vegetation is, additional to mire species, characterized by species of forests, shores and springs. The special conditions they need are a result of thin peat, flow of spring waters or abundance flooding waters. The species diversity is at the highest in mire margin vegetation. The largest species group is joint species with mineral soil forests. It contains about 250 species, i.e. about 60 per cent of all mire species. Also the good growth of tree stand is typical of this communities when compared with other mire vegetation. In Finland, these mire margin types, characterized by the effect of mineral soil, are called to korpi (in German: Bruchmoor; Heikurainen 1953, Ruuhijärvi 1960).

The abundance of common species with forests indicated that mires and forests belong to the same boreal vegetation system. Thus their regionality can be jointly studied in boreal forests – mire biome.

Ground water effect creates springs in the mires and at the same time gives a niche to meso-eutrophic spring vegetation and flora. Springs are also cool, and in winter frostless habitats, giving a niche for frost sensitive plant species. The surface water effect creates the flooded habitat vegetation (in German: Sumpfigkeit). It is strongest on the sides of streams and lakes, which are flooded regularly. Weakest the flood influence is in fens in the central parts of aapamires, where flood comes from the melting water in mires and its surroundings. That has been also called as melt water influence (Eurola & al. 1994). In fell areas and arctic areas, the water of mires is mostly frost and snowmelt water. Flood, and more commonly melt water, is an important source of minerotrophy; keeping aapamires in a minerotrophic state. The water from outside the mire is most often less acidic, and preserves and dilutes the effect of humus acids, and so prevents the mires to develop to ombrotrophic bogs(Tahvanainen & al. 2003).

Mire expanse

The central part of the mires is living with the nutrients fed by precipitation and in fens additional minerals and nutrients from the mineral soil. The mire expanse influence is identified by the presence of real mire plants and by the lack of the species indicating mire margin influence. All ombrotrophic vegetation is mire expanse vegetation, and also the treeless open fens and thick peated minerotrophic pine mires.

Hummock – mud bottom gradient

The surface of mires consists of several microtopographical features, from dry hummocks to vegetationless mud bottoms and water pools. The differences in different mire water table are most clear in the mire expanse vegetation of bogs. The gradual moisture gradient is commonly divided on the basis of plant species to hummocks, lawns, moss carpets and mud bottoms. Many mire site types have several of these features. Site types are most often named after the prevailing level of features.

Other variation of mires

Hydrotopography

Mires can also be classified after the hydrology, topography (morphology) or combinations of hydrology and topography (hydrotopography). In raised bogs these approaches has been a tradition already for a long time (e.g. Weber 1902, Osvald 1923, Aario 1932). In the case of aapamires this approach has been less used, and it has not been equally logical, although the division into ombrotrophic, mire margin and sloping fen part is easy to make, using aerial photographs (Ruuhijärvi 1960, Havas 1961). Recently Laitinen & al (2005) have made an analysis on the structure of a of case aapamire complex, about the peripheral and central parts in relation to hydrological flows of surface and soil waters. They showed that doing this, it is easier to explain the location of mire site types and surface topography and also the effect of the ground soil

Regional variation

The hydrology and vegetation is also a result of climate, especially oceanity – continentality gradient is important. Although mires can develop ombrotrophic everywhere in boreal and temperate vegetation zones, minerothrophic mires have, however, their specific areas, where they are dominant among mires (Cajander 1913, Кац 1948, Ruuhijärvi 1960, Юрковская 1975, Yurkovskaya 1995, Boch & Masing 1983, Moen 1998)

Time

The spatial model of mire vegetation has also a fourth dimension; time. While peat deposits are getting thicker and the moisture and nutrient relations of sites change also. The application of the slow natural change to the model is difficult, but important in forecasting future, e.g. the effect of global warming. The drying of mires after drainage for forestry is quick and well documented. The succession stages of drainage areas: (drainage stage, transitional stage and peat heath stage) can be identified in the beginning to each mire site type and later in different nutrient level and mire margin influence level. These drainage succession habitats have been studied actively in peatland forestry (Paavilainen & Päivänen 1995). Drainage has resulted in a remarkable change in Finnish mire landscapes, because more than half of the mire area has been drained. The drainage has destroyed over 90 percent of their area in the case of many forested mire site types habitats. The hydrological effect of drainage reaches often outside the drainage area, causing slow succession.

Main elements of the mire vegetation system

The authors have studied and evaluated mires many decades. During that period we have summarized with our field experience and with collected data our concepts of the character of mire vegetation and mire classification. They are as following:

1. Mire vegetation forms a model of a multidimensional spatial system. It is possible also to determine it as a coordinate system or network, where the axes form the ecological gradients, including hydrology, topography, geographic regions and time.
2. Mire plants, and ecological groups of plants and plant communities are located in this model in serial order as a continuum, without boundaries and probably also without dense locations or nodes.
3. There is order in mire vegetation, but not organization, no hierarchical classes as it is in the systematics of plants and animals. Language needs an organization and names, to make it possible to understand each other.
4. Classes or mire site types are abstracts, averages and agreed. Multidimensionality makes the organization difficult, also different divisions are optional. Any of the divisions is necessarily not more correct than others. The question is how the spatial system and the time continuity has been divided to a specific need to use it.
5. It has been typical for the Finnish mire site classification system to use short site type names, but also to use with them names of plants, ecological adjectives and attributes containing description. This makes it possible to describe gradual natural variation and the relationships between site types. Site type name is a short description and definition of the vegetation.
6. Mires (as well as forests) can be seen as a network of nature, a network which is like a general law of nature. The same idea can be seen also inside living cells in network and interaction of proteins. Also the world wide web has a similar way to function.

Conclusions

The Finnish mire site classification is an ecological classification system, which covers all the botanical diversity of mire vegetation. The classification system is natural and thus it is flexible and adaptive fitting to the demands of modern mire science.

The mire classification system is a spatial organisation, and it describes the order of nature using plants and plant groups representing different ecological gradients. In this coordinate system or network, the structure of the plant community and the ecology of the site have a direct relationship. To classify the variation of mire vegetation to mire site types is to split the gradual continuity technically to wider or to more strict units: main site types and sub site types. The modern approaches of vegetation science have not caused a need to change the basic structure of the Finnish mire site classification system. The position of individual mire sites in modern studies has been clarified.

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Mire plant species and their ecology in Finland

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Traditionally four main mire type groups are distinguished in Finland: spruce mires (*korpi* in Finnish), pine bogs (*räme*), poor fens and hollow bogs (*neva*) and rich fens (*letto*) (Cajander 1913). Compared to the ecology of the mire plants it is too few, and later their number was added to six (Eurola & Kaakinen 1978, 1979): swamps (*luhta*) and groundwater influenced vegetation (*lähde* & *lähdesuo*). In addition to these, a seventh group, transitional to mire, littoral or aquatic and heath vegetation, aro wetlands, has been distinguished (Laitinen & al. 2005). It has a habitat and species combination of its own, but very few species, e.g. *Juncus supinus*, new for mire vegetation. The plants of aro wetlands tolerate seasonal drought (Table 1).

Explanations for the concepts: Base status indicates the availability of nutrients for plants. This in turn depends greatly on the acidity affected by carbonate content but also wetness of the habitat. Plants growing in **ombrotrophic** (extremely poor) habitats tolerate conditions where the pH value of the mire water may be < 4, conductivity (mS/m) < 10, and calcium content < 2 mg/l (Tolonen & Hosiaisluoma 1978; Ca content < 1 mg/l after Tahvanainen 2004). Their species are mostly indifferent, not habitat specialists. Species of the **oligotrophic** (poor) habitats are lacking in ombrotrophic sites but are indifferent in relation to more rich ones. Average water analysis values for the oligotrophic sites: pH value 4, conductivity 26, calcium < 4 mg/l, after Tahvanainen (2004) < 2 mg/l. When the analyses are made from dry peat, the differences of the ombro- and oligotrophic sites are not clear (Eurola & Holappa 1985), e.g. calcium content is almost the same, < 3 mg/l (DW). The corresponding values for the **mesotrophic** (intermediate base level) sites are: pH value about 5, conductivity < 40, calcium in dry peat < 5 mg/l, after the water analyses of Tahvanainen (2004) over 2 mg/l. The mesotrophic species do not grow in ombro- and oligotrophic sites, but of course in **eutrophic** sites, the analysis values of which are higher than before, e.g. according to the water analyses of Tahvanainen (2004) the pH value over 6 and Ca content over 5 mg/l. There are many eutrophic specialists. The classification is based on the exchange capacity of the species.

Cypripedium calceolus is a rare and threatened species, which grows in herb-rich forests and the marginal parts of rich fens in calcareous areas. Photo Raimo Heikkilä

The trophic scale is not in good correlation with the productivity determined by other ecological factors, e.g. oxic/anoxic conditions (acrotelm/catotelm), quantity and solubility of nitrogen and phosphorus. Generally the mesotrophic sites with their indifferent and oligotrophic species are the most productive ones.

In the **hydrotopographic groups** (Table 1) the water level is ± stable. The **hummock level** (dry level) plants grow on sites where the free water surface is usually in the depth of 20 cm or more. The pH value and nutrient status are lower than on wetter habitats beside. Dwarf shrubs, bushes and trees (mycorrhiza species) are common on these ± oxic sites. The **intermediate water level** (lawn, moist level) plants grow on sites where the water surface is in the depth of 5-20 cm. It is a favourite habitat for many *Sphagnum* species and short sedges (*Carex pauciflora*, *Eriophorum vaginatum* and *Trichophorum cespitosum*). **Flark level** (carpet and mud-bottom level) species demand or tolerate conditions where free water is almost on the site surface or above it. Anoxic conditions prevail in the root layer. The mud-bottom is a special habitat where the mire “eats itself” (corrosion by Sjörs 1990). Small hepatics (*Cladopodiella fluitans* and *Gymnocolea inflata*) and blue bacteria (Cyanobacteria) are found on its bare peat.

On sites of the unstable water level (**aro wetlands**) the moisture conditions may change from aquatic to seasonal drought. Only some mire species tolerate so heavy water fluctuation, and the peat accumulation is prevented. The phenomenon occurs on well-drained soil on sandy substratum or in small pond-like depressions (Laitinen & al.2005).

Table 1. Ecological indications of mire species of notable diagnostic significance. The original table is chiefly based on Eurola & Kaakinen (1978), see also Eurola & al. (1984). The concept is based on field observations and/or measurements.
Explanation for the columns (Note that the indicative value of several taxa may vary between bioclimatic regions.):
(a) Nomenclature follows Hämet-Ahti & al. (1998) for vascular plants, Ulvinen & al. (2002) for mosses and liverworts, and Vitikainen & al. (1997) for lichens. Asterisk denotes seasonal drought tolerance.
(b) Base status (columns 1-4). A cross in two columns indicates difficulties in assigning the plant to either; a cross in brackets denotes unclear status or a tendency in the direction mentioned.
Om: ombrotrophic, Mi: minerotrophic, Ol: oligotrophic, Me: mesotrophic, Eu: eutrophic.
Examples: to be truly an ombrotrophic species there must be cross-mark in Om and Ol –columns; crosses in Me and Eu –columns indicates upper mesotrophy, i.e. mesoeutrophy.
(c) Hydrotopographic level (columns 5-7).
Hu: hummock (dry) level; Int: Intermediate (moist) level; Fl: flark (wet) level.
Example: A cross in two columns indicates that the plant has a wide amplitude – or placed e.g. in Int and Fl columns indicates lower lawn, i.e. carpet level.
(d) Supplementary nutrient (mire margin) and inherent nutrient (self-sufficiency, mire expanse) effect (columns 8-13).
GW: Ground-water influence; SW: Surface-water (swamp) influence; SM: Spruce mire influence; HB: Hummock-level bog influence; Ne: *Neva* influence (poor fen / flark or intermediate-level bog influence); RF: Rich fen influence.
(e) The previously used six-fold division (column 14).
(f) Lä: species growing primarily on ground water effected types;
Lu: species growing primarily on surface water effected types;
K: species growing primarily on spruce mire types (*korpi* in Finnish);
R: species growing primarily on räme vegetation types;
N: species growing primarily on neva vegetation types;
L: species growing primarily on rich fens (*letto* in Finnish).
(f) Distribution (column 15)
Presence of the species in the climate-based mire regions 1-7. Mire zones of Finland after Ruuhijärvi (1988): 1) Plateau bogs, 2) concentric bogs, 3) eccentric and forested bogs, 4) southern aapa mires, 5) northern aapa mires, 6) Forest-Lapland aapa mires and 7) palsa mires. No mark: appearance in all zones; m: occurrence only on sea shores; brackets: rare in the zone.

	Base status				Level			Effect						Mire type group	Distribution
	Om		Mi					Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF		
TREES AND SHRUBS															
Alnus glutinosa			x	x	x	x		(x)	x	(x)				K Lu	1 - 4
A. incana			x	(x)	x	x		(x)	x	x				K Lu	
Betula nana	x	x			x	x					x	x		R N L K	
Betula pendula (B. verrucosa)			x		x					x				K	
B. pubescens	(x)	x	x		x	x			x	x				K N L R Lu	
Daphne mezerum				x	x	x		(x)		x				K	1 - 5
Fraxinus excelsior				x	x	x		x	x					K	1 - 2
Juniperus communis			x	x	x	x				x			x	K L	
Myrica gale			x		x	x			x					N K	1 - 3
Picea abies		(x)	x		x					x				K R	
Pinus sylvestris	x	x			x						x			R	
Populus tremula			x		x					x				K	
Prunus padus			x	x	x			x	x	x				K	
Rhamnus frangula (Frangula alnus)			x	x	x	x			x	x				K	1 - 5
Ribes nigrum			x	x	x	x			x	x				K	1 - 5
R. spicatum			x	x	x	x		(x)		x				K	
Rubus idaeus			x	x	x	x				x				K	
Salix aurita		x	x		x	x			x	x				K R	1 - 5
S. caprea			x		x					x				K	
S. cinerea			x		x	x			x					K	1 - 4
S. glauca			x			x		x	x					K Lu Lä	4 - 7
S. hastata			x			x		x	x					K Lu Lä	4 - 7

	Base status				Level			Effect						Mire type group	Distribution
	Om		Mi					Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF		
S. lanata			x			x		x	x					K Lu Lä	6 - 7
S. lapponum		(x)	x		x	x			x					K Lu	
S. myrsinifolia ssp. borealis			x	x	x	x		x	x					K	5 - 7
S. myrsinifolia ssp. myrsinifolia			x	x	x	x		x	x					K Lu	
S. myrsinites				x	x	x		x					x	K L	4 - 7
S. myrtilloides		x	x		x	x			x			x		N R K	
S. pentandra			x	x		x			x					K Lu	1 - 5
S. phylicifolia			x		x	x			x	(x)				K	
S. repens (incl. S. rosmarinifolia) *			x		x	x			x	x				K	1 - 4
Sorbus aucuparia			x	(x)	x					x				K	
Viburnum opulus			x	x	x	x			x	x				K	1 - 4
DWARF SHRUBS															
Andromeda polifolia	x	x			(x)	x					(x)	x		N K L	
Arctostaphylos alpinus (Arctous a.)	x	x			x						x			R	5 - 7
Calluna vulgaris	x	x			x						x			R	
Chamaedaphne calyculata	x	x			x	x					x	(x)		R N	2 - 5
Empetrum nigrum coll. (incl. E. hermaphroditum)	x	x			x						x			R K	
Ledum palustre (Rhododendron tomentosum)	x	x			x						x			R K	
Salix herbacea		x	x		x	x		x						R L	6 - 7
S. reticulata				x		x	x	x						Lä	5 - 7
Vaccinium microcarpum (Oxycoccus microcarpus)	x	x			x						x			R	
V. myrtillus	(x)	x	x		x					x	x			K R	
V. oxycoccos (Oxycoccus palustris)	x	x	x			x	x		(x)			x		N R L K	
V. uliginosum	x	x			x						x			R K L	
V. vitis-idaea	x	x			x						x			R K	
SEDGE PLANTS															
Carex acuta (C. gracilis)			x			x	x		x					N K Lu	1 - 5
C. acutiformis (C. paludosa)			x	x		x	x	x						K L Lä	2
C. appropinquata (C. paradoxa)				x	(x)	x		x						L Lä	1 - 5
C. aquatilis		x	x			x	x		x			x		N K L	
C. atherodes (C. aristata)			x	x		x		x	(x)					L K Lu	2 - 4
C. atrofusca (C. ustulata)				x		x		x	x					L	7
C. bigelowii (C. rigida)		x	x		x	x								R N	5 - 7
C. brunnescens (C. persoonii)			x		x	x				x				K	
C. buxbaumii ssp. b. (C. polygama ssp. subulosa)			x	x		x	x		x				(x)	L N	
C. buxbaumii ssp. mutica (C. adelostoma)			x	x		x	x	x	(x)					L Lä	4 - 7
C. canescens (C. cinerea, C. curta)		x	x			x	x	(x)	x					K N Lu	
C. capillaris				x		x		x					(x)	L K Lä	3 - 7
C. capitata (incl. C. arctogena)				x	(x)	x		x					(x)	L K	4 - 7
C. cespitosa			x	(x)		x	(x)	x	x					K N L	
C. chordorrhiza		x	x			(x)	x					x		N L K	
C. diandra (C. teretiuscula)			x	x		x	x	x	x				(x)	L N	
C. dioica			x	x	x	x						x	x	L N	

	Base status				Level			Effect						Mire type group	Distri-bution
	Om		Mi					Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF		
C. disperma (C. tenella)			x		x	x		x		(x)				K	
C. echinata (C. stellulata, C. muricata)			x			x	x	x						K M L	1 - 5
C. elata (C. stricta, C. hudsonii)			x	x			x			x				N K	1 - 4
C. elongata			x	x		x	x	(x)	x					K N Lu	1 - 4
C. flava				x		x	(x)	x					x	L K	
C. globularis		x	(x)		x					x				K R	
C. heleonastes			x	x		x	x	x	(x)				(x)	L N	2 - 7
C. lapponica (C. canescens ssp. lapponica)			x				x		x					N	2,4 - 7
C. lasiocarpa (C. filiformis) *		x	(x)			x	x		(x)			x		N L	
C. laxa			x	x		x	x					x	x	N L	3 - 7
C. lepidocarpa ssp. jemtlandica (C. jemtlandica)				x		x	x						x	L	(4 - 5)
C. limosa	x	x	(x)				x					x		N L	
C. livida			x	x			x					x	x	N L	
C. loliacea			x		x	x		x						K	
C. magellanica (C. irrigua, C. paupercula)		x	x			x	x		x			x		N L K R	
C. microglochin				x		x		x	x					L	5 - 7
C. nigra ssp. juncella (C. juncella) *		x	x			x	x		x					N K Lu	
C. nigra ssp. nigra *			x			x	(x)		x					N K	
C. norvegica ssp. inferalpina (C. angarae, C. media)			x	x		x		x		(x)				K	4 - 7
C. panicea				x		x	(x)						x	L	
C. paniculata				x			x	x						L	1 - 2
C. parallela (C. dioica ssp. parallela)			x	x		x		x						L	7
C. pauciflora		x			x	x					x	x		N R	
C. pseudocyperus			x	x		x	x		x					N K	1 - 3
C. rariflora	(x)	x	x				x					x		N L	5 - 7
C. rhynchophysa (C. laevirostris)			x	x		x	x	x	x					K	2 - 5(6)
C. riparia			x	x			x		x					K N	1 - 2
C. rostrata (C. inflata, C. ampullacea)		x	x			x	x		(x)			x		N L K	
C. rotundata		x	x				x					x		N	4 - 7
C. saxatilis (C. pulla)			x	x		x	x	x	x				(x)	L	7
C. tenuiflora			x			x	(x)		x					K	3 - 7
C. vaginata (C. sparsiflora)			x	x	x	x		x		x				K R L	
C. vesicaria			x				x		x					N K	
C. viridula var. bergrothii (C. bergrothii)				x		(x)	x						x	L	(1-8)
C. viridula var. viridula (C. serotina ssp. serotina)			x	x		x	x		x				(x)	N L	1 - 5
Eleocharis palustris (Scirpus palustris)			x				x		x					N	
E. quinqueflora (Scirpus pauciflorus)				x			x	(x)					x	L	
Eriophorum angustifolium (E. polystachyum)		x	x			(x)	x		(x)			x		N L Lu	
E. brachyantherum (E. opacum)				x		x		x						K L	4 - 7
E. gracile			x	(x)		x	x		x			(x)		N L	
E. latifolium				x		x		x					x	L	
E. russeolum	(x)	x	x				x					x		N	4 - 7
E. scheuchzeri		x	x			x	x	(x)	x					N	4 - 7

	Base status				Level			Effect						Mire type group	Distri-bution
	Om		Mi					Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF		
E. vaginatum	x	x			x	x					x	x		N R	
Rhynchospora alba	x	x	(x)				x					x		N	I - 4(5)
R. fusca *			x	(x)			x		x			(x)		N L	I - 4
Schoenoplectus lacustris (Scirpus l.)			x	x			x		x					Lu	I - 5
S. tabernaemontani (Scirpus t.)			x	x			x		x					Lu	m
Schoenus ferrugineus				x		x	x						x	L	(3,5
Scirpus sylvaticus			x	x		x	x	x	x					K Lu	I - 4(5)
Trichophorum alpinum (Scirpus hudsonianus)			x	x		x	x					x	x	N L	
T. cespitosum (Scirpus c., Baeothryon c.)	(x)	x	(x)			x						x	(x)	N L	
GRAMINEOUS PLANTS															
Agrostis canina *			x			x			x					N L K	I - 5
Anthoxanthum odoratum ssp. alpinum			x			x		x	x					N K L	
Calamagrostis canescens (C. lanceolata)			x			x	x		x					K	I- 5(-7)
C. epigejos			x	x		x		x						L	
C. purpurea (ssp. phragmitoides)		(x)	x			x			x					K	
C. stricta (C. neglecta)			x			x	x		x					N L	
Deschampsia cespitosa			x			x		x	x					K	
D. flexuosa (Avenella flexuosa)		(x)	x			x				x				K	
Elymus caninus (Agropyron c., Roegneria c.)			x	x	x	x				x				K	
Festuca ovina			x	x	x	(x)		(x)					x	L	
F. rubra			x	x		x			x				x	N L	
Glyceria fluitans			x				x		x					Lu	I - 4
G. lithuanica			x	x			x	x	(x)					K Lu	2 - 4
Hierochloë hirta			x	(x)		x			x					K N L	
Juncus biglumis				x			x	x						L Lä	5 - 7
J. filiformis *			x			x	x		x					N	
J. stygius			x	(x)			x					x	(x)	N L	
J. triglumis				x			x	x						L Lä	(4)5 - 7
Luzula pilosa			x		x					x				K	
L. sudetica			x	x		x		(x)	x					N L	2 - 7
Melica nutans			x	x	x	x				x				K	
Milium effusum			x	x	x			(x)		x				K	
Molinia caerulea *			x	(x)		x			(x)	(x)		x	x	N L K	
Nardus stricta			x	(x)		x		x						L N	
Phalaris arundinacea (Phalaroides a.)			x			x			x					K N	
Phragmites australis (P. communis)			x	x		x	x		x			(x)	x	Lu N L	
Poa alpigena (P. pratensis ssp. alpigena, P. rigens)			x	x		x		x						L Lä	
P. palustris			x			x			x					N	
P. remota			(x)	x		x		x						K	I - 4
P. trivialis			x	x		x	x	x						K L Lä	
HERBS															
Alisma plantago-aquatica			x				x		x					Lu	I - 4(5)
Angelica archangelica			x	(x)			x	x						Lä L K Lu	
A. sylvestris			x	x	x	x		(x)		x			(x)	K L Lä	I - 5

	Base status				Level			Effect						Mire type group	Distribution
	Om		Mi					Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF		
Athyrium filix-femina			x	(x)	(x)	x		x	(x)	(x)				K	
Bartsia alpina			(x)	x	x	x		x					x	L Lä	4 - 6
Calla palustris			x				x		x					Lu K	1 - 5
Caltha palustris			x			x	x	(x)	x					Lu K N	
Cardamine amara			x	x		x	x	x						Lu K	1 - 3
C. pratensis			x	x			x	x	x					Lu N L Lä	
Chrysosplenium alternifolium			(x)	x			x	x						Lä K	1 - 3(4)
C. tetrandum			x	(x)			(x)	x	(x)					Lä K	5 - 7
Cicerbita alpina (Lactuca a., Mulgedium a.)			x	(x)		x		x		(x)				K	4 - 7
Cicuta virosa			x	(x)		x	x		x					Lu N L	1 - 5
Circaea alpina			x	x			x	x						K	1 - 5
Cirsium helenioides (C. heterophyllum)			x	x	(x)	x		x	x					K L Lä	
C. palustre			x	(x)		x		x	x					K L Lä	1 - 5
Coeloglossum viride			(x)	x	x	x		(x)		x				K L	
Convallaria majalis				x	x	x		x	(x)					L K	1 - 4(5)
Corallorhiza trifida			x			x	x	x	(x)					K	
Cornus suecica			x			x		x	x	(x)				K	
Crepis paludosa			x	x		x		x						K L Lä	1 - 5
Cystopteris montana				x		x		x						Lä K	4 - 7
Cypripedium calceolus				x		x		x		x				K L	1,3 - 5
Dactylorhiza incarnata (Orchis incarnata)			x	x		x						x	x	L N	
D. maculata (Orchis maculata)			x	(x)	(x)	x				x			x	K L	
D. traunsteineri (Orchis traunsteineri)			(x)	x		x							x	L	
Diplazium sibiricum (Athyrium crenatum)				x	x	x		x		x				K	3 - 5
Drosera longifolia (D. anglica)	x	x	(x)				x					x		N L	
D. rotundifolia	x	x			x	x					x	x		R N L	
Dryopteris expansa			x		x					x				K	
D. carthusiana (D. spinulosa)			x		x					x				K	1 - 5
D. cristata			x			x			x					K N Lu	1 - 4
Epilobium alsinifolium			x	x			x	x						Lä	4 - 7
E. angustifolium (Chamaenerion angustifolium)			x		x	x				x				K	
E. davuricum				x			x	x						Lä L	4 - 7
E. hornemannii			x	(x)			x	x						Lä	4 - 7
E. laestadii				x		x	x	x					(x)	Lä L	
E. palustre			x			x	x	x	x					K N L Lä	
Epipactis palustris (Helleborine palustris)				x		x		x						L	(1 - 4)
Equisetum arvense			x		x	x		(x)	(x)	x				K Lä	
E. fluviatile (E. limosum)		x	x			x	x		x			x		Lu N L K	
E. hyemale			x	x	x	x		x						K L	
E. palustre			x	x	(x)	x	(x)	x	x					K L Lä	
E. pratense			x	x	x	x				x				K L Lä	
E. scirpoides				x	x	x		x						K L Lä	1,4 - 7
E. sylvaticum		(x)	x		x	x		(x)		(x)				K	
E. variegatum				x		x		x					(x)	K L Lä	

	Base status				Level			Effect						Mire type group	Distribution
	Om		Mi					Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF		
Euphrasia frigida				x	x	x		x					(x)	L Lä	4 - 7
Filipendula ulmaria			x	x		x		x	x					K L	
Galium boreale			x	x	x	x				x			(x)	L	
G. palustre			x			x	x	(x)	x					N K L Lu	
G. trifidum			x			x	x		x					K N Lu	
G. triflorum			x	x	x	x				x				K	I - 5(6)
G. uliginosum			x	(x)		x			x					N L K Lu	
Geranium sylvaticum			x	x	x	x		x		x				K L	
Geum rivale			x	x		x		x						K L Lä	
Goodyera repens			x		x					x				K	
Gymnadenia conopsea				x	x	x		x		x			x	K L	
Gymnocarpium dryopteris (Lastrea dryopteris)			x		x					x				K	
Hammarbya paludosa (Malaxis paludosa)			x	x			x		x			(x)	(x)	N L	I - 5
Hieracium sylvatica -group			x		x	x				x				K	
Hippuris vulgaris			x				x		x					Lu N	
Huperzia selago (Lycopodium selago)			x		(x)	x				x		x		K N L	
Impatiens noli-tangere			x	x		x	x	x						Lä K	I - 3(4)
Iris pseudacorus			x	x			x		x					Lu N	I - 4
Lathyrus palustris			x	(x)		x			x					K Lu	I - 5
Linnaea borealis			x		x					x				K	
Listera cordata			x		x	x				x				K	
L. ovata			(x)	x		x		x						K L Lä	I - 5
Lychnis flos-cuculi			x	(x)		x		x						K L Lä	I - 4
Lycopodiella inundata (Lepidotis inundata) *			x				x		x			x		N	I - 4(5)
Lycopodium annotinum			x		x					x				K	
Lycopus europaeus			x	x			x		x					N Lu	I - 3
Lysimachia thyrsiflora (Naumburgia thyrsiflora)			x			(x)	x		x					Lu N K	
L. vulgaris			x			x	x		x					Lu N K	I - 4
Lythrum salicaria			x			x	x		x					Lu N	I - 4
Maianthemum bifolium			x		x					x				K	
Malaxis monophyllos (Microstylis monophyllos)				x		x		x						L K	(I - 4)
Matteuccia struthiopteris (Struthiopteris filicastrum)			x	x		x		x	x					K	
Melampyrum pratense	x	x			x					(x)	x			K R	
M. sylvaticum			x		x					x				K	
Menyanthes trifoliata		x	x				x		(x)			x		N L K	
Moneses uniflora (Pyrola uniflora)			x		x	x				x				K	
Montia fontana (M. lamprosperma)			x	(x)			x	x						Lä K	
Nuphar			x				x		x					N	
Nymphaea			x				x		x					N	
Orthilia secunda (Pyrola s., Ramischia s.)			x		x					x				K	
Oxalis acetosella			x	x	x					x				K	I - 4(5)
Paris quadrifolia			(x)	x	x					x				K	
Parnassia palustris			x	x		x		x	x					L K	
Pedicularis lapponica			x		x					x	(x)			K R	5 - 7

	Base status				Level			Effect						Mire type group	Distribution
	Om		Mi					Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF		
P. palustris			x	(x)		x	x		x			(x)		N L	
P. sceptrum-carolinum			x	(x)		x		(x)	x					N K L	
Petasites frigidus			x	(x)		x	x	x	(x)					L K Lä	3 - 7
Peucedanum palustre (Thyselium palustre)			x			x	x		x					N	1 - 5
Phegopteris connectilis (Thelypteris phegopteris)			x		x			(x)						K	
Pinguicula alpina				x		x		x					x	L Lä	(4)5,7
P. villosa	x	x			x						x			R	4 - 7
P. vulgaris			x	x		x		x					x	L Lä	1,3 - 7
Polemonium acutifolium (P. campanulatum)			x			x			x					K	4 - 7
Polygonum viviparum			x	x	x	x		x	x					K L Lä	
Potentilla erecta			x	x	(x)	x		x		x			x	K L	
P. palustris		(x)	x			x	x	(x)	x			(x)		Lu N K L	
Pyrola minor			x		x					x				K	
P. rotundifolia			x	x	x	x				x			(x)	K L	
Ranunculus acris			x	(x)	x	x		x						K L	
R. hyperboreus			x				x	x						K	
R. lapponicus			x			x	x	x	x					K	4 - 7
R. repens			x			x	x	x	x					K N	
Rubus arcticus			x		x	x			(x)	x				K	
R. chamaemorus	x	x			x					(x)	x			R K	
R. saxatilis			x		x	x				x				K	
Rumex acetosa			x	x		x		x						K L	
R. aquaticus			x	x		x	x	x	x					Lä Lu	
Saussurea alpina			(x)	x	x	x		x					x	L K	4 - 7
Saxifraga aizoides			(x)	x			x	x						Lä	5, 7
S. hirculus				x		x		x						Lä L	2 - 7
S. stellaris			x	x		x	x	x						Lä L	7
Scheuchzeria palustris	x	x					x					x		N	1 - 6
Scutellaria galericulata			x			x			x					Lu K N	1 - 5(6)
Selaginella selaginoides			x	x		x		x				(x)	x	L N K	
Solanum dulcamara				x		x	x		x					Lu K	1 - 3
Solidago virgaurea			x	x	x	x				x			x	L K	
Stellaria alsine (S. uliginosa)			x	(x)		x	x	x						Lä K	1 - 3
S. borealis (S. calycantha)			x			x	x	x	(x)					Lä K	4 - 7
S. crassifolia			(x)	x		x		x	x					Lä L N	(1)2 -7
S. longifolia			x		x	x				x				K	
S. nemorum			x	x		x		x	(x)					K Lä	
S. palustris			x			x			x					Lu N	1 - 5
Taraxanum			x		x	x		x		x				K Lä	
Thalictrum alpinum				x		x		x					(x)	L	(5)6 -7
Thelypteris palustris (Lastrea thelypteris)			x	x		x	x		x					Lu	1- 4(5)
Tofieldia pusilla			x	x	(x)	x						x	x	L N	4 - 7
Trientalis europaea			x		x	x				x				K	
Triglochin palustre			x	x		x	x	x					x	L Lä	
T. maritimum				x		x							x	L	(5+m)
Trollius europaeus			x	x		x		x	x					K	

	Base status				Level			Effect						Mire type group	Distri-bution
	Om		Mi					Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF		
Tussilago farfara				x		x	x	x						Lä K	
Typha			x	x			x		x					Lu	I - 4
Urtica dioica			x	x		x			(x)	x				K	
Utricularia intermedia		(x)	x				x		x			x		N L Lu	
U. minor			x				x		x			x		N L Lu	
U. vulgaris			x				x		x					Lu N	
Viola epipsila			x			x		(x)	x					K L N	
V. palustris			x			x			x					K N Lu	
HEPATICAE															
Aneura pinguis (Riccardia pinguis)			x	x			x	x				(x)	x	L N	
Barbilophozia kunzeana (Orthocaulis kunzeanus)			x			x						x	x	N L	
Calypogeia (sphagnicola)	x	x			x	x					x	x		R N	
Chiloscyphus polyanthos			x				x	x							
Cladopodiella fluitans	x	x					x					x		N	
Gymnocolea inflata	x	x				x	x					x		N	
Lepidozia reptans	x	x			x	x					x	x		N R	
Leiocolea rutheana (L. schulzii, Lophozia r.)				x		x							x	L	
Marchantia alpestris (incl. M. aquatica)			x	(x)			x	x							
M. polymorpha			x			x	x		x						
Mylia anomala (Leptoscyphus anomalus)	x	x			x	x					x			R N	
Odontoschisma elongatum	x	x				x	x					x		N	
Pellia			x			x	(x)	(x)	x					K L	
Ptilidium ciliare	(x)	x			x	x						x			
Scapania			x				x	x							
Tritomaria quinquedentata			x	x		x	x	x				x	x	L N	
SPHAGNIDAE															
Sphagnum affine (S. imbricatum)		x				x			(x)					R, N	I
S. angustifolium (S. parvifolium)	x	x			x	x					x	x		R N L K	
S. annulatum (incl. S. jensenii)	(x)	x					x					x		N	
S. aongstroemii (S. insulosum)		x	x			x		(x)	(x)			x		N K	
S. balticum	x	x				x	x					x		N	
S. capillifolium (S. nemoreum, S. acutifolium)	x	x			x						x			R K	
S. centrale			x		x	x				x				K	
S. compactum *	(x)	x				x						x		N	
S. contortum				x		x	x	x	x				x	L	I - 5
S. cuspidatum	x	(x)					x					x		N	I - 3(4)
S. denticulatum (auriculatum, incl. inundatum)			x	x			x		x					Lu L N	I - 3
S. fallax (apiculatum, recurvum v. mucronatum)		x	(x)			x	x		(x)			x		N K	
S. fimbriatum			x			x			x					K N Lu	
S. flexuosum (recurvum v. amblyphyllum)		(x)	x			x		(x)	x			x		K N	
S. fuscum	x	x			x						x			R N	
S. girgensohnii			x		x	x				x				K	
S. lindbergii	x	x	(x)			(x)	x					x		N	
S. magellanicum	x	x			x	x					x	x		R N	
S. majus (S. dusenii)	(x)	x					x					x		N	

	Base status				Level			Effect						Mire type group	Distri-bution
	Om		Mi					Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF		
S. molle		x				x						x		N	
S. obtusum			x			x	x		x					L N Lu	
S. palustre (S. cymbifolium)			x		(x)	x			x	x				K	
S. papillosum	(x)	x	(x)			x						x		N	
S. platyphyllum *			x	(x)			x		x			x	x	L N Lu	
S. pulchrum		(x)	x			x	x					x		N	
S. quinquefarium			x		x					x				K	
S. riparium		(x)	x				x	x	x					N K Lu	
S. rubellum	x	x			x	x						x		N R	I - 5
S. russowii (S. robustum)	x	x			x	x				(x)	x			R K	
S. squarrosum			x			x			x					Lu K N	
S. subfulvum			x	x		x						x	x	L N	
S. subnitens (plumulosum)			x	x		x						x	x	L N	I- 3(-5)
S. subsecundum			x	x		x	x		(x)			x	x	N L	
S. tenellum (molluscum)	x	x				x						x		N	I - 5
S. teres			x	x		x	(x)	x	x					L K N Lu	
S. warnstorfii			(x)	x		x		x					x	L K Lä	
S. wulfianum			x		x					x				K R	
BRYIDAE															
Aulacomnium palustre	x	x	(x)		x	x					x			R L K	
Brachythecium reflexum			x		x					x				K	
B. rivulare			x	x			x	x						Lä K	
B. rutabulum			x		x	x			x	x				K	
B. starkei			x		x					x				K	
B. turgidum (B. salebrosum var. turgidum)				x		x		x						L Lä	4 - 7
Breidleria pratensis (Hypnum pratense)			(x)	x		x		x	(x)					K L	
Bryum pseudotriquetrum (B. ventricosum)			x	x		x	x	x	x				x	Lä K L	
B. weigelii (B. duvalii)			x	(x)			x	x						Lä	
Calliergon cordifolium			x				x	(x)	x					Lu K N	
C. giganteum			x	x			x	x	x					Lu K L Lä	
C. megalophyllym			x	x			x		x					Lu N L	
C. richardsonii				x			x	x	(x)					L	
Calliergonella cuspidata			x	x		x	x	x	x					K N Lä	
C. lindbergii (Hypnum l.)			x			x	x		x					N K Lu	
Campylium stellatum				x		x	x	(x)					x	L	
Catoscopium nigritum				x			x	x					x	L Lä	
Cinclidium stygium				x			x	x					x	L Lä	
C. subrotundum			x	x					x				x	L N Lu	3 - 7
Climacium dentroides			x			x			x	(x)				K	
Cratoneuron filicinum				x			x	x						Lä	
Dicranella cerviculata	x	x			x	x		On bare peat							
D. palustris (Anisothecium palustre)			x	(x)		(x)	x	x						Lä	3 - 7
Dicranum angustum			(x)	x	x	x		(x)					x	L	3 - 7
D. bergerii (D. affine, D. undulatum)	x	x			x						x			R	
D. bonjeanii			(x)	x	(x)	x		(x)					x	L	
D. elongatum	x				x						x			R	3 - 7

	Base status				Level			Effect						Mire type group	Distri-bution
	Om		Mi					Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF		
D. fuscescens	(x)	x	x		x					x				K	
D. leioneuron			x		x	x						x		N	
D. majus		(x)	x		x					x				K	
D. polysetum (D. rugosum, undulatum)	x	x			x					x	x			R K	
D. scoparium	x	x			x					x	x			K R	
Drepanocladus aduncus (D. polycarpus)			x	x			x	(x)	x					Lu L	
Fissidens adianthoides				x		x	x	(x)	(x)				x	L	
F. osmundoides			x	x		x	x		x				x	L Lu	
Fontinalis antipyretica			x				x	x						Lä	
Hamatocaulis lapponicus (Scorpidium l.)			(x)	x		(x)	x		x			(x)		Lu N L	
H. vernicosus (Drepanocladus, Scorpidium l.)				x		x	x	x	(x)					L	
Helodium blandowii			x	x		x		(x)	x					L N K Lu	
Hylocomiastrum umbratum (Hylocomium u.)			x		x			x		x				K	I - 5
Hylocomium splendens		(x)	x		x					x				K R L	
Loeskypnum badium (Drepanocladus badius)			x	x		x	x	x				x	x	N L Lä	
Meesia longiseta				x		x	x	x	x				(x)	L	
M. triquetra			(x)	x		x	x	(x)	(x)				x	L	
M. uliginosa				x		x	x	x	(x)				x	L	
Mnium hornum			x		x	x			x					K	I - 4
Oncophorus virens			(x)	x		x		x						Lä	
O. wahlenbergii			x	x		x		x	x					L	
Paludella squarrosa			x	x		x	x	x						Lä L	
Palustriella commutata (Cratoneuron commutatum)				x			x	x						Lä	4 - 7
P. decipiens (Cratoneuron d.)				x			x	x						Lä	
P. falcata (Cratoneuron falcatum)				x			x	x						Lä	
Philonotis calcarea				x			x	x						Lä	I - 5
P. fontana			x	x			x	x						Lä	
P. seriata			x				x	x						Lä	2 - 7
P. tomentella			x	x			x	x						Lä	
Plagiomnium elatum (Mnium seligeri)			(x)	x			x	x	(x)					K L Lä	
P. ellipticum (Mnium rugicum)			x	x		x	x	x	x					K L Lä	
P. medium (Mnium affine var. medium)			x	(x)		x		(x)		x				K Lä	
P. undulatum			x	x		x		x						Lä K	I - 3
Plagiothecium			x		x					x				K	
Pleurozium schreberi	x	x			x						x			R K	
Pohlia nutans		x			x						x			R K	
P. wahlenbergii (P. albicans, Mniobryum w.)			x				x	x						Lä	
Polytrichastrum formosum (Polytrichum attenuatum)			x	x	x	x				x				K	I- 4(5)
P. longisetum (Polytrichum gracile)		(x)	x			x			x		On bare peat			N R	
Polytrichum commune *		x	x		x	x				x				K R	
P. jensenii (P. commune var. jensenii) *			x			x			x					Lu N	
P. strictum (P. alpestre)	x	x			x						x			R	
P. swartzii (P. commune var. swartzii)			x	(x)		x	x		x					Lu N	

	Base status				Level			Effect						Mire type group	Distri-bution
	Om		Mi					Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF		
Pseudobryum cinclidioides (Mnium c.)			x			x	x	x	x					Lu K N Lä	
Pseudo-calliergon angustifolium				x		(x)	x		x					Lu L	4 - 7
P. lycopodioides (Scorpidium, Drepanocladus l.)				x			x		x					Lu L	
P. trifarium (Calliergon, Scorpidium t.)				x		x	x						x	L	
Rhizomnium magnifolium (R. perssonii)			x	(x)			x	x						Lä K	
R. pseudopunctatum (Mnium p.)			x	x		x	x	x					(x)	Lä K L	
R. punctatum (Mnium p.)			x			x	(x)	(x)	(x)	x				K L	
Rhodobryum roseum			x			x				x				K	
Rhytidiadelphus subpinnatus (R. calvescens)			x		x	x				x				K	
R. triquetrus			x		x					x				K	
Sanionia uncinata (Drepanocladus uncinatus)			x			x		(x)		x				K N L	
Scorpidium cossoni (Limprichtia intermedia)				x		x							x	L	
S. revolvens (Limprichtia, Drepanocladus r.)				x			x						x	L	
Scorpidium scorpioides			(x)	x			x		x				x	L	
Straminergon stramineum (Calliergon s.)		x	x			x	x	x	x			x		N K L Lä	
Thuidium recognitum			x	x		x		(x)		x				K L	
Tomentypnum nitens				x	x	x		(x)					x	L	
Warnstorfia exannulata (Drepanocladus e.)			x				x	x	(x)			(x)		N L K Lä	
W. fluitans (Drepanocladus f.) *	x	x					x					x		N	
W. heinrich-schulzei		x					x					x		N	
W. procera (Drepanocladus procerus)			x				x		x			x		N L	
Warnstorfia sarmentosa (Calliergon, Sarmentypnum)			x	(x)		x	x	x						Lä L N	
W. tundrae (Drepanocladus t.)			x	x			x	x	x					L Lä	
LICHENS															
Cladonia, subgenus Cladina	x	x			x						x			R	
Cladonia, subgenus Genomyce	x	x			x	(x)					x	(x)		R N	
Cetraria ericetorum	x	x			x						x			R	
C. islandica	x	x			x						x			R	

The **supplementary (mire margin) and inherent (expanse) effects** indicate the quantity of the ecological independence of the mire vegetation from other nature. Species are indicators of these phenomena. Peat thickness, continuous width of the mire, ridge-hollow structure, small quantity of the outside melt-waters, poor bedrock and soil, and topogenous mire surface favour the development of the inherent nutrient status and further its transformation into ombrotrophic bog vegetation also in the northern “aapa mire Finland”.

The **groundwater** (spring and seepage, in Finnish *lähteisyys*) influence is distinguished by moving water from the ground. At best its water is cold (eustatic) and rich in oxygen. The base status is meso- or eutrophic. Flark or sometimes intermediate water level prevails. The microclimate of the eustatic springs is ± oceanic. Some alpine species have at/in springs their southernmost localities, and southern species their northernmost sites. Over 100 vascular plant species and 40 bryophytes favour the groundwater influence habitats.

Sphagnum wulfianum is a beautiful species growing in low hummocks in thin-peated spruce mires. Photo Tapio Lindholm

The **surface-water** (swamp, In Finnish *luhtaisuus*) influence is associated with the general spring flood of lake and river systems or with ± permanent limnogenous waters. Thus its influence varies from a repetitive rhythm to a continuous situation. Pure thaw waters do not cause a clear surface-water effect on the vegetation but may keep on a weak minerotrophic status of the poor aapa mire complexes. The nutrient status of the vegetation influenced by the surface-waters is usually meso- or eutrophic. Flark or intermediate water level prevail, hummocks are situated at the trunk base of the trees and on rotten logs. Over 120 vascular plant species and 30 bryophytes favour swamp sites.

In the **spruce mire** (thin peat, in Finnish *korpisuus*) influence supplementary nutrients originate from the mineral soil and water movement in peat itself. The peat layer is thin, in an average about half a metre thick in Finland (Ilvessalo 1957). Trees (*Picea abies* and *Betula pubescens*) and other mesic and rich forest species are common. Spruce mire habitats are often influenced by other supplementary phenomena, which appear as mosaic vegetation. However, in the ideal spruce mire habitat, meso- or meso-eutrophic hummock-level vegetation prevails. In consequence of the water movement the nutrient status values may be lower than supposed. A variable hilly landscape favours the development of the spruce mires in valley outlets. Therefore they are common in Lake-Finland, but also on southern and southwestern coastal plain, and are nowadays mainly ditched. Almost 70 vascular plant species and 20 bryophytes favour spruce mire habitats.

The **melt water (thaw)** influence is typical for the arctic permafrost areas where glaciers and snow-patches are common. In the alpine soil conditions of the northern Kjölen it is impossible to distinguish this effect from the groundwater influence, and in lowlands from other surface waters.

The **hummock-level bog** (In Finnish *räme*) influence is characterized by ombro- or oligotrophic dry-level vegetation. Thus the inherent nutrient status prevails. However, the lawn level is typical for cottongrass pine bogs. Except for mire plants, Scots pine and species of dry heath forests are common in the vegetation. The räme bogs are the most common mire type group in Finland and form combination types with neva (see below) and rich fen vegetation. Less than 20 vascular plant species and the same number of bryophytes favour the hummock bog habitats.

The **poor fen / flark or lawn level bog** (In Finnish *neva*) influence is characterized by an inherent ombro-, oligo- or mesotrophic wet or moist vegetation. As combination types the *neva* vegetation forms the basic surface on which the *korpi* or *räme* hummocks and ridges "are afloat". However, on the southern bog complexes *Sphagnum fuscum* bog forms usually the basic level of the *Fuscum*– (*Cuspidata*) hollow bog type. In correlation to the decreasing evapotranspiration the *neva* vegetation increases in Finland towards the north and forms the central part of the aapa mire complexes. Over 30 vascular plant species and less than 30 bryophytes favour the *neva* habitats.

The **rich fen** (In Finnish *letto*) influence is characterized in its purest form by an inherent, lawn or flark level, eutrophic vegetation. However, indifferent species and indicators of all supplementary effects may be common on the *letto* habitats. The *letto* indicators have a low exchange capacity and cannot grow on the more poor habitats. Combination types with the *räme* and *korpi* vegetation are common. Rich fens are rare (< 1 %) in Finland, due to our acidic bedrock and soil, but also the man, and their species are endangered. 30 vascular plant species and about the same amount of bryophytes demand *letto* habitats.

A mire **site type** is an abstract concept formed of the sites with ± similar flora and ecology (Cajander 1913). About 60 genuine mire site types can be distinguished in Finland. They form six main type groups (Table 2): 1) the groundwater influenced vegetation (springs, seepages, spring mires; 6 types), 2) swamp (*luhta*; 6 types), 3) spruce mire (*korpi*; 11 types), 4) hummock-level bog (*räme*; 11 types), 5) poor (oligo- or mesotrophic) fen and lawn/carpet/mud-bottom level bog (*neva*; 14 types), and 6) rich fen (*letto*; 9 types). In addition there are 17 combination types (forested *neva* or rich fen vegetation). In this division the *neva* group is ecologically problematic and is possible to be divided into the fen and wet bog main type groups, in which the ecologically equivalent combination types are joined.

Table 2. Ecological values of the Finnish mire site types, mainly after Eurola & Kaakinen (1978) and Eurola & al. (1994). Abbreviations in the columns 1-13 like in Table 1. Occurrence of trees in the columns 14-15: Y = yes, N = no.

	Trophy				Level			Effect						Treed	
	Om	Mi						Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF	Y	N
SPRUCE MIRES															
Thin-peated Vitis-idaea spruce mire		(x)	x		x					x	(x)			x	
Thin-peated Myrtillus spruce mire			x		x					x				x	
Thin-peated herb spruce mire			x	x	x					x				x	
Thin-peated eutrophic spruce mire				x	x	(x)		(x)		x			(x)	x	
Myrtillus spruce mire		(x)	x		x					x				x	
Vitis-idaea spruce mire		x	x		x					x	(x)			x	
Rubus chamaemorus spruce mire		(x)	x		x	(x)	(x)		(x)	x	(x)			x	
Equisetum sylvaticum spruce mire			x		x	(x)	(x)	(x)		x				x	
Herb-Myrtillus spruce mire			x	(x)	x					x				x	
Fern spruce mire			x	(x)	x	x		(x)		x				x	
Herb-grass spruce mire			x	x	x	x	x	(x)	x	x				x	

	Trophy				Level			Effect						Treed	
	Om	Mi						Margin			Expanse				
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF	Y	N
SWAMPS															
Reed-rush swamp			x	x			x		x						x
Horse-tail swamp			x	x			x		x						x
Sedge herb swamp			x	x		(x)	x		x			(x)			x
Willow swamp			x			x	x		x			(x)			x
Black alder swamp			x	x	(x)	x	x	x	x					x	
Birch swamp			x		(x)	x	x		x					x	
SPRING AND SEEPAGE VEGETATION															
Mesotrophic spring		(x)	x				x	x							x
Mesoeutrophic spring			x	x			x	x							x
Eutrophic spring				x			x	x							x
Mesotrophic spring fen			x			x	x	x				(x)	x		x
Mesoeutrophic spring fen			x	x		x	x	x					x		x
Eutrophic spring fen				x		x	x	x					x		x
RÄME VEGETATION															
Thin-peated pine mire		x			x					(x)	x				
Cotton-grass pine bog	x	(x)			(x)	x					x	(x)		x	
Ordinary spruce-pine mire		x			x					x	x			x	
Carex globularis spruce-pine mire		x			x					x	x			x	
Carex globularis pine mire		x			x	(x)				x	x			x	
Ordinary dwarf-shrub pine bog	x	(x)			x						x			x	
Betula nana pine bog	x	x			x						x			x	
Calluna-Fuscum bog	x				x						x			x	x
Empetrum-Fuscum bog	x				x						x			x	x
Palsa bog	x				x						x				x
Thin-peated hummock bog		x	(x)		x	x	x				x	(x)			x
NEVA VEGETATION															
Swamp fen			x			x	x		x			x			x
Ombrotrophic low-sedge bog	x					x						x			x
Ombrotrophic hollow bog	x						x					x			x
Ordinary low-sedge fen		x				x	(x)					x			x
Mesotrophic ordinary low-sedge fen			x			x						x			x
Mesotrophic Papillosum low-sedge fen			x			x	(x)					x			x
Oligotrophic ordinary tall-sedge fen		x	(x)			x	(x)		(x)			x			x
Oligotrophic Papillosum tall-sedge fen		x				x						x			x
Mesotrophic ordinary tall-sedge fen			x	(x)		x	(x)	(x)	(x)			x			x
Mesotrophic Papillosum tall-sedge fen			x	(x)		x						x			x
Oligotrophic flark fen		x					x					x			x
Mesotrophic flark fen			x				x	(x)	(x)			x			x
Mesoeutrophic ordinary fen			x	x		x	(x)	(x)				x	x		x
Mesoeutrophic flark fen			x	x			x	(x)	(x)			x			x

	Trophy				Level			Effect							Treed	
	Om	Mi						Margin			Expanse					
	Om	Ol	Me	Eu	Hu	Int	Fl	GW	SW	SM	HB	Ne	RF		Y	N
RICH FENS																
Eutrophic swamp fen				x		x	x	(x)	x				x			x
Eutrophic Warnstorfii fen				x	(x)	x		x		(x)		(x)	x			x
Eutrophic Tomentypnum fen				x	(x)	x		(x)					x			x
Eutrophic Campylium fen				x		x		(x)				(x)	x			x
Eutrophic Diandra-Hirculus fen				x	x	x		x					x		(x)	x
Eutrophic birch fen				x		x	x	x	x	(x)		(x)	x		x	
Eutrophic Scorpidium flark fen				x			x					(x)	x			x
Eutrophic Revolvens flark fen				x			x					(x)	x			x
Eutrophic Richardsonii flark fen				x			x	x	x			(x)	x		(x)	x
COMBINATION TYPES																
Eutrophic spruce fen				x	x	x		x		x			x		x	
Swampy birch fen			x		x	x	x		x	x		x			x	
Carex nigra birch fen		x	x		x	x			x	x			x		x	
Oligotrophic tall-sedge birch fen		x	(x)		x	x	(x)		(x)	x		x			x	
Mesotrophic tall-sedge birch fen			x		x	x	x	(x)	(x)	x		x			x	
Cotton-grass spruce fen		x	(x)		x	x				x		x			x	
Eutrophic supplementary pine fen				x	x	x		x		(x)	(x)		x		x	
Eutrophic self-sufficient pine fen				x	x	x					(x)	(x)	x		x	
Eutrophic flark pine fen				x	x	x	x	(x)		(x)	(x)		x		x	
Mesoeutrophic pine fen			x	x	x	x	(x)	(x)				x	(x)		x	
Oligotrophic tall-sedge pine fen		x	(x)		x	x					x	x			x	
Mesotrophic tall-sedge pine fen			x		x	x	(x)		(x)		x	x			x	
Oligotrophic low-sedge pine fen		x			x	x	(x)				x	x			x	
Mesotrophic low-sedge pine fen			x		x	x	(x)				x	x			x	
Oligotrophic flark pine fen		x			x	x	x				x	x			x	
Mesotrophic flark pine fen			x		x	x	x		(x)		x	x			x	
Fuscum hollow bog	x				x	x	x				x	x			x	x

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Land uplift phenomenon and its effects on mire vegetation

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Historical background

On the coastland of Bothnian Bay in Finland and Sweden, the regression of sea line is rapid and easy to recognize even during a lifetime of a man. So this phenomenon has been familiar to the local people for a long time and scientific descriptions have been made for more that 300 years. It caused even a scientific debate in Sweden in 18th century (see Edelmann 1991). The observations collected from local people at that time handled e.g. the change of shallow-water bays to hay growing pastures and growth of new rocks and islands in the middle of the sea. Descriptions like these have been mentioned in the reports of bishops and other civil servants. Some well known Swedish scientists (especially Celsius and Linne) discussed the question of the falling of the sea level. On the basis of observations made on the coastlands of northern Baltic Sea they presented that sea level was generally going down. These thoughts were, however refused as impossible. The strongest argument of the opponents was, that this regression should have been visible also on the coastlands of the southern Baltic and other seas, where no such phenomenon however had been noticed. In the year 1765 E.O.Runeberg, a surveyor, who had worked on the coastlands of Ostrobothnia showed that the regression of sea line was a fact in this district. He also was the first to present the idea that this was not due to the falling of the sea level, but to the uplift of land in that region. As evidence of the possibility of that kind of uplift he presented e.g. the shifts and faults seen in mines and quarries. This idea, that the bedrock was not motionless, was accepted gradually as it got support from the observations of geology, a new branch of science developing in Europe at that time. Some founders of geological science (e.g. English Charles Lyell) did visit the coasts of Bothnian Bay and were convinced that similar slow, long-term movements could cause all the topographical features on the earth`s crust. Later it became clear, that the land uplift of Fennoscandia is exceptionally quick (Fig. 1) and different by origin from the movements taking place in mountain-building.

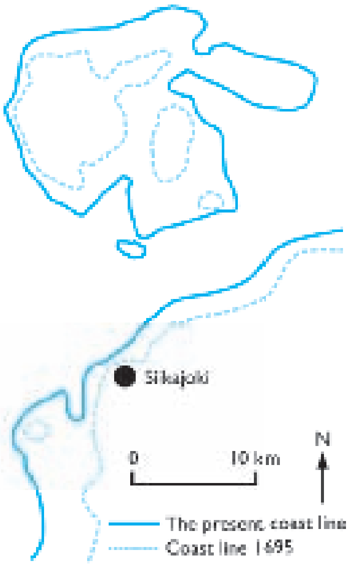

Fig. 1. An example of the regression of the coastline of Bothnian Bay around the parish of Siikajoki during the last 300 years. The shoreline has moved towards the sea, at some places even many kilometres during the last 300 years.

The factors influencing land uplift and shoreline displacement

The rate of land uplift has been measured by levellings (e.g. Kääriäinen 1966, Kakkuri1985). The land uplift is quickest (about 9 mm/year in relation to the mean sea level) on the Bothnian Bay area a little north of the towns Vaasa in Finland and Umeå in Sweden and decreasing outwards from this centrum. It is equal to zero e.g. in the eastern end of the Gulf of Finland, in southern Sweden and on the Norwegian coastland (Fig. 2). The centre of the land uplift area happens to be the same as the thickest centre of the last (Weichselian) ice-sheet during the last glaciation. In the same district there is also a negative anomaly in the gravitation and gravimetric geoid (Kakkuri 1985, Torge & al. 1983). These results prove, that the land uplift is due to the rebound of earth's crust after the vanishing of the ice sheet, which pressed it (glacial isostacy) (e.g. Niskanen 1943). The convections in the earth's crust and beneath it lead also to a

Fig. 2. Isobases of the contemporary land uplift in Fennoscandia. (Kakkuri 1985)

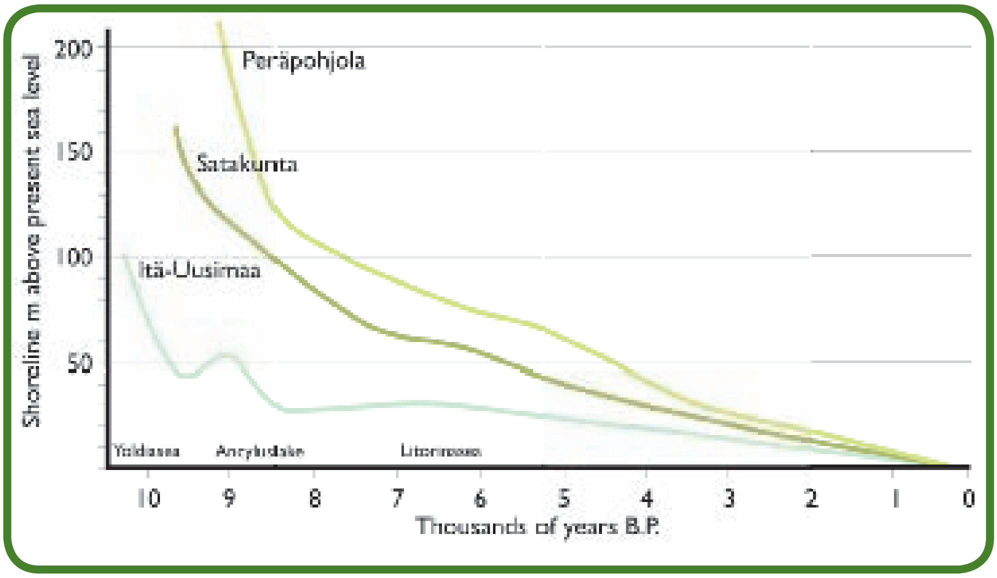

Fig. 3. The shoreline displacement in different parts of Finnish coastland (Taipale & Saarnisto 1991), northern part of Bothnian Bay (Peräpohjola), southern part of Bothnian Bay (Satakunta), central part of Gulf of Finland (Itä-Uusimaa)

belt of weak land subsidence around the area of land uplift. This can be seen as slow marine transgression on the southern coast of Baltic and on the coasts of the North Sea. An additional evidence of the linkage between the continental ice sheet and the land uplift in Fennoskandia is that in Northern America there is a land uplift pattern of very similar extent and magnitude (Peltier 1990). The centre of this land uplift area is around the Hudson Bay, where the last (Laurentide) ice sheet was thickest.

Besides the glacial isostasy also tectonical movements of the Earth's crust can cause land uplift and subsidence in every part of the world. These movements are however typically much slower than the uplift in Bothnian Bay or Hudson Bay, but continuing millions of years these movements can raise some areas to high mountains. E.g. the tectonic uplift of Himalayan mountains, which is very quick on global scale, has according to geological evidence been estimated to be about 5 mm/year at maximum (Gansser 1982). Also in Fennoscandia these tectonic movements take place and they can cause local unevenness to the land uplift pattern (Kakkuri 1985).

The observable shoreline displacement on the coast of the Bothnian Bay is a result of two factors; the land uplift and the eustatic change of sea level. The position of shorelines at different times can be studied by radiometric dating of sedimentary layers formed e.g. when a lake has grown separate from the sea (Okko 1967, Glückert 1976, Saarnisto 1981, Glückert et. al. 1993) (Fig. 3). With the help of shoreline displacement curves it is possible to assess for each place the time which it has been above the sea level on the ground of its altitude. According to the curves of the shoreline displacement published for the coastlands of Finland (Taipale & Saarnisto 1991), the regression has been quickest (even many times faster than now) just after the ice sheet had melted out and gradually slowed down after that. During the last 4000 years it has gone on quite evenly so that the approximate value of one meter change in altitude in 100 years can be considered valid in the area of the quickest land uplift. The eustatic rise of seawater during the warmer period about 8000-5000 years ago caused a little lowering in the regression on the coastlands of the Bothnian Bay. In Southern Finland, where land uplift has beer slower, occasional transgressions of the sea took place during that epoch.

The glacial-isostatic land uplift process has been estimated to continue still 7000-12000 years although becoming gradually weaker (Kakkuri 1985). To which extent this leads to shoreline displacement depends on the future changes in the sea level. The current eustatic rise of the sea level (about 1 mm/year) (Lisitzin 1974 is clearly slower than the land uplift on the Bothnian Bay). The warming of the climate and the melting of the glaciers are however predicted to accelerate the rise of the sea level in future (Johansson & al. 2004). In most of these scenarios it is predicted, that the accelerating rise of sea level will exceed the land uplift on the shores of Gulf of Finland, but on the Bothnian Bay the regression of the sea would still continue after the next 100 years, although not as rapidly as now. The uncertainties concerning the sea level changes are however remarkable and even a greater rise than that predicted in the above mentioned scenarios could be possible.

The effect of the shoreline regression on the vegetation on the shores of the Bothnian Bay

Because of the rapid shoreline displacement, the littoral belt is continuously changing. New land is revealed from the sea and at the same time the highest parts of the littoral belt are rising above the influence of the sea water. Consequently the belts of vegetation must move towards the sea all the time. This gives a chance to many species, which need open ground and which can rapidly colonize new sites. The species growing on the littoral belt must stand very strong fluctuations and they must have the ability to recover from the destructions caused by storms and ice (Ecke & Rydin 2000). Many of the most unique features of the vegetation on coastlands of Baltic Sea are combined with the situation caused by rapid shoreline regression. The endemic plant taxons (Ericson & Wallentinus 1979) have usually their centres of distribution on the coastlands of Bothnian Bay. These include species (e.g. *Deschampsia bottnica, Alisma wahlenbergii*) and subspecies (e.g. *Artemisia campestris* ssp. *bottnica*) specialized to open littoral habitats. Another interesting group of plant species typical for these littoral habitats is the *Primula sibirica* -group (Ericson & Wallentinus 1979). These are species with their main distribution on the coastlands of Arctic Ocean and White Sea and separate stands on the coastlands and river deltas of the northern Baltic Sea. Both groups have many species, which have become threatened on the shores of the Baltic Sea. The main reason for that is considered to be the denser growth of competing vegetation, particularly reed (*Phragmites*) and willows (*Salix* spp.), caused by man-made eutrophication and ceasing of grazing and mowing of the coastlands.

The Baltic Sea is a large basin with brackish sea-water. Its salinity is highest near the straits of Denmark and lowest (0,2-0,3 %) in the northern end of the Bothnian Bay. The fluctuations of sea-level are combined with the strength and direction of the wind, the effect of tidal fluctuation is very small. The highest sea-level occurrences are caused by the storms, and the fluctuation is greatest at the ends of long bays (Lisitzin 1960). At the northern end of the Bothnian Bay the sea level can occasionally rise 2 m above the mean during southerly storms and descend 1 m beneath it during long north-eastern winds. In normal years the highest values are usually a little more than 1 m above the mean (Siira 1999). The littoral belt is situated beneath the highest sea line. The shallower parts of the littoral belt are seashore meadows (Siira 1999, Kukko-oja & al. 1999), which are continuously moving so that each place belongs to the belt of seashore meadows about 100 years. Above the meadows the willow thickets are very typical.

In the initial stage of primary mire formation the vegetation consists of a mixture of aquatic and mire plants. Slightly saline water has an almost continuous influence on the vegetation. During high water periods and storms, waves throw plant remnants and garbage in the young mire.
Photo Tapio Lindholm

The succession of forests

The studying of primary succession stages of forests has been intensive on the coast of Bothnian Bay, where the land uplift is most rapid. The first stage in the succession is usually dominated by broadleved trees. In the northern part of the Bothnian Bay, grey alder (*Alnus incana*) is typically the first tree-species to appear after seashore meadows and willow thickets. It is also the dominant tree in the belt of alder forests situated on the upper part of the littoral belt. There the alder trees grow some 50 years and are then replaced by other trees (Havas 1967, Svensson & Jeglum 2003). In the southern parts of the Bothnian Bay, black alder (*Alnus glutinosa*) is a common dominant tree on a corresponding belt near the shore (Ericson & Wallentinus 1979). Also birch (*Betula pubescens*, in some places also *B. pendula*) is very common in the young stages of primary succession. The largest birch forests are typically met on islands, where grazing has affected the composition of trees (Rinkineva & Bader 1998). The young broadleaved stages of primary succession have been divided into several site types (Havas 1961, 1967), the richest of them resembling true herb-rich forests. Coniferous trees (pine on the barren ground, spruce on the richer ground) begin to grow just above the highest sea level where they rapidly become dominant. At the same time, other species typical for the littoral belt are largely replaced, and so this primary succession leads to the site types of boreal heath forests. In a study made on the Quark area in the middle of the Bothnian Bay it was observed that spruce becomes the dominant tree on a ground 160 old. After that, the forest can develop into a climax state of coniferous forest, which can be reached about 300 years after the rising above the sea level.

Chemically distinguishable soil horizons can be separated already on ground less than 1000 years old on both sandy (Petäjä-Ronkainen 1990) and morainic (Väänänen 1992) topography. The development of the podzol profile is relatively rapid in the first 2000 years and slows down after that (Starr 1991). However, it takes several thousands of years for the podzol profile to become fully developed. The land uplift coast gives also a good opportunity to follow the amounts of nutrients and base cations in relation to age. On younger belts near the shore (Lindroos 1988, Kukko-oja & al. 1999) one has often noticed an increase in the amounts of calcium and magnesium as well as main nutrients when shifting from the coastline to the alder groves. The amount of phosphorus has been noticed to have even more long-term increase with age in the succession of heath forest soils (Starr 1991). In the time sequences covering longer periods, the local differences in the quality of the soil and in the succession stage of the forest can influence more than the age. In some comparisons (Väänänen 1992, Petäjä-Ronkainen 1990) it has been noticed some decrease with age in the contents of calcium and magnesium on the soil horizons several thousands of years old, possibly due to leaching. When measuring the groundwater levels on the land uplift coasts of the Bothnian Bay (Lindroos 1988), a clear difference between sand and till soils has been noticed: on the former the groundwater level descends evenly with land uplift, on the later it stabilizes just after the littoral belt to a level dammed by some threshold.

The development of lakes on the land uplift coast

The principles of the gradual development of lakes on the land uplift coast have been presented in many studies (e.g. Lindholm & al. 1989, Lindholm 1991, Munsterhjelm 1997, Rinkineva & Molander 1997). The first stage is the “flada”, which still is continuously connected with sea via one or more shallow straits. The salt content in it is usually about the same as in the surrounding sea although the fluctuation and stratification can cause increasing changes in ecology. The next stage, in which the threshold has raised so that the sea water gets to the basin only temporarily is called “glo”. Together these stages last a few hundreds of years on the land uplift coasts. After the influence of sea water has come to an end, these basins start to develop to ordinary lakes. In this process, pH and nutrient contents of the water typically go down. The development of successive stages of lakes has been followed e.g. on the coasts of Hailuoto island (Vainio 1987), where the glo-lakes are typically eutrophic but lakes only a few hundred years older have become oligotrophic or dystrophic ponds very similar to comparable ponds on older land. Quite a remarkable part of small, shallow ponds on the littoral belt become rapidly filled by a lush vegetation and develop into mires.

The development of mires on the land uplift coast

The origin of mires by paludification and terrestrialization has been a target of study for a long time on the land uplift coastland, where new land is continuously rising above the sea line and mires cover a very large part of the terrain even quite near the coast. In the first studies (Backman 1919) it was observed that sediments of filled up lakes were encountered on only about 5% of the studied mire area in Central Ostrobotnia, mainly in the deepest and most thick-peated parts. Paludification of forests was considered to be responsible for nearly all mires of the area and the expansion of mires was thought to be a serious treat to the forests of Finland (Lukkala

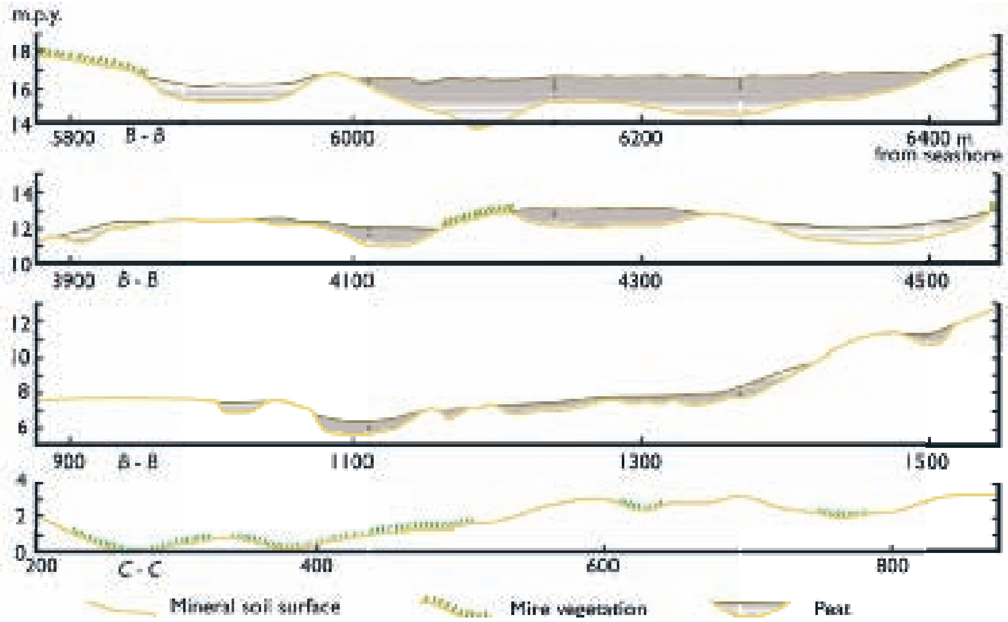

Fig. 4. Examples of the development of mire basins of different ages (Huikari 1956). The primary mire formation of the basins and the later expansion of mires to the heath forests can be seen.

1933) in spite of contradictory results from Sweden (Malmström 1931). The primary mire formation of land rising from the sea was, however, known at that time (e.g. Kujala 1924) and one had started to think about it as a phenomenon of its own kind (Malmstöm 1931). It was defined as a straight colonisation of mire vegetation on revealed land, which is not turned into heath forest at any stage. This was observed to be a very usual pathway of succession on land uplift coast (Huikari 1956). According to Huikari's results on land uplift coastland, about a half of the area of mires has been turned into mires directly from the seashore vegetation and about a half by the expansion of mires to the bordering heath forests (Fig. 4). Also on the geologically older land (areas above the highest post-glacial coastline), primary mire formation (of land emerged after the disappearance of the ice or ice-dammed lakes) was assessed to be almost equally important. The paludification of forests was found to be most vigorous on the land uplift coastland at the belt of 5-15 m a.s.l. (about 500-2000 years old) where the formerly separate primary mire basins get filled with peat and start to expand so that they become large, united mire complexes.

Species typical for the wet depressions, which are the starting point of the primary mire formation on the littoral belt are e.g. *Potentilla palustris, Carex aquatilis, Carex canescens, Carex nigra, Cicuta virosa, Eriophorum angustifolium, Lysimachia thyrsiflora, Pedicularis palustris* and *Peucedanum palustre* (Havas 1967). Many species typical for fens (*Carex chordorrhiza, Carex rostrata, Equisetum fluviatile* and *Menyanthes trifoliata*) appear in the littoral belt only at sites where terrestrial water is flowing (Elveland 1976), and their amount is greatest on the highest part of the belt. Also some *Sphagnum* species (mainly *S. squarrosum, S. fimbriatum* and *S. riparium*) can grow in the littoral belt at places least affected by the sea (Elveland 1976). These *Sphagnum* mosses start to grow abundantly in the uppermost parts of the littoral belt, where they can cover wet depressions and damp sites of willow thickets and broadleaved forests. So, wet shore meadows turn gradually into young swamp-like minerotrophic mires. Typical species appearing with the paludification of forests are e.g. *Sphagnum girgensohnii, S. capillifolium, Equisetum sylvaticum* and *Carex globularis* which don not occur in the littoral belt (Elveland 1976).

The studies of the development of mire complexes in the land uplift coastlands have been concentrated to the southern parts (Satakunta and Southern Ostrobothnia), where development into ombrotrophic bogs prevails. According to Aario (1932) the development has advanced evenly determined by the internal growth dynamics of the mire complex. A typical series starts from the swamps and spruce mires near the coast and is followed by fens and more acid cottongrass (*Eriophorum vaginatum*) dominated mires gaining finally the stage of an ombrotrophic bog. Brandt (1948) separates the following belts: swamps (0-1 m a.s.l.), swamp fens and tall-sedge fens (1-5 m a.s.l.), dwarf-shrub pine mires (5-10 m a.s.l.) and *Sphagnum fuscum* bogs (10-18 m a.s.l.). Patterned bogs prevail above 18 m a.s.l. Thus a bog needs of at least 2000 years to develop in that area.

The succession series of young coastland mires has been used also as a dating method for climatic changes. Brandt (1948) (contradictory to the results of Aario, 1932) considered the effect of climatic fluctuations very important for the development of mires. He separated eight "Grenzhorizons"from the peat layers of the oldest peat bogs and thought them to indicate shifts from drier to wetter conditions. In the peat layers of younger mires only a part of them was to be found. The contemporary warm stage was considered to affect so that the invasion of *Sphagnum* mosses to the young swamps takes place sooner than before. The interpretation of the separate peat horizons as simultaneous is however thought to be uncertain (e.g. Korhola & Tolonen 1996) and the whole question would need more studying.

The development of mires on Fennoscandian land uplift coast can be compared with that on the land uplift coast of Hudson Bay in Canada, where mires are very large. The differences in the climate are quite remarkable; a great deal of the Hudson Bay coastland belongs to the North Boreal or Arctic zone, where permafrost is usually met in the mires. The studies about the development of the mires in that region (Klinger & Short 1996) have been made in the southernmost corner, where permafrost does not appear and where the development into ombrotrophic bogs prevails. The process of bogs to get dominant has been assessed to last about 4000 years.

The zone of minerotrophic aapamires (Ruuhijärvi 1960) stretches to the land uplift coast of Fennoscandia in the northern part of the Bothnian Bay. Here it is hence possible to follow the development of aapamires in the same way as the development of bogs in more southern districts. The studies made on the land uplift coast of the aapamire zone have been concentrated to the extent of different ways of paludification (Huikari 1956), the vegetation differences between littoral belt and mires above it (Elveland 1976) and the distribution of main site type groups (Kukko-oja & al. 2003). The development of aapamires seems to have same principal features as the development of bogs, but the central parts of the basins stay minerotrophic. The abundance of rich fens in the young succession stages of aapamires is also noticeable. There is some basic research concerning the ecology and development of aapamires of the land uplift coast going on in the University of Oulu. The chronosequence of the mires on the coastland of Bothnian Bay is also used in a co-operation project studying the flux of gases responsible for the greenhouse effect during the primary succession of mire ecosystems. The results of this project become completed in the near future (Merilä & al.. 2006).

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Palsa mires in Finland

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Introduction

The term palsa was originally used by the Sami people and Finns, and in their languages it means a large peat hummock with a frozen core, rising above the surface of a mire (Lundqvist 1969, Seppälä 1972, Nelson & al. 1992, Gurney 2001). Palsas are characteristic to the discontinuous circumpolar permafrost zone (Seppälä 1997) provided that the peat layer is thick enough. They contain a permanently frozen core of peat and/or silt, small ice crystals and thin layers of segregated ice, which can survive the heat of summers. An insulating peat layer is important for preserving the frozen core during the summer. The peat should be dry during the summer, thus having a very low thermal conductivity, and wet in autumn, when freezing starts, giving a much higher thermal conductivity. This allows the cold to penetrate so deep into the peat layers that they do not thaw during the summer.

In western Finnish Lapland palsas are located north of 68º30'N latitude and in eastern Lapland north of Lake Inari (Fig. 1). Palsas are found in valleys with an insulating peat layer sufficiently thick to preserve the frozen core. The vertical distribution of palsas in northern Finnish Lapland varied from altitudes of 180 m to 390 m a.s.l. (Luoto & Seppälä 2002). On lower altitudes there is probably too much snow and on higher levels peat layers are too thin.

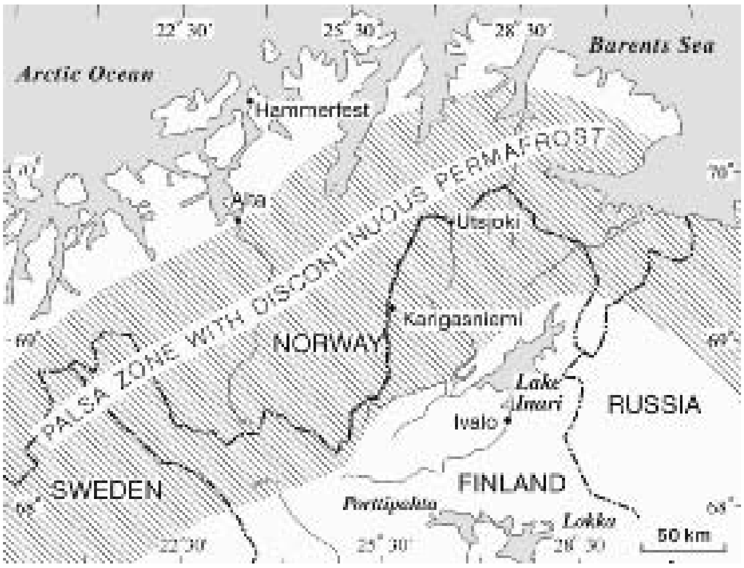

Fig. 1. Distribution of palsas in northern Fennoscandia (Seppälä 1988).

Climatological characteristics of palsa region

The optimum areas of palsa mires in northern Europe occur in areas of low precipitation (<450 mm) and the mean annual air temperature between -3°C and -5°C (Luoto & al. 2004).

In Finnish Lapland the southern limit of the palsa region coincides with the -1ºC mean annual air temperature. Lundqvist (1962) characterized the general distribution of palsas in Sweden requiring 200-210 days with temperature below 0ºC. Åhman (1977) in northern Norway found that the region could be delimited as having temperatures below -8°C for 120 days. The minimum temperatures in palsa region are often below -40°C in northern Finland. Maximum summer temperatures can rise up to +30°C. The warm air is not so damaging to palsas as summer moisture which decreases the insulation properties of the peat.

Freezing indices in palsa region in northern Finland range from 2000 to 2300 degrees and thawing indices from 1100 to 1400 degrees calculated from the daily mean values for period 1980-1991 (Seppälä & Hassinen 1997). Air temperatures do not directly affect permafrost formation because of snow cover.

Annual precipitation in palsa region is usually less than 400 mm, and less than half of precipitation is snow, received during 8-9 winter months when the air temperature is below zero.

Morphology and internal structure of palsas

Palsas can be classified according to their morphology: dome-shaped, elongated string-form, longitudinal ridge-form, and extensive plateau palsas as well as palsa complexes with many basins, hollows and ponds of thermokarst origin (Fig. 2) (Åhman 1977).

The diameter of dome-shaped palsas ranges from 10 m to 150 m and the heights from 0.5 m up to 7 m in Finland (Fig. 3). Longitudinal ridge-form palsas can be up to 0.5 km long and 6 m in height. Palsa plateaus rise 1-1.5 m above the surface of the surrounding peat surface and they can cover an area of a square km.

Palsas are either peat-cored or silt-cored. Peat-cored palsas have a perennially frozen core of peat with segregated ice and small ice crystals filling the pores. Silt-cored palsas contain frozen silt or silty till with thin ice lenses under a thin layer of peat insulating the frozen core.

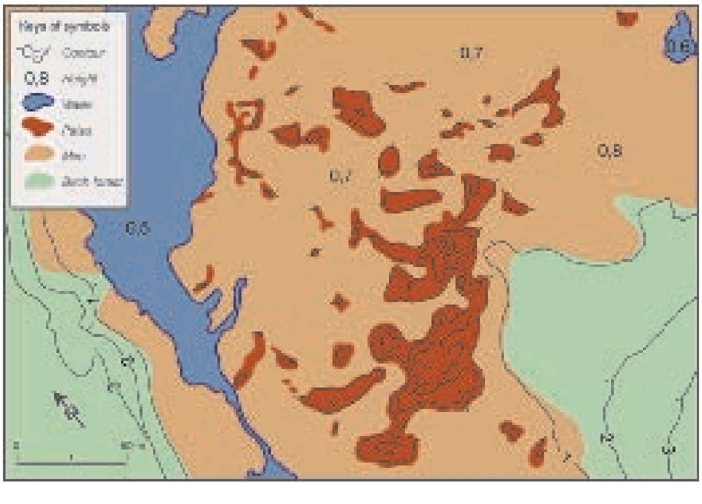

Fig. 2. A detailed map of a part of Vaisjeäggi palsa mire, Utsjoki, Finland. Contour interval 1 m.

Fig. 3. A mature, dome-shaped palsa in litto, Enontekiö. Photo Matti Seppälä.

Once a palsa hummock rises above the mire surface, peat formation on its top ceases almost entirely. The surface peat on an old palsa is produced mainly by Bryales mosses, lichens and Ericales schrubs. It can be also old moss peat eroded by wind. Below the dry surface, peat is the original mire peat formed of *Sphagnum*, *Carex* and *Eriophorum* remains (Seppälä 1988).

Dating of palsas

The dating of palsas is based on changes in ecological conditions caused by the uplift of the mire surface (Seppälä 2005). To date the formation of a palsa, samples should be collected from the contact of normal mire peat and of the dry peat formed on the palsa after its formation (Fig. 4).

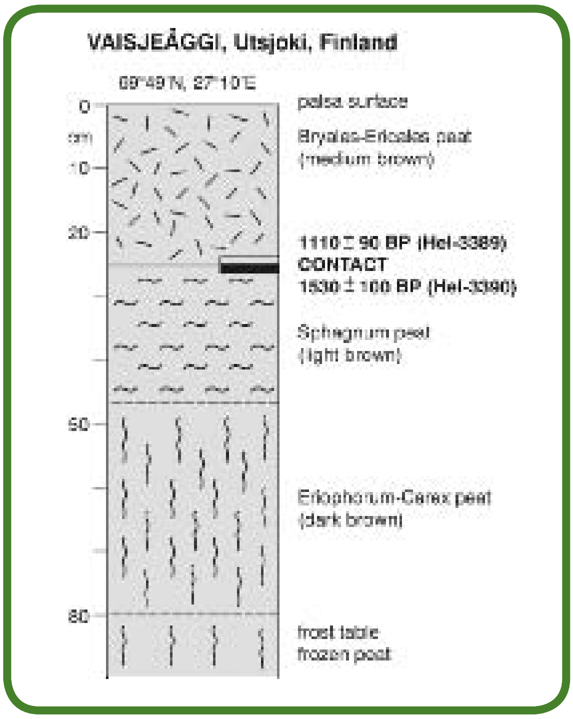

Fig. 4. Example of the stratigraphy of a palsa with datings from the contact of xerophilic and wet fen peat (Seppälä 2005).

Fig. 5. Some new 1.5 years old palsas on Vaisjeäggi palsa mire, Utsjoki in 2003. Photo Matti Seppälä.

According to radiocarbon datings obtained from Finnish Lapland most palsas are less than 1000 years old (Seppälä 2005). By means of plant macrofossil analyses, physico-chemical analyses and AMS-radiocarbon dating of peat deposits Oksanen (2006) concluded that the first permafrost aggradation on a palsa mire in northernmost Finland took place c. 2460 years B.P.

Some small palsas are much younger and since winter 2001-02 we have observed new palsa embryos (30 cm in height and 3-5 m in diameter) on Vaisjeäggi palsa mire, Utsjoki (Seppälä 2005)(Fig. 5). They occur occasionally after winters with thin snow cover and/or strong storms (Seppälä 1990) and survive a few years. Sometimes they may grow bigger, up to 60-80 cm in height, in favourable conditions even at present (Seppälä 2003).

Active layer on palsas

In Finnish Lapland the summer thawing forms only some 50 to 70 cm thick active layer on the summit of palsa.. On the southern slopes of palsas the active layer gets deeper and on the edges the permafrost table is almost vertical (Seppälä 1976, 1982b, 1983b). Small palsas thaw less than the high ones. On new palsa embryos the active layer is often less than 30 cm in thickness. Vegetation cover effects the active layer: thickest layers are found on lichen-covered surfaces and thinnest under *Betula nana* bushes (Rönkkö & Seppälä 2003). A surprising observation is that the bare wind abraded peat surface did not increase the thawing of the active layer (Rönkkö & Seppälä 2003, Seppälä 2003). The much abraded and collapsing palsas have a thicker active layer than uneroded palsas.

In recent summers, an unfrozen layer in some palsas has been found between the permafrost table and the thawing seasonal frost layer indicating some mild winters. This has not increased the final thickness of the active layer.

Fig. 6. Snow free palsa surface on Vaisjeäggi palsa mire in March 1994.
Photo Matti Seppälä.

Origin of palsas

The process of palsa formation is a product of the physical characteristics of peat. The thermal conductivity of dry peat is very low, that of saturated peat is considerably higher and that for frozen peat can approach the value for ice (Seppälä 1988). This means that during winter the cold penetrates easily into the mires especially through the snow-free positions, but during summer much more heat and time is needed to thaw the frost underneath dry peat layers.

Freezing of palsas takes place from above because there is no frost in surrounding soil layers. This is a difference when compared palsa formation with pingos which belong to the zone of continuous permafrost. The freezing front sucks moisture and segregated ice lenses are formed in the frozen core.

Fries and Bergström (1910) postulated that palsa formation was triggered when wind turbulence was responsible for the thinning of the snow cover on certain parts of a mire surface, so that in these places frost could penetrate especially deeply into the peat.

Experimental palsa studies and importance of snow

Low air temperatures together with low precipitation and a thin snow cover are found to be the most prominent limiting factors for palsa formation. The hypothesis that palsas are formed in places with thin snow cover has been proved experimentally by cleaning the snow off from the mire surface several times during three winters and it formed a permafrost layer in the peat and a man-made small palsa (Seppälä 1982a, 1995).

Wind drift controls the thickness of snow cover on the mire surface. Thin snow cover allows the frost to penetrate deep into the peat, and in these places the frost fails to disappear completely during the seasonal thawing and part of it remains under the insulating peat. In the following winters the unthawed layer of frost becomes thicker and the mound starts to rise. The wind then carries away snow from the exposed hump more easily and the freezing process accelerates (Fig. 6). This process increases the water content of the frozen core, which can be 80-90 per cent of the volume.

Cyclic development of palsas

The concept of cyclic palsa development is based on field observations and experimental studies in Finnish Lapland (Seppälä 1982, 1986, 1988, 2004)(Fig.7):

(A, B): The formation of a palsa begins when snow cover is locally so thin that winter frost penetrates sufficiently deeply to prevent summer heat from thawing it completely. The surface of the mire is then raised somewhat by frost processes.

(C): During succeeding winters frost penetrates still deeper, the process of formation accelerates and the hump shows further heaving due to the freezing of pore water and ice segregation. As the surface rises, the wind becomes ever more effective in drying the surface peat and keeping it clear of snow.

(D, E): When the freezing of the palsa core reaches the till or silt layers at the base of the mire, the mature stage of palsa development begins. By this time the palsa stands well above the surface of the mire, displaying a relief of up to 7 m in western Finnish Lapland.

(F): Degradation now starts, and peat blocks from the edges of the palsa collapse along open cracks into the pools which often surround the hummocks. During later stages, the vegetation may be removed so that the palsa surface is exposed to deflation and rain erosion.

(G): Old palsas are partially destroyed by thermokarst, and become scarred by pits and collapse forms. Dead palsas are unfrozen remnants: either low (0.5 to 2 m high) circular rim ridges; or rounded open ponds and pond groups; or open peat surfaces without vegetation.

(H): From such pools a new palsa may ultimately emerge after a renewed phase of peat formation, and the cycle of palsa development recommences from the beginning.

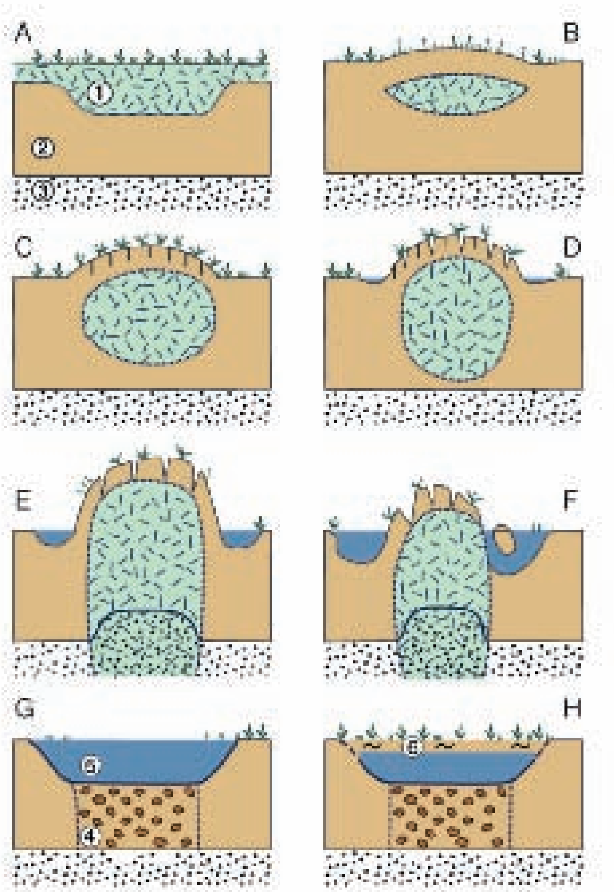

Fig. 7. A general model of the formation of the frozen core (1) of a palsa in a mire (2) with a silty till substratum (3). A. The beginning of the thaw season. B. The end of the first thaw season. C. Embryo palsa. D. Young palsa. E. Mature palsa. F. Old collapsing palsa surrounded by a large water body. G. Fully thawed palsa giving a circular pond on the mire (5). The thawed peat is decomposed (4). H. New peat (6) formation starts in the pond. (Seppälä 1982; 1986; 1988; 2004).

Thermokarst and the future of palsas

Palsa mires occur at the marginal zone of permafrost distribution. Therefore they may react easily on small changes in environmental conditions like warm air, but especially on summer precipitation and thick snow cover.

Thermokarst is a normal feature in the cyclic palsa formation. It modifies the large palsas in rather irregular and complicated shapes (Fig. 2). It can also fully destroy a palsa and leave just small ponds on the mire. During recent years several authors (Matthews & al. 1997, Zuidhoff & Kolstrup 2000, Luoto & Seppälä 2003, Luoto & al. 2004) have discussed the degrading of palsas probably because of climatic warming. The palsa area has been earlier much larger than today (Luoto & Seppälä 2003).

Present observations indicate that also new palsas are formed among the old degrading ones. Warm summers which we have had several during the last years have not melted the palsa cores, because the summers have been also rather dry and dry peat is a good insulator. Also new recently formed permafrost has been found in Lapland (Seppälä 1998, Luoto & Seppälä 2002).

Some palsa mires have been heavily abraded by wind drifted snow and ice crystals and among the palsas can be found thermokarst ponds (Fig. 8). If this process increases it will destroy palsas in large areas.

Fig. 8. A thermokarst pond among abraded mature palsas on Luovdijeäggi palsa mire, Western Utsjoki in August 1999. Photo Matti Seppälä.

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Cultural land use history in Finland

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Forested cultural landscape

The ancient bedrock and the recent glaciation history are the two main geological features characterizing the Finnish landscape. The Fennoscandian Shield bedrock predominantly consists of Precambrian silicate rocks, which are overlain by mostly a thin cover of loose superficial deposits. Owing to the low weathering rate of the common rock types, the soils are generally acidic and of low fertility. Throughout Finland the general relief of the land is rather flat, but the microtopography is very variable, due to the last Ice Age, at the end of which the ice retreated from the present Finnish territory between 12,000 and 7,000 yr ago. Glacial action and the post-glacial high water phases of the Baltic and the large inland lakes have shaped the geomorphic features of the terrain everywhere.

Most of Finland belongs to the Boreal coniferous forest zone. The southernmost coastal areas are attributed to the Boreonemoral zone, while the northernmost arctic fjell and upland areas belong to transitional forest tundra and treeless tundra vegetation types. Due to the generally low relief and consequent poor drainage, and the cool and moist climate, extensive paludification of the terrain has taken place.

Forest cover developed on the land soon after the ice retreat. Birch (*Betula* spp.) as a pioneer, followed by Scots pine, alder and aspen (*Pinus sylvestris, Alnus glutinosa, A. incana, Populus tremula*) spread throughout the land. Several deciduous tree species spread only to the southern parts of Finland (*Tilia cordata, Corylus avellana, Acer platanoides, Quercus robur, Ulmus glabra, U. laevis, Fraxinus excelsior*). A major change in the forest structure took place when spruce (*Picea abies*) migrated across Finland from the east between 5000 and 3000 years ago, which led to a decline in the southern tree species (Tolonen & Ruuhijärvi 1976).

Soon after the Ice age, Finland also got its first inhabitants. As a consequence of the generally harsh natural conditions, the human population density has never been very high. The boreal forest in its natural state could sustain a very limited number of people, even though the early inhabitants presumably made effective use of the resources available. The key food resource was probably animal protein, provided by moose (*Alces alces*), forest reindeer (*Rangifer tarandus fennicus*), smaller game and fish, but the foraging economy also utilized a broad range of vegetable nutrition: berries, young shoots, roots and rhizomes of several wild plants, tree phloem (Fi. *pettu*) of pine and aspen, mushrooms, lichens etc. The total population of Finland in the late stone-age Comb-Ceramic Period is estimated at 2 500 - 11 000, which equals a population density of approximately one person per 25 to 100 km^2 (Nuñez 1991).

Still today, Finland is predominantly a forest-covered land. It is not a wilderness landscape, however, because there is a very long history of varied and extensive forest use. Especially since the Second World War the use of forests has been very intensive. Practically all the forests show more or less strong signs of human interference, so Finland could be described as a land of forest-dominated cultural landscapes.

Agricultural uses of forest lands

Forest clearance for agriculture

In much of continental Europe, land clearance for agriculture created open cultural landscapes already during the Bronze Age - the so called *landnam* phase. In the Boreal forest zone, however, both climate and soil conditions posed obstacles for the northward spreading and establishment of cultivation (Zvelebil and Dolukhanov 1991).

According to archaeological and palaeobotanical evidence, crop agriculture was established in SW Finland during the Bronze Age, with some signs of cultivation already during the Late Stone Age. Pollen analyses have revealed scattered and usually weak records of cultivation even in the interior from these periods, i.e. some 5000 to 2000 yr ago. All along, there are also signs of cattle (sheep, goat and cow) husbandry. However, a general, landscape-level change mainly begins first during the Iron Age, not more than 2000 years ago in the SW, and much later, after AD 1000 in the interior and eastern parts of the country (Orrman 1991, Taavitsainen & al. 1998).

Burning of the forest was the typical way of starting agricultural clearance. The subsequent use of the site depended very much on the soil type. Permanent arable fields were most successfully established on the fairly limited areas of waterlain clay and silt soils with deep, well humified brown topsoils. Quite early, alredy during the first millennium AD, an open cultural landscape developed in river valley and lowland areas in the southwestern provinces of Varsinais-Suomi (Finland Proper), Satakunta ('Hundred') and Häme (Tavastia). However, the most common soils in the boreal zone are acidic podsols, characterized by a sharp contact between the poorly decomposed organic surface layer and the leached mineral soil below. These soils tended to lose their fertility in a few years after burn-clearance. Therefore, rotational slash-and-burning or swidden agriculture became widely practised.

The northern climate was another obstacle, to which both the farmers and the crop plants had to adapt. In Finland there is quite a prominent climatic gradient which is accentuated by the north-eastwardly rise of the terrain. From the point of view of crop agriculture, the growing season length is critical, and the incidence of summer night frosts interrupting the growth is an even more crucial phenomenon. Local microclimatic conditions are very decisive in this respect; sub-zero temperatures may develop on calm nights in low-lying areas, but rarely on hilltops and seldom on the shores of large lakes. Solantie (1988) identifies growing-season frost as the principal risk factor limiting crop cultivation in the interior area. Indeed, avoidance of frost-prone sites is clearly reflected in the placement of farms in central ad northern Finland.

Domestic animals have always played an important role in the Finnish agriculture, despite the hardships of the long winter, especially regarding sufficiency of fodder and availability of water. Forests provided both pasturing and winter fodder for the animals. Before industrial fertilizers, cattle manure was the sole fertilizer available for cultivated fields.

Rotational slash-and-burning, or swidden agriculture

Rotational swidden cultivation proved a highly successful means of Boreal forest ecosystem exploitation, but it required extensive land areas to remain sustainable. Swidden was suitable on poor podsol soils on till and even sand and gravel bottoms; various techniques and crop rotation practices were developed for different conditions (Fig. 1., Grotenfelt 1899, Heikinheimo 1915, Soininen 1974).

Barley (*Hordeum*) was the earliest grain crop plant in Finland, but rye (*Secale*) became the most common swidden cereal, with local varieties adapted for the special conditions of the burned soil. Turnip or swede (*Brassica rapa*, Fi. *nauris*) was also commonly grown on swidden plots. Depending on the soil conditions, usually only 2-4 crops could be grown on a swidden site, after which it could be used as pasture, and eventually became reforested.

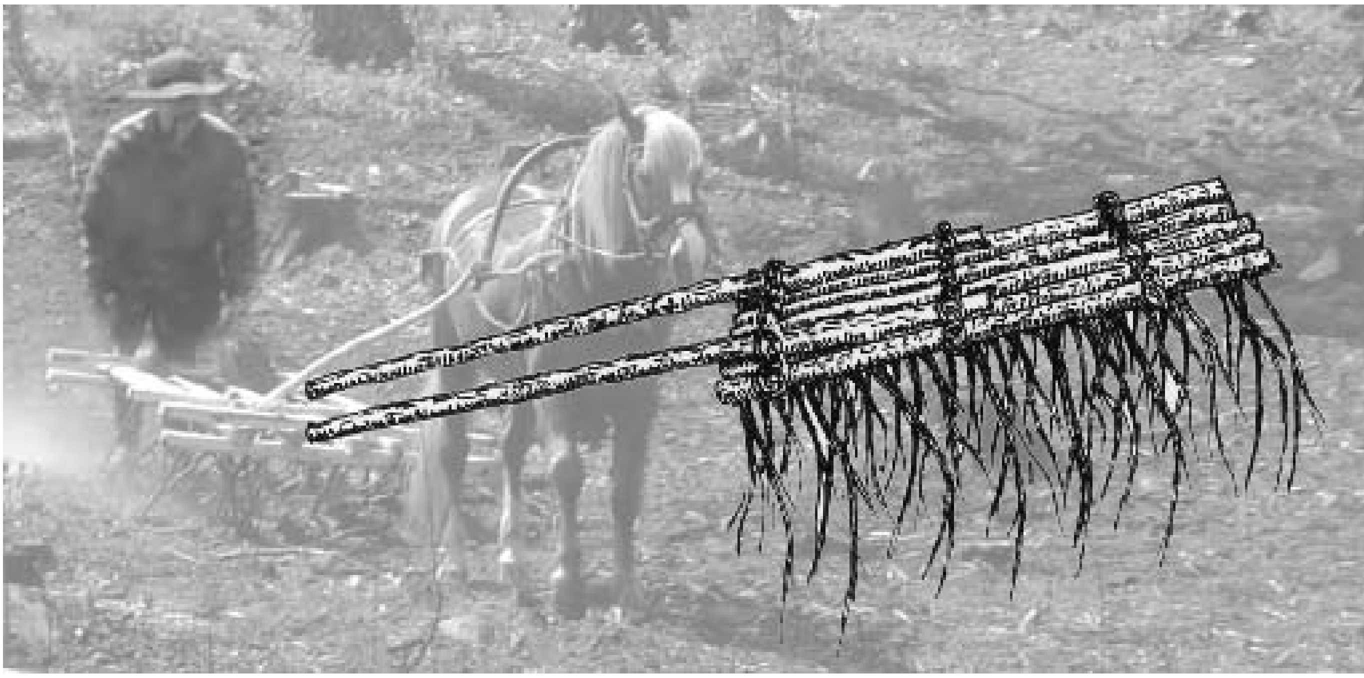

Fig. 1. A swidden harrow, built of densely branched spruce trunks (Grotenfelt 1899). This device is an example of the ingenious wood use in the traditional forest culture. The spruce trunks were cut and split with an axe and tied together with juniper bark strips, so the harrow could be built at the site of the swidden plot without any extra materials. Besides, it was eminently suitable for preparing the swidden plot, which typically was stony and full of tree stumps and roots.
Photo HAMK Mustiala, drawing and image manipulation Martti Salo.

Swidden cultivation enabled the expansion of crop agriculture northwards up to the Arctic circle (Kuusamo), and led to population growth, actually a gradual population explosion lasting for several centuries (Taavitsainen & al. 1998). From about 50 000 around the year 1300, the population had grown to some 500 000 in 1750, despite high-mortality periods caused by epidemies, famine and Swedish-Russian wars (the present population of Finland is just over 5 million). The developing population pressure was released by migration, first northwards within Finland, and since the 1500s, also to other uncultivated forested areas in Scandinavia (Finnskoga at the Swedish-Norwegian border; thence even to New Sweden in present-day Delaware in North America during the 1630s) and North-Central Russia (Tver and Novgorod areas).

Ever since the late 1600s there was increasing concern of the harmful effects of swidden culture on forests and soils (Fig. 2), and the government tried to prohibit the practice, but in the peripheric eastern and northern parts of Finland swidden actually remained as the main method of cereal crop cultivation until the latter half of the 1800s (Soininen 1974).

M. G. H.
OVÅLDUGE TANKAR,
OM JORDENS
SVEDANDE
OCH
KYTTANDE
I
FINLAND;
FÖRSTA DELEN,
YTTRADE AF
PEHR ADRIAN
GADD,
AF
ANDERS AGRICOLA,
JACOB MERCKELL.

Fig. 2. A thesis paper, publicly defended at the Turku (Åbo) University in 1753, presenting 'W(ith) G(od's) H(elp), Critical Thoughts about Swidden and Smoulder-cultivation in Finland', by docent (later professor) Pehr Gadd and his pupil Anders Agricola.

At its heyday in eastern Finland in the mid-1800's, swidden agriculture was rapidly approaching a crisis, especially within the climatically most favourable Southern Boreal vegetation zone. In the Lake District the 200 m height level marks a climatic boundary, coinciding with the transition between the South and Middle Boreal forest zones. Below and to the south of this boundary, practically all land was in swidden use, and with growing population the rotation times had to be shortened, from the initial several decades down to only 15-20 years, which led to soil impoverishment, declining crops and increasing famine risk. It is known from historical records that the landscape of eastern Finland was generally open and mostly devoid of mature coniferous forests. The people even suffered from a general shortage of construction timber. Swidden practicing ceased first when the emerging industries started creating demand and value for timber. As an evidence of swidden history, relatively high proportions of birch and alder characterized the forests of eastern Finland until late 1900s.

The typical swidden landscape was characterised by very extensive semicultural habitats - old swidden plots remained in use as meadows for herb and sapling fodder collection, forest pastures etc. In the modern landscape there is much more strict demarcation of forestry and agricultural areas. The semicultural habitats have dramatically diminished: the present area of meadows and pastures is only some 20 000 hectares, or about 1 percent of that a hundred years ago.

Agricultural use of peatlands

The burn-clearance technique was applicable also on forested peatlands, and there are historical records of peatland cultivation already in the 1600s. Often some measure of drainage was required to make the peat surface dry enough to burn. In the river valleys of Ostrobothnia, on the western coast of Finland, a special cultivation technique called *kytö*, or 'smoulder cultivation' was developed on the extensive peatlands typical for the level terrain. In this technique, the field surface was regularly burned at a few years' intervals, which allowed continuous cultivation on the site, until the entire peat layer was wasted away. The typical *kytö* cultivation involved a rotation of crop and fallow years the same way as on ordinary arable fields. The peatland field soils were often improved by spreading clay or till material on the surface, in addition to the customary cattle manure.

It is estimated that altogether about one million hectares, or ten percent of the original peatland area of Finland, has been taken into cultivation during the past centuries. While the most fertile sites have always been preferred, this has very much impoverished the biological diversity of peatland ecosystems in southern Finland.

In the old traditional agriculture, sedge- and herb-rich mires were also used for collecting of winter fodder for cattle, and to some extent even directly as pastures. Especially in the north, suitable peatlands were often flooded in the spring by dams, to suppress trees and shrubs and to enhance the growth of herbs. Besides fodder, also *Sphagnum* peat was collected from natural peatbogs, mainly for use as cowhouse litter.

Forest product utilization

Domestic uses of wood and other tree materials

The traditional Finnish folk culture is pre-eminently characterized by skillful and versatile use of wood materials for a wide variety of purposes (Talve 1997). The timber, bast and bark, even roots and twigs of each woody species had their own specific uses in various constructions and utensils. The locally available wood materials often served as substitutes for other, more expensive or unattainable materials.

In the self-sustained rural economy the biggest needs for wood materials were for fuelwood (mainly deciduous trees) and for construction timber (predominantly pine). However, in terms of wood utilization, these needs were quite insignificant relative to the huge impact that the simultaneous swidden practice had on forest ecosystems. However, it is possible that the timber utilization also brought about some irretrievable changes in the Finnish nature. Thus, pine may have retreated from parts of Fjell-Lapland and oak from the interior southern Finland because of over-explotation of these valuable trees at their marginal spreading ranges.

Charcoal and tar

Charcoal was used in local metal industries, mainly in processing of lake iron ore. To some extent charcoal burning was practiced already in medieval times, but its impacts on the forests remained rather local even at the peak of domestic iron working during the 18th and early 19th centuries.

Tar became the first major export product of the Finnish forests. Tar is distilled from resinous pine wood splinters in large tar-burning pits, and it was traditionally used as a protective coating for all kinds of wood materials exposed to moisture or adverse weather conditions. At the era of wooden sailing ships, there was an unlimited demand of tar in all European shipyards.

Political history and transport conditions defined the tar production areas in Finland. Initially, tar burning developed in the eastern Lake district (Saimaa) during the 1600s and early 1700s, but after Sweden had lost the south-eastern coastal ports to the expanding Russia, the production shifted to the West coast. Practically all pine forests along the western watercourses draining to the Gulf of Bothnia became heavily exploited for tar burning. To increase the resin content, it was customary to scar the trunks of living trees a few years before they were felled. Tar demand as well as the export prices increased steadily until around the 1870s, after which the export rapidly declined, marking the time when the British navy shifted over to steel ships. During the long period of profitable export trade, all suitable pine forests had been taken into use, and the tar burning area had gradually shifted up along the rivers, until reaching the main water divide, across which it was not feasible to transport the tar.

The main water divide that runs SW-NE across Finland actually became a significant demarcation line for differing forest exploitation practices in southern Finland. While the tar barrels were transported to the coastal harbour towns by floating, all the western river courses were cleared out to facilitate this transport. As a consequence, also timber floating readily developed on these river catchments at pace with the developing steam-engine sawmilling industry during the 1800s. Thus, the forests of the west coast catchments have been effectively exploited commercially for a long time.

In contrast, on the south-eastern side of the main water divide, especially on the upland areas that had remained outside the most intensive swidden activities, the forests retained much longer their wilderness character. This was still evident by the abundance of dried-out standing kelo-trees recorded in the Second nationwide forest inventory in 1936-1938 (Fig.3, Kalliola 1966, Simola 1995), and during the early 1990s, when a special protection programme was established for the last vestiges of old-growth forests in southern Finland (Rassi & al. 1992b).

Fig. 3. The records of dried-out standing kelo-trees (mainly Scots pine) on the transects of the Second nationwide forest inventory, conducted in 1936-38, demonstrated that still at that time old-growth forests were fairly common in the eastern and northern parts of the country, and also in central Finland within a strip extending from the eastern border along the southern side of the Suomenselkä water divide (Kalliola 1966).

Industrial wood acquisition

Industrial wood processing - sawmilling since the early 1800s and pulp and paper industry from around 1900 onwards - have been central elements of Finland's industrial development and export economy throughout the country's modern history. The beginnings of economical forestry coincide historically with the process of land reparcelling (Fi. *isojako*), by which ownership was established on the former common-use lands. Large unclaimed wilderness areas remained public domain, and a governement institution, initially named General Board of Land Survey and Forestry, was established in 1859 to manage the crown lands. Today this organization, Metsähallitus, is a state enterprise that administers about 12 million hectares, or one third, of the land and water areas of Finland, including most of the nature protection areas.

To make full use of the forest resource, the Finnish government has practiced quite a strong forestry-promotion policy ever since the mid-1800s. This has involved development of legislation, establishing of administrative and advisory organizations for the private forest sector and promotion of industry by various measures. A governmental Forest Research Institute, Metla, was founded in 1917 - the same year as Finland became independent. Nationwide forest inventories, the first one conducted during the 1920s, and the ninth just completed, have been a major research task of Metla. Thanks to these inventories, the forest resources and their development are known in great detail, which has enabled intensive use of the forest resources on an economically sustainable basis. The active and nationally coordinated forestry policy has profoundly impacted the forest nature of Finland, especially since the last war.

The post-war history

Starting points: intensified forestry to compensate losses of war

In the Second World War Finland lost about 10 percent of its territory to Soviet Union, and had to resettle about 400 000 evacuees from the ceded areas. Further losses included several industrial establishments and about half of the nation's built hydropower capacity (Klinge 1997).

In that situation, the need to intensify forest use to rebuild the economy and to compensate for the losses, was quite understandable. This period of a kind of heroic high-power forestry lasted well into the 1980s, and its spirit still lingers, at least in the ever-continuing debate concerning proper forestry conduct. New forceful forestry practices were adopted, all in large scale, including clearfelling, soil ploughing, tree planting, peatland drainage, fertilizer and biocide use etc. These measures were in a way accepted as uncontested doctrines of rational forestry. This process also involved change from man-and-horse work to motorized logging techniques.

Changing forest nature and landscapes

As a consequence of the government's active industry promotion policies, also the wilderness forest resources of northern Finland were taken into full use. This involved expansion of the road network and building of several state-owned wood processing factories in eastern and northern Finland. Owing to very large clearfelling areas logged at a rapid pace in the pristine forests, the shape of Finland and particularly the eastern borderline became clearly visible in satellite pictures during the 1980s - since then, loggings on the Russian side of the border have again gradually obliterated the image.

Unprofitable forestry drainage of *Sphagnum fuscum* bog in Kauhajoki, western Finland in 1982, 10 years after ditching. Light-coloured sand in the ditch in the foreground has eroded from a drained thin-peated mire. Photo Raimo Heikkilä.

Peatland drainage was another large-scale activity to which the forestry organisations were prompted by the grim post-war situation. About five million hectares of peatlands were ditched in order to initiate or improve forest growth. Thus, nearly half of the initial peatland area was irretrievably altered, and in large areas of southern Finland, practically all natural peatlands were destroyed. At current estimates, between 20 and 30 % of all the ditchings were useless, without any positive consequences on wood production (Eurola & al. 1988).

From the forestry management point of view, the intensive forestry measures are quite dramatically reflected by the nationwide forest inventories, as a change over to a very regular 'normal forest' age structure, with equal sized age cohorts providing a steady and maximized flow of timber for the industry. The forest tree species composition has also been altered. The wood processing industry in the post-war period in Finland could, unfortunately, only utilize conifer fibre, so deciduous trees, e.g. birch and aspen, were considered completely worthless. Especially pine was inordinately preferred, even on sites on which pine does not grow too well. On the other hand, the extermination of birch and aspen was so effective that the recently emerged demand for their fibres has to be largely met by import from Russia.

Present and future trends of land use in Finland

At present, rapid depopulation of the countryside, especially in the sparsely inhabited eastern and northern areas, is taking place. The post-war settling of the evacuees and war veterans on newly parcelled farmsteads effected a last blooming of life in these rural areas, but now the traces of agricultural activities are in many places rapidly and completely disappearing from the landscape. Often the abandoned fields have been re-planted into forests, accelerating the fading away of human presence in these areas. The loss of the cultural and semi-cultural habitats of the agrarian environments often means regionally a great loss of biodiversity.

On the other hand, modern intensive agriculture is thriving in the southern areas climatically best suited for cultivation. This development is characterized by increasing farm and field sizes, heavy machinery, specialization etc. Grain crops, sugarbeet and dairy farming are among the main production lines. In the modern rural landscape there is little space for semi-natural meadow of pasture habitats, except for obligatory buffer zones that according to EU:s water protection regulations should be maintained at waterfronts. Other types of modern open habitats, such as roadsides, power lines etc provide at least potential environments for the declining biota of the former semicultural habitats of the traditional agriculture.

The present forest landscapes throughout Finland are characterized by intensive management. Owing to the long history of exploitation, the forest nature has lost much of its natural character; besides, the forests are thoroughly fragmented by a network of 120 000 km of forest roads. Forestry practices have homogenized forest structure everywhere, save for the remotest areas in the North. Throughout southern and middle Finland there are practically no old-growth forests, nor natural forested peatlands left, the amount of dead wood is a fraction of that in natural forests, and mixed woods have been largely converted to even-aged one-species plantations. The main structural diversity is quite artificially created by the clearcut loggings: the modern forest mosaic consists of patches of tree stands of different ages. At the landscape level the age distribution of these stands is quite even with equal amounts of each age cohort within the maximally 100-years' logging age span.

By side of this development, forest biodiversity protection has become an issue of great concern. The Finnish Red Data Book (Rassi & al. 1992a) listed over 700 species endangered in Finland due to forestry management practices. This has already affected the forest management, with softer and ecologically more considering methods taken into use in ordinary forestry, with habitat restoration methods being developed for instances where former management operations have proved useless or harmful, and with protection area network gradually developed.

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The use of mires for agriculture and forestry

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The use of mires for agriculture

Agricultural use of mires began in the Stone-Age with hay-making on sedge-dominated mires by lakeshores and riversides. The earliest written accounts on the agricultural use of mires are from the late 17th century. During that time, the vicar of Isokyrö (Ostrobothnia), Elias Brenner, described successful peatland cultivation carried out by his father. The cultivation method started by ditching the mire, which was then followed by the burning of the dry surface, and thereafter worked over and fertilized for the sowing of rye. This cultivation method later spread from Ostrobothnia to other regions, including Savo and Karelia (Lappalainen 1996).

The foundation of the Finnish Society of Peat Cultivation in 1894 was significant for the development of the use of mires for agriculture. The Society published its first yearbook in 1897, and through its work many esteemed scientists became very influential in Finland, for example Mauno J. Kotilainen, Erkki Kivinen, and Yrjö Pessi (Lappalainen 1996). The Society also made the first inventory of the proportion and distribution of organic soils in Finland, showing that they represented 25% of the cultivated field area. This would have meant a total area of 500 000 ha in the whole country (Malm 1922).

Later Pessi (1966) calculated that the proportion of mire originated fields would be 29.7%, which would mean approximately 720 000 ha based on the total agricultural land area of the year 1950, and 750 000 ha based on the total agricultural land area of the year 1960. Although Pessi (1966) concluded that the peatland fields would be underestimated in the sampling and thus their total area would still be higher than he calculated, he proposed – based mainly on Juusela & Wäre (1956) and Kurki (1963) – that the area of mire originated fields would be 700 000 ha in Finland. This has been the most used figure in several calculations and publications until now. However, Valmari (1982) has estimated that the total amount of mires cleared for agriculture in Finland would have been as much as one million hectares. Part of the organic soils would first have changed to mull soils and finally to mineral soil fields. This change is based on the continuous decomposition of organic matter as well as the mixing of organic and mineral soil layers by ploughing or by adding mineral soil on peat.

In summary, a total of 0.7 – 1.0 million hectares of peat soils have been cleared for agriculture in Finland. However, most of these peat fields were used for only a relatively short period of time and they have probably been changed back to forest land, and a large proportion of cleared shallow-peated areas have become mull or mineral soils. The need for new fields was greatest when the population started to increase more than 100 years ago, and after the Second World War when new arable land was needed to compensate for the land lost during the war (Myllys 1996).

According to the latest inventory of cultivated organic soils in Finland (Myllys & Sinkkonen 2004), the area of organic soils containing more than 40% organic matter (i.e. peat) was 85 000 ha (3,8% of the arable land). The area of organic soils containing between 20 – 39,9% organic matter and often occurring with a mineral subsoil, was 214 000 ha (9,7% of the arable land). Altogether, the area of these soils was 300 000 ha, which is 13.6% of the arable area in Finland (Myllys & Sinkkonen 2004). The proportion of organic fields is greatest in northern Finland (13-15%) and smallest in southern Finland (1-2%, Fig. 1). It is important to identify the areas of organic arable soils, for the leaching of nutrients (especially N and P) to watercourses (Huhta & Jaakkola 1993) and greenhouse gas emissions (CO_2, N_2O) (Martikainen & al. 2002), which are greater from peatland fields than those from mineral soil fields.

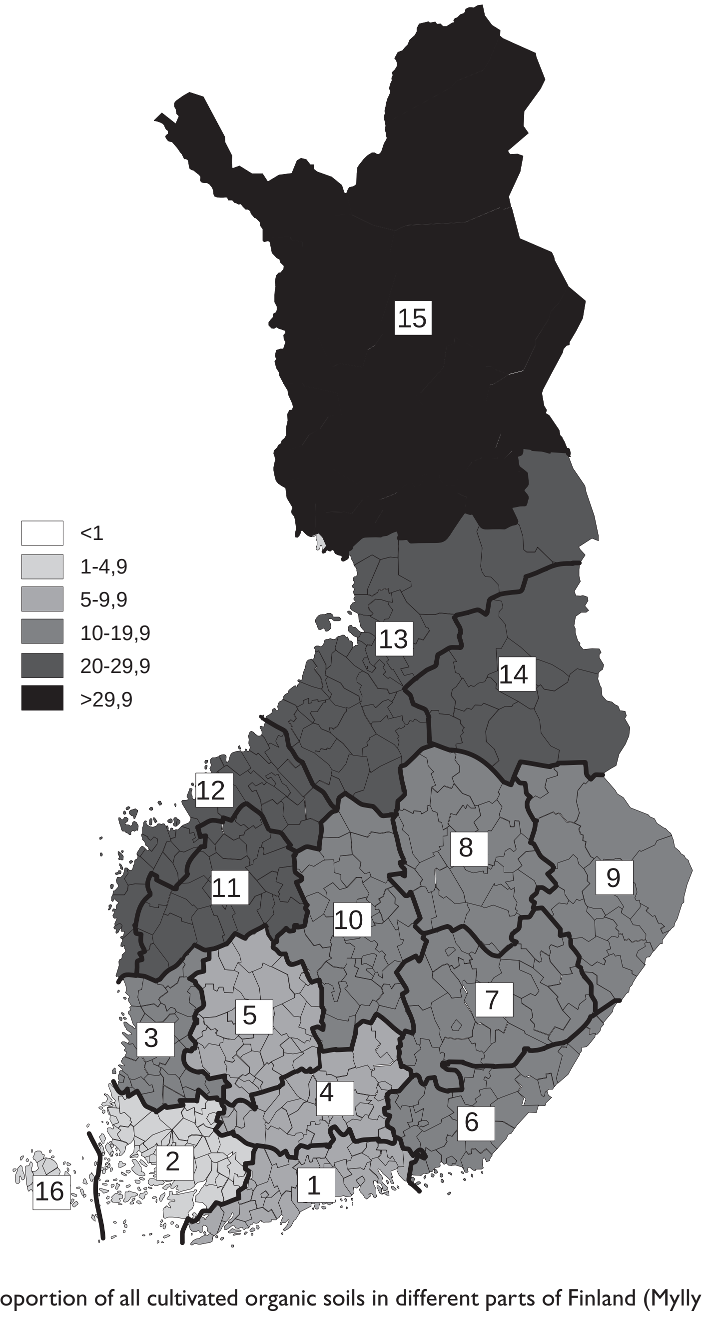

Fig. 1. The proportion of all cultivated organic soils in different parts of Finland (Myllys & Sinkkonen 2004).

Peatland in Ilmajoki, western Finland, taken into agriculture around the year 1800.
Photo Raimo Heikkilä.

Mires used for forestry

The earliest mire drainage operations in Finland took place during the famine years (1866-1868). At that time, the aim was to provide work for the unemployed and to occupy new arable land. More systematic drainage aimed at increasing the growth of tree stands on peat soils or wet mineral soils started on state- and industry-owned land in1908. The private sector started forest drainage in 1928 when the first Forest Improvement Act was introduced. Forest improvement legislation directing government subsidies and low-interest loans to private forest owners has had a decisive impact on the level and scope of forest drainage in Finland (Päivänen & Paavilainen 1996).

Forest drainage activity developed into a nationwide campaign to increase forest growth in the 1970s. The area drained annually increased steadily up to 1969, when 295 000 ha was drained. According to the forestry statistics, the total forest drainage area is about 6,0 million ha. The real area of drained mires is, however, smaller, because forestry statistics include old drainage areas, which have had complementary ditching and thus have been counted twice. On the other hand, the area of forest drainage in national inventories is too small as some of the mires originally drained for forestry have been cleared for agriculture or peat harvesting, and some of the drained sites with a shallow peat layer have later been classified as drained mineral soil (Päivänen & Paavilainen 1996). According to the latest inventory (Tomppo 2006) the area drained for forestry in Finland is approximately 5.5 million ha, of which 4.9 million ha are drained mires and 0.6 million ha are drained mineral soils, which have probably been thin-peated originally. Since drainage of mires for forestry ended practically speaking in the mid-1990s and forest certification does not allow new drainage at all, the drainage area realized is and will be lower than was planned in Finnish national plans (6,5 – 7.5 million hectares, Heikurainen & al 1960, Kuusela 1972). About 10% of the drained area has been estimated to be too poor for forestry (Eurola & al. 1991, Hökkä & al. 2002). By at least partially restoring this area, we could increase the regional diversity of mire fauna and flora as well as decrease the harmful effects of cuttings and fertilization on recipient water-courses through restored buffer zones in peatland forestry (Silvan & al. 2003, Vasander & al. 2003).

Drainage and fertilization of mires and peatlands have considerably increased the total volume and annual increment of peatland forests. According to the National Forest Inventories (NFI), the total volume and increment of peatland forests have developed since the beginning of 1960s as follows:

	Standing volume mill. m^3	Total annual increment mill. m^3
NFI 3 (1951-53)	252	9.9
NFI 7 (1977-84)	291	14.9
NFI 8 (1986-94)	377	17.4
NFI 9 (1996-03)	479	21.2

About 23% of the total stand volume of Finnish forests grows on peatlands. The average volume on drained peatlands is 80 m^3ha^{-1} which is clearly smaller than the average volume on mineral soil forest (100 m^3ha^{-1})(Tomppo 2006). Spruce-dominated drained peatland forests have approximately similar-sized stands as on mineral soils but pine-dominated stands are clearly smaller. Also, younger development classes on drained peatlands than on mineral soils, on average, partly explain the volume differences between drained peatland and mineral soil forests (Hökkä & al. 2002, Tomppo 2006).

The total annual increment of peatland forests measured in NFI 9 was 21.2 million m^3 of which majority (18.1 million m^3) grew on drained peatland forests and the remaining (3.1 million m^3) on undrained treed mires (Tomppo 2006). The total amount of annual growth is slightly more than double compared to NFI3. Also, the mean annual growth of drained peatland forests has increased from 2.5 m^3 ha^{-1} in NFI 3 to 3.7 m^3 ha^{-1} in NFI 9 (Tomppo 2006). Heikurainen & al. (1960) and Kuusela (1972) estimated that the annual growth of drained peatland forests would be between 18 – 23 million m^3 in the middle of 1990's. The present total annual growth falls between these estimations even though the total drained area is 0.8 – 1.8 million ha smaller than the predictions and estimations given by Heikurainen & al (1960) and Kuusela (1972). Thus, the growth of drained peatland forests has been greater than was estimated some decades ago. It must, however, be noticed that the increase in total stand volume and annual increment is not dependent only on the ameliorative effect of drainage and fertilization but also on the small amounts of cuttings (Päivänen & Paavilainen 1996).

Scots pine (*Pinus sylvestris*) is the dominant tree species on about 70% and Norway spruce (*Picea abies*) on about 15% of drained peatlands. However, the proportion of Scots pine of the total volume of peatland forest stands (about 50%) is clearly smaller than the prevalence of pine-dominated stands would indicate. The reason is that the volumes of tree stands are much larger on drained peatland forests dominated by Norway spruce and deciduous tree species, while they are more nutrient-rich sites (Hökkä & al. 2002).

Rikala (2003) compared the qualitative properties of peatland trees to those grown on mineral soil and evaluated the suitability of the wood for various end-uses. He concluded that spruce sawn timber from drained peatland forests was of good quality, decreasing only slightly from butt towards the top of the tree. The quality of sawn timber from peatland spruces corresponds to that produced by mineral soil sites.

Monotonous pine stand in a drained and PK fertilised mire near Seitseminen National Park, western Finland in 2005. Originally the site has been probably sedge pine mire, drained in 1972. Photo Tapio Lindholm.

Thus, peatland spruce sawn timber may be utilized in the same end-use areas as spruce sawn timber in general, i.e. mainly in construction. The quality of sawn timber from pine butt logs was good, but numerous dead and unsound knots lowered the quality of sawn timber from the upper parts of stems. This means that peatland pine sawn timber is slightly poorer than that of upland sites. Sawn timber from butt logs is suited for purposes from construction to visible joinery. The primary uses for pine middle logs are construction and end-uses that are to be painted or covered. Rikala (2003) gave no suggestions for the use of pine top logs but probably they would be used mainly for pulp and paper industry or biomass fuel.

One problem in practical peatland forestry has been that the cuttings realized are far behind the plans and calculations made by forest authorities and researchers. In NFI 8 it was estimated that there would be a need for cuttings on 2.35 million ha during the next ten year period. A little more than 0.5 million ha of stand cleanings or fellings has been estimated to be in delay (Hökkä & al. 2002). In NFI 9 this delayed stand cleaning or felling area was estimated to have rosen to 750 000 ha (Tomppo 2006). Nuutinen & al (2000) estimated that the annual amount of sustainable fellings would be 9.7 million m^{-3} between 1996-2005. Furthermore, they estimated that with this amount of cuttings, timber harvests on drained peatland forests would comprise almost 18% of the total volume harvested in Finnish forests by the year 2026. Similarly, it was estimated in NFI 8 that complementary ditching would be needed on an area of 1.5 million ha (Hökkä & al. 2002), which is a higher figure than was estimated a decade earlier (1.1 million ha, Keltikangas & al. 1986). The area estimated to be in need of complementary dicthing was estimated to have increased to 1.7 million hectares during NFI 9 (Tomppo 2006). This would mean complementary ditching (ditch cleaning and supplementery drainage) on about 120 000 ha annually.

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Destruction of mires in Finland

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Introduction

Finland is a land of mires. The rapid and intensive land use in 20th century has changed the faces of "mother Finland" so greatly that the role of mires in Finnish nature is very different from what is was 100 years ago. When considering the results of mire conservation (Kaakinen& Salminen 2006) there are many representative mires in nature reserves. Only in northern Finland there are more or less intact mires also outside nature reserves. In southern Finland, most mires outside nature reserves have been destroyed as functioning mire ecosystems. They have been changed in most cases into peatland forests, fields or peat mining areas. This article deals with the effects and scale of the destruction process. Also the role of different purposes for the destruction are discussed.

The utilization of mires has been has been much more intensive in Finland than in other northern regions in the world. Forestry, agriculture and peat harvesting have in general destroyed original mire habitats, and hence also the fauna and flora. The total amount of mire area has decreased in different ways: some mires have totally disappeared: mineralized peatland fields, originally thin peated mires mineralized after silvicultural drainage. Former mires, which have been destroyed by reservoirs, roads and urbanization belong to this category also. The main reason for the destruction of mires has been the attitude that mires are worthless wastelands if they are not managed. Any human activities changing mires have been thought to be useful. This has lead to overoptimistic attempts in forestry and agriculture, often without any real profit. The state has during decades supported financially the destruction of mires. In southern and central Finland cheap loans and partial direct support have been given to landowners, but in northern Finland, Lapland and Kuusamo, the state has paid all the expenses of forestry drainage on the basis of the special "Lapland law", despite the fact that forestry is least profitable there. Even nowadays e.g. the water and biodiversity protection principles of the EU water policy directive are not fully taken intoa account in connection with forestry.

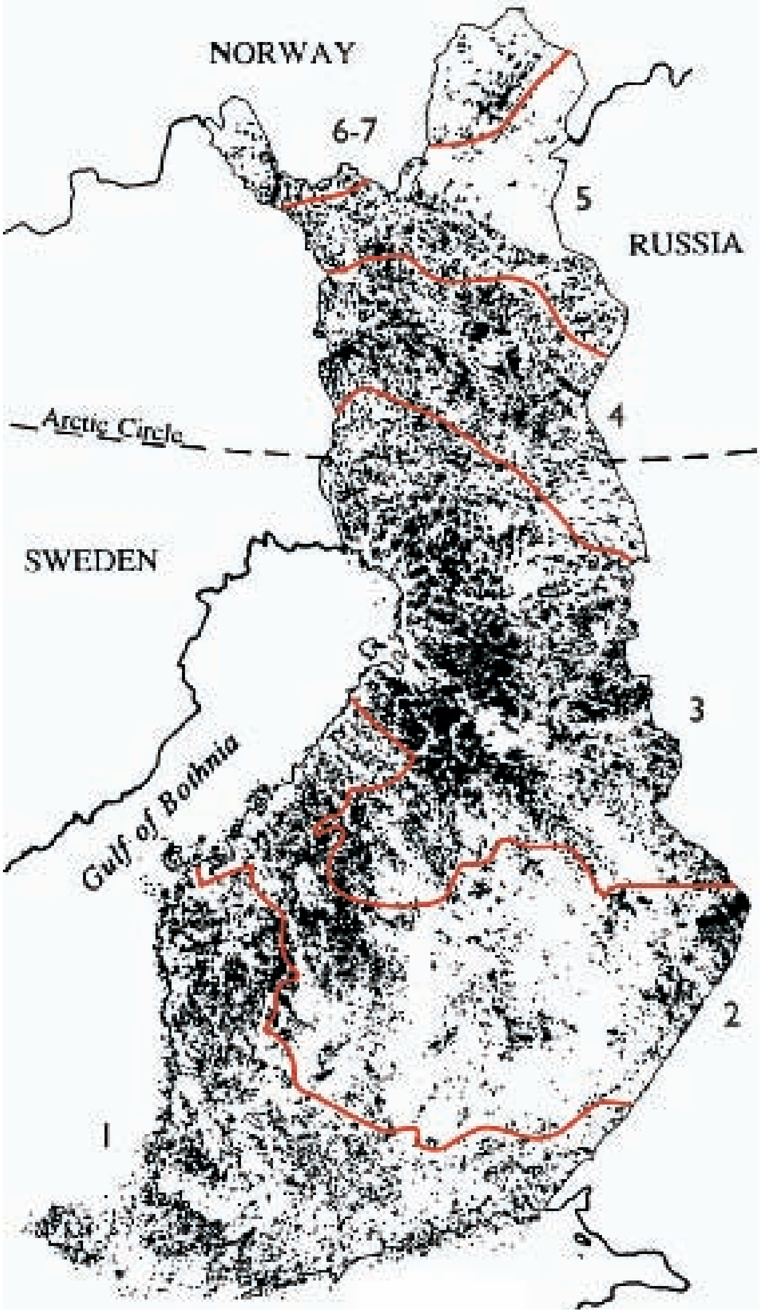

Fig. 1. Mire massif zones according to Ruuhijärvi (1988) and distribution of mires in Finland. 1. Concentric bogs and plateau bogs, 2. Eccentric bogs, 3. Sedge aapamires, 4. Flark aapamires, 5. Pounikko aapamires, 6-7. Palsamires and orohemiarctic mires.

What we have had

Finland's mires covered a total of about 10,4 million hectares in the beginning of 1950s (Ilvessalo 1956), representing about one third of the country's entire land area. The term mire covers here also wooded, but paludified habitats. Thus, some of the mires have been also regarded as forests with fairly good timber production, but a greater deal of mires have been sparsely wooded with poor timber growth and the rest of the mires have been open. In geological sense (> 20 ha > 0.3 m) the area of mires has been about 5 million ha (Lappalainen & Hänninen 1993). In northern Finland, in the northern and middle boreal forest zone, there are areas where more than 60 % of the land area has been covered by mire vegetation, while in some southern parts of Finland the proportion of mires has been under 10 % of land area (Fig. 1). Reasons to this are differences in both climate and topography (Ruuhijärvi 1988). The diversity of mires on massif and site level has been great. Due to climatic reasons, bogs have dominated in the southern half and aapamires in the northern half of Finland. Differences in bedrock and Quaternary deposits have caused variation on site level.

Rich fen in Merlampi mire in Juuka, eastern Finland in 1989. On the right, cattle had been still grazing. *Eriophorum latifolium*, *Carex capillaris* and many other rich fen species were much more abundant than on the left side of the fence, which was not grazed. Photo Raimo Heikkilä.

The traditional use of mires

Formerly many mires – particularly in northern Finland – have been used for collecting winter fodder for livestock. In many areas most of the open mires, growing sedges and grasses have been used as mire meadows. This kind of activity is now history. The long tradition generally ceased in 1950s, as well as domestic peat harvesting for cattle litter, even though in a few cases it continued up to 1980s. This kind of use did not destroy mires. Instead, there is evidence, that the management has favoured rich fen vegetation (Simola 2006). Picking berries did not change the mires, but the populations of a few bird species decreased due to hunting, which was not always sustainable.

Peatland forestry

The first attempts to improve timber growth by ditching of mires were made in limited areas during the 1866-1867 famine years (Lukkala 1937), but the first scientific study about the profitability of drainage in Finnish conditions was published by Tanttu (1919). In the beginning, ditching was made by spade up to 1930s after the first law on forest improvement in 1928 (Tuokko 1992). During the Second World War there was no ditching, and it was started in large scale in the beginning of 1960s after the release of timber production improvement programmes (MERA). Ditching was most active in 1960s and 1970s, and it was done with excavators. Mires were usually fertilized after ditching (Tuokko 1992, Vasander 2006). Before the excavators, also the use of other kind of machinery and explosives was attempted.

Drainage of a spruce mire after clearcut near Seitseminen national park, western Finland in autumn 2004. Even though it is said that the ditching of pristine mires has ended, this kind of treatment is typically done in mire margins. In addition to the destruction of mire habitats, it causes leaching of nutrients and humic substances into watercourses, which is against the principles of the EU water policy directive. Another point is that this kind of destruction of biodiversity also is against water policy directive. Photo Tapio Lindholm.

Forestry is an important industrial sector in Finland and pristine mires have been regarded as a valuable resource for forestry. Therefore, large areas of mires have been drained for forestry purposes, covering a total of 5.9 million hectares of former mires. Thus Finland has carried out the world´s most extensive programme of mire draining, being most active in 1970 s, when almost 3 000 km2 of mires were drained annually. According to the 8th National Forest Inventory the total amount of drained mires for forestry is at the moment 46 807 km2 (Virkkala ym. 2000). The different figures are mainly due to different ways of compiling the statistics, and because in large areas of thin-peated mires, peat has decomposed, and the former mires have turned into mineral soil forests

Up till now, draining of pristine mires has almost ceased, and most activities are concentrated on the maintaining of ditches in peatland forests. Most of the mires drained for forestry are developing gradually to resemble forest vegetation, but hummock plants survive for decades in the drained areas, while plant species of moist sites disappear quickly. In addition to economically profitable ditchings, approximately 20-30 % of the ditchings have been done in so poor sites that no timber growth improvement was obtained, but only pristine mires were destroyed (e.g. Heikkilä 1984).

As a part of peatland forestry, forestry roads have covered about 35 000 ha of mires (Lappalainen & Hänninen 1993). The coverage of mires is not the main ecological influence of roads. Much more important has been and is even today the effect of roads as dams, causing big changes, as well as ditching in connection with the road construction. Also local roads and highways have the same effect. Typically the nice mire scenery, which can be seen from a new road will get a curtain of developing trees on both ditched sides of the road.

Peatland agriculture

Clearing mires for arable fields

Mires have been cleared for agriculture from ancient past in southern Finland. Probably fens and rich spruce mires with a thin peat layer were used. Up to 1600s mires were taken for agriculture in small scale only. Ditching technicues were developed in the 1700s during the utilitarism time, and large-scale cultivation of mires started, especially in the river valley plains in southern and western Finland. In the 1800s mires were understood as wastelands, which should be taken into use. This view was greatly supported by literature. Authors like J.L. Runeberg in his poem "Saarijärven Paavo" and A. Kivi in his novel "Seitsemän veljestä" created characters who cultivated mires, fighting against night frost, and with furious labour finally succeeded and became wealthy. In the end of 1800s, Finnish Peatland Cultivation Association was established to promote mire cultivation. The association made large-scale inventories of mires up to 1950s to find suitable sites for agriculture, forestry and peat mining.

The agricultural use of mires has reduced the mire area by about 1,2 million ha. Especially rich fens and fertile spruce mires, and their specialized fauna and flora have disappeared (Heikkilä 1991). The activity of peatland agriculture was great in 1950s and 1960s. After the Second World War numerous new farms were established to settle the 400 000 refugees from the eastern part of Finland, which was taken by the Soviet Union. Also many men who had served in the army during the war were given possibilities to start agriculture, in many cases by taking mires in use. At present, there are only few activities to establish new areas for peatland agriculture. Instead, some 85% of these fields have been abandoned and some of them have been converted to peatland forests.

The period of mire burning

There was two traditional uses of mires in agriculture. Both were based on the using of fire (Soininen 1974). In western Finland, the main system was burning over burning, which was close to the heath burning (e.g. Chapman 1967). In this method the raw acrotelm peat was burned repeatedly. The mires were drained several years before the starting of burning. The burning released nutrients of the peat, especially in deeper layers, when also sedge peat below *Sphagnum* peat was burned. During the burning phase the yields of the fields were rather good, but finally this lead to impoverishment of the soil.

Big areas of alluvial fens and different bogs were destroyed this way. In general, that lead in certain river valleys to a big shift of landscape structure, because the mire landscape changed during 19th century to arable field landscape. No one has estimated the degree of biodiversity losses, but all alluvial fens disappeared, and also many bogs. On species level that has probably lead to a local extinction of many alluvial species. There is concrete data only from the fens along the river Kyrönjoki, western Finland. In the end of the 19th century there were still some remnants of alluvial fens left (Lindberg 1905). Dominant species of the fens were e.g. *Carex diandra* and *Sphagnum teres*. Also *Stellaria crassifolia* was probably rather common. This kind of flooded intermediate fens have completely disappeared from Finland.

In eastern Finland the burning method was derived from slash and burn cultivation. Narrow strips of intermediate and rich forested mires were burnt in valleys or mire margins (Soininen 1974, Simola 2006). Many of these habitats were destroyed already in the 19th century, later forestry drainage destroyed the rest.

Peat mining

In small scale and locally there has been peat mining especially in southern and western Finland from the beginning of 1900s. In large scale it was started after the energy crisis of 1973.

Peat mining is concentrated in the central parts of the country. About 662 000 ha have been reserved for future peat mining, but at the moment some 100 000 ha have been taken in peat mining (Lappalainen & Hänninen 1993). Peat mining is still growing in Finland, and new mires are needed.

Even though the area used for peat mining is small when compared with forestry and agriculture, it has badly damaged mire nature by using large mire systems, which also had a high conservation value. There have been agreements between environment administration and ministry of trade and industry about which mires should be protected, and which to be used for peat mining. By time the situation has changed, and a re-evaluation has been made in the 1990s. However, there are still a number of valuable mires for protection, threatened by peat mining. In the Kyoto protocol peat was classified as a fossil fuel, but the government of Finland is at the moment trying to change the status of peat as a slowly regenerating fuel.

Reservoir construction

After the II World War, numerous hydroelectric power plants were constructed, and for the regulation of discharge, water reservoirs were built. In smaller rivers in western Finland reservoirs were built also for flood control, as well as for industry process water supply. Most of the reservoirs were built in mires, covering altogether 60 000 ha. The area is less than one per cent of Finnish mires, but the largest aapamire of Finland, Posoaapa mire was drowned in Lokka reservoir (Häyrinen 1970). There have still recently been plans to build one more large reservoir in Vuotos area in Lapland, to cover almost 20 000 hectares, mostly mires, which are very diverse in vegetation. Numerous threatened plant species grow in the area. It is also very important for bird fauna, and it is included in Natura 2000 programme (Lindholm 2003).

Regional loss of mire biodiversity

As a consequence of mire utilization, the remaining pristine mires have been greatly fragmented, and a large proportion of undrained mires has changed due to ditching in mire margins (Kallio & Aapala 2001). The ditches prevent minerogenous waters from the surroundings to flow into the mires, and thus large areas have changed to be ombrogenous nowadays (Eurola & al. 1988, 1991). Only in Lapland there are relatively large areas where most of the mires are pristine on regional level (Fig. 2).

The regional habitat diversity has clearly decreased and some formerly dominating mire habitats have become less abundant, and certain habitats have become threatened (Heikkilä 1993). Also certain characteristic features of mires have in great scale disappeared. These are ecotones between mires and forests, which have been common in mire-forest mosaic systems. Hydrologically undisturbed mire massifs (Laitinen & al 2006) and different rich mires have become rare. Finally, the quality of undrained mires and mire patches has decreased and will decrease more in time because of the draining, cutting and road construction. The remaining fragments of landscape mosaic should be protected. Also the value of succession series of land uplift mires has been realized only recently, and the remaining few sites are still threatened by forestry (Heikkilä 1995).

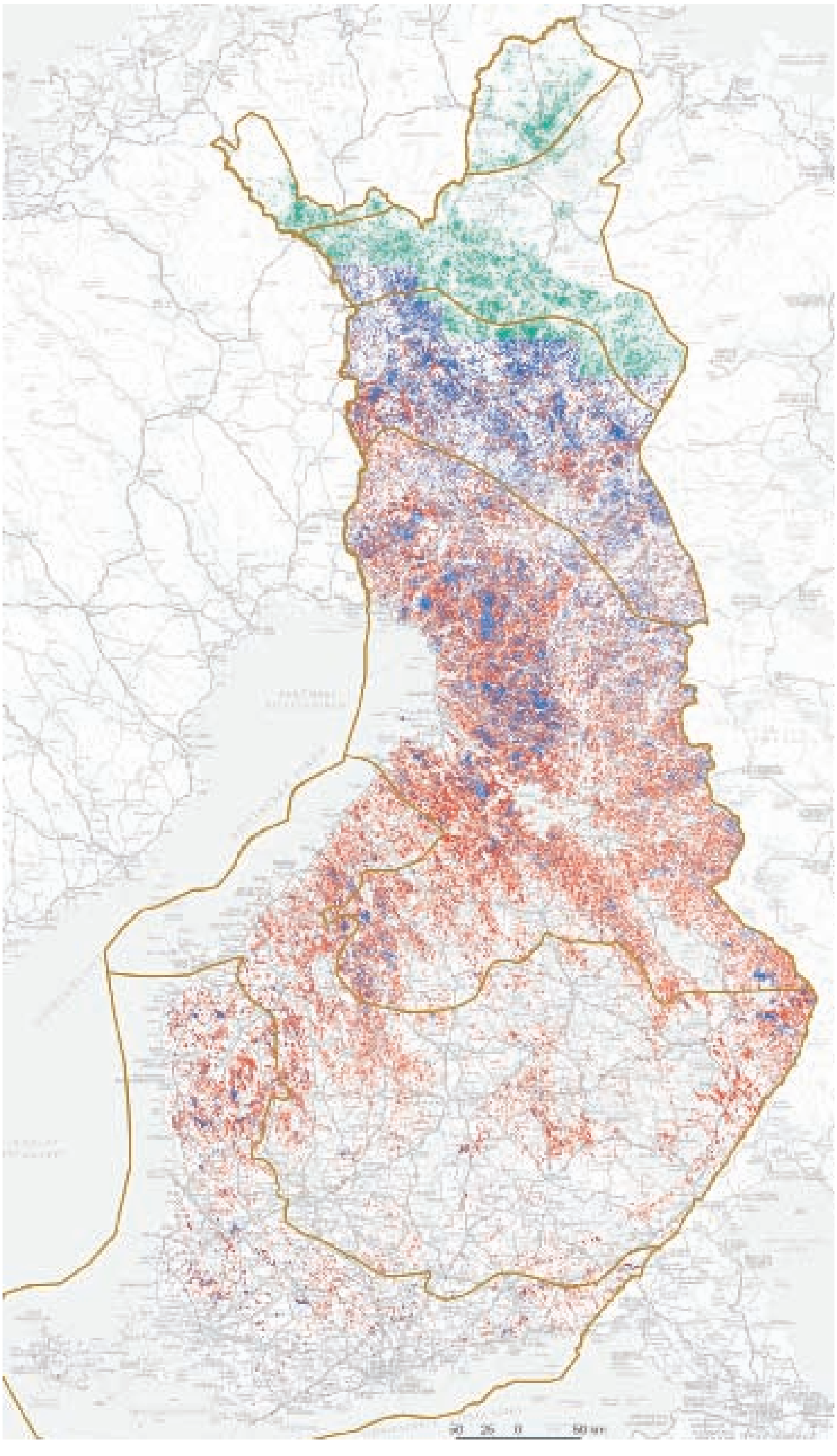

Fig. 2. Distribution of drained (red) and pristine (blue) mires in Finland. Green areas in the north are not classified due to lacking GIS information, but practically all of them are pristine. Map: Seppo Tuominen, Finnish Environment Institute. Base maps © Genimap Ltd., permission number L4659/02 and National Board of Survey, permission number 7/MYY/2006.

On landscape level the status of mires is clearly illustrated by the situation in the river Kyrönjoki drainage basin in western Finland, covering 5000 km^2 (Heikkilä 1999). In the basin at least 92 % of the original mires have been destroyed by forestry, agriculture and peat mining.

The time scale of the main changes in mires can be seen when comparing the situation in an area of 100 km^2 in central Finland in the years 1955 and 1995 (Aapala & Lappalainen 1998). In 1955 practically all the mires in the area were in natural condition, but during 40 years most of them have been drained for forestry, and a big deal taken in agriculture and peat mining. It must be emphasized, however, that in this randomly selected square the state of mires is exceptionally good due to three relatively large mire reserves, which happen to occur there, due to land ownership history. State owned mires were not drained as actively as those owned privately.

The boundaries of mire reserves

In Finland we have several different nature reserves, from National Parks and Strict nature reserves to different other reserves and special mire reserves. The work to create them has been rather difficult and there has been a lot of forestry political pressure to minimize their area as much as possible. Especially when making mire reserves there was a strict demand to leave the forests surrounding the mire systems out of the boundaries of the reserve. That has created rather unnatural boundaries to the reserves. It has been especially destructive, when the areas outside the boundaries have later been drained for forestry, and in some cases also taken for peat mining. (Keränen & al 1995, Aapala & Lindholm 1999, Kallio & Aapala 2001)

In raised bogs that has meant that the spruce mires around the bog have been left out of the reserves and they have also been taken rather early in forestry and agriculture use, noticed already by Isoviita (1955). He also pointed out the destruction of the central parts of raised bogs. In aapa mire zone the effect of poor boundaries and drainage outside of the reserves has fatally disturbed the hydrology of the central parts of aapas. These mires are in danger to dry out and to develop to more dry and poor habitats, even to become as ombrogenous habitats. That has caused different biodiversity losses, and there is a need to continue the evaluation of the boundaries of nature reserves, also because restoration is sometimes rather difficult when there is not enough minerogenous water to flow in mires, and also because the restoration procedure can lead the water to rise also outside the boundaries, causing damage in forestry areas.

The big destruction of Finnish mires after the second world war

The changes in the frequency and abundance of some selected very common mire plants in Finland since 1950s tell about the big change of Finnish mire landscapes and species distibution pattern. The analysis of floristics changes is based on the material of National Forest Inventories (Reinikainen & al. 2000). The information shows clearly how much mire ecosystems have lost their original character and biodiversity during the last five decades.

Andromeda polifolia (Reinikainen 2000a) is a small open mire dwarf shrub, which thrives in sites varying from ombrotrophy to moderately rich sites. *Andromeda* has lost many of its past habitat due to the drainage of the sites for forestry in the southern boreal zone.

Betula nana (Reinikainen 2000b) grows in various habitats from ombrotrophic to moderately rich sites. It is rather small in size but it can benefit sometimes much from the drainage for silviculture. If the drainage is successful, it finally disappears. It has happened in the southern boreal zone and also in the coastal area in the Middle Boreal Zone.

Chamaedaphne calyculata (Reinikainen 2000c) has been abundant in different fen and bog habitats in Eastern Finland and in the northern coastal area of Botnian Bay. Because its best sites have been also profitable for forestry drainage, *Chamaedaphne* has clearly diminished.

Vaccinium microcarpum (Reinikainen 2000d) is a small species of hummocks in poor, often ombrogenous mires. It has clearly decreased in Southern and Western Finland. The destiny of this tiny species of poor habitats also indicates the amount of unprofitable drainage in these regions.

Vaccinium oxycoccos (Reinikainen 2000e) is a creeping species of different bog and fen habitats, especially poor and intermediate fens. It has decreased clearly due to the drainage for forestry, but this diminishing will continue, because it can survive some time after drainage. Already now it has decreased clearly in southern Finland up to the boundary between middle and northern boreal zones.

Carex lasiocarpa (Hotanen 2000a) is a sedge of different minerogenous treeless and sparserly treed fens. Its abundance has diminished dramatically especially in southern Finland, but also in the north. The sites of *Carex lasiocarpa* have been largely drained for forestry (Fig. 3).

Carex pauciflora (Silfverberg 2000) is small sedge species of carpets and low hummocks of open *Sphagnum papillosum* fens and sparserly treed poor pine and spruce mires. It has decreased dramatically due to the drainage of most of its habitats in southern Finland.

Menyanthes trifoliata (Reinikainen 2000f) is a species of minerogenic wet fen habitats. It has dramatically decreased everywhere in southern Finland. Most common it has been in the north in the zone of flark aapas, where it is still rather abundant.

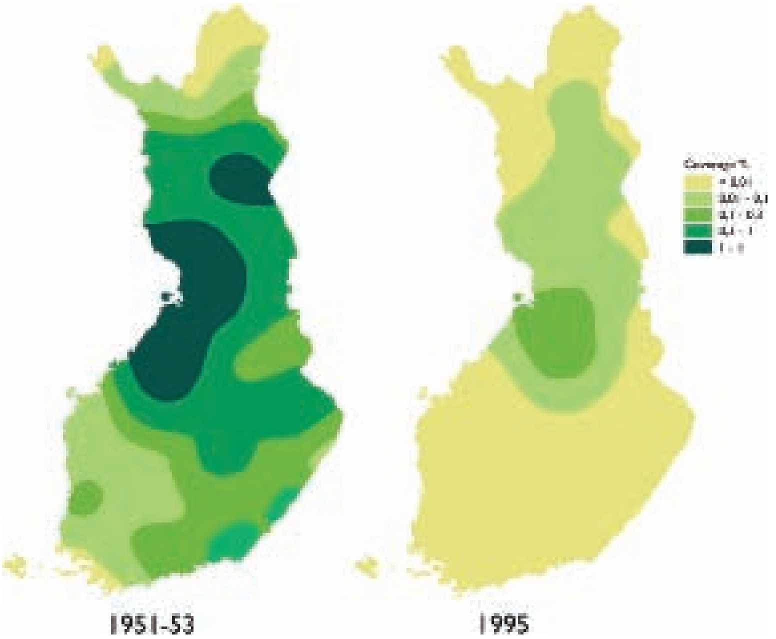

Fig. 3. Distribution and abundance of *Carex lasiocarpa* in Finland in early 1950s and in 1990s (Modified from Hotanen 2000a).

Sphagnum papillosum (Hotanen 2000b) is a species of aapamires in sedge aapa zone, especially in non-patterned aapa mires. These have been common in central Finland. Now most of them have been drained, and *Spagnum papillosum* has lost most of its sites.

In the zones of eccentric and concentric bogs most of mires have been drained. Mainly only open bogs have remained in natural condition. The bog zones are much more dominated by bogs than before drainage. Most minerogenic mires, different fens, spruce mires and minerogenic pine mires and pine fens have been destroyed, and the diversity of mire sites and species has greatly decreased in the bog zones.

In the zone of sedge aapamires the process has been similar. Most of the different fens have been drained or reserved for peat mining. The existence of fens and aapamires is now completely based on the network of nature reserves. Most of the former fens are now *Betula pubescens* forests and thickets (Saramäki 1977), and the general appearance of mires is characterizised by different bogs or poor pine mires.

The situation of mire plants can obviously develop even worse. In many cases they can survive a long time in suboptimal conditions, even though their original habitats have already disappeared. Also habitats still in fairly good condition can gradually lose their original ecology. That happens when the ditches stretch their effect to habitats which have not been directly drained. In minerogenic mires the drying effect of ditching has been found to reach areas in up to three kilometres distance (Kimmo Tolonen, personal communication 2002). Thus fens and aapamire massifs can lose their natural state, when the ditches prevent the waters to come into mires from mineral soils. So they gradually develop into bogs.

Threatened mire site types

The assessment of threatened habitats of all habitat groups has started in Finland. It was started by a pilot project, where the criteria and methods to be used in the assessment were developed (Kontula & Raunio 2005). The assessment is being carried out during the years 2005-2007. The final result will contain descriptions and lists of extinct, endangered, vulnerable, least concern and data deficient habitats. Also the nomination of habitats for which Finland has international responsibility in European Union is one of the tasks of the project.

The concept of threatened mire habitats is not new in Finland. In the description of the national mire protection programme, Ruuhijärvi (1978) made a list of “rare mire site types” which would especially in southern Finland need more inventories, establishment of small nature reserves, and which should not be drained. These mire site types were listed as threatened or rare mire site types in the two basic programmes for mire conservation (Haapanen & al. 1977, Haapanen & al. 1980)

Further Heikkilä (1991) studied threatened rich fen types and their status in the southern half of Finland. Later analyses of her materials (1450 relevés of rich fens in southern half of Finland) have shown that very probably many rich fen types have

Table 1. Threatened mire site types (in Finnish) according to Ruuhijärvi (1978), used in the basic programme for mire conservation (Haapanen & al. 1977, Haapanen & al. 1980). English names translated for this purpose differ from the older names used e.g. by Eurola & al. (1984).

lehtokorpi	Herb rich forest mire
ruoho ja heinäkorpi	Herb grass forest mire
tervaleppäkorpi	Black alder swamp
saniaiskorpi	Fern forest mire
lähdekorpi	Spring forest mire
lettokorpi	Rich forest fen
koivuletto	Rich birch fen
lettoneva	Herb rich sedge fen
varsinainen letto	Lawn rich fen
rimpiletto	Flark rich fen
lähdeletto	Rich spring fen
lettoräme	Rich pine fen

already disappeared and many are disappearing (Hanna Kondelin, personal communication 2006). As a national synthesis Aapala & al. 1996 and Aapala & al. 1998 have proposed a national list of threatened mire site types based on a list compiled by R. Heikkilä in 1993 for the environment guide for forestry in state forests, based mainly on the list of Ruuhijärvi (1978) and a statistical study on the distribution of mire site types in southern Finland (Eurola & al. 1991). Some of these threatened mire site types have been originally rather rare but have become endangered due to intensive drainage for agriculture and for forestry.

In the 1950s, spruce mires have covered 26%, pine mires 46%, open bogs and fens 27%, swamps 1% and rich fens 0,4% of pristine mires (Ilvessalo 1956). In late 1980s the percentages were 18% for spruce mires, 35% for pine mires, 45% for open bogs and fens, 2% for swamps and 0,01% for rich fens (Eurola & al. 1991). Between these two studies about 50% of the mires were drained for forestry, and for example the amount of rich fens in late 1980s was only 5% of the amount in early 1950s (Heikkilä 1992).

Due to this, a great deal of mire site types are nowadays endangered, in southern Finland more than 25 % of all site types (Aapala & al. 1996), and many species of plants, animals and fungi have disappeared from large areas (Rassi & al. 1992, 2001, Heikkilä 1990). Nationally only 5 % of endangered species are mire species, because in Lapland there are still much intact mires, but to the south of the Polar Circle, more than 25 % of regionally endangered plant species in each province are mire plants (Heikkilä 1995).

Table 2. Twenty-three mire site types regarded as threatened in Finland in Aapala & al. (1996) and Aapala & al. (1998), either nationally or regionally. Abbreviations of the site type names are according Eurola & al. (1994).

Finnish name: Aapala & al. 1998	**English name**: Aapala & al. 1996	**Abbreviation**
Threatened in whole country		
Lehtokorpi	Thin-peated eutrophic spruce mire	LhK
Saniaiskorpi	Fern spruce mire	SaK
Lähdekorpi	Spring spruce mire	LäK
Luhtaletto	Rich swamp fen	LuL
Varsinainen letto	Rich fen	VL
Koivuletto	Rich birch fen	KoL
Lettoneva	Loeskypnum fen and Subsecundum flark fen	LN
Tervaleppäluhta	Alnus glutinosa swamp	AlnLu
Tihkupinta	Mires with seepage effect	Tihkupinta
Mesotrofinen lähde ja lähdesuo	Warnstorfia exannulata spring and spring fen	MeLä
Meso-eutrofinen lähde ja lähdesuo	Paludella spring and spring fen	MeEuLä
Eutrofinen lähde ja lähdesuo	Cratoneuron spring and rich spring fen	EuLä
Threatened in the ombrotrophic bog area		
Ruoho- ja heinäkorpi	Herb-grass spruce mire	RhK
Kalvakkaneväräme	Sphagnum papillosum pine fen	KaNR
Rimpinevaräme	Flark pine fen	RiNR
Threatened to the south of Forest and Fell Lapland zone		
Lettokorpi	Rich spruce mire	LK
Lettoräme	Rich pine fen	LR
Rimpiletto	Rich flark fen	RiL
Threatened in the aapa mire area		
Ruohoinen mustikkakorpi	Herb Vaccinium myrtillus spruce mire	RhMk
Carex nigra-nevakorpi	Carex nigra birch fen	NigNK
Koivuluhta	Betula swamp	KoLu
Kuljuneva	Fuscum hollow pine bog	KeR, KuN

Conclusion

Our analysis shows that mire biodiversity has catastrophically decreased regionally and on landscape, massif, site and species level in a very short time, mainly since 1950, everywhere in southern and central Finland. Only in northernmost Lapland mires are mostly intact. In the south there are pristine mires left practically only in nature reserves. Without the activity of the persons, especially Rauno Ruuhijärvi, Urpo Häyrinen, Pekka Salminen and Eero Kaakinen, who in a very difficult political and economical atmosphere made a huge work for the preparing of mire conservation programmes there would be nothing left.

Thin-peated minerotrophic fens have been almost totally destroyed in southern and central Finland. They are often profitable sites for timber growth, and their hydrology is very sensitive for all changes in the hydrological system. This kind of mires disappear completely after drainage due to the mineralization of the peat layer. The drainage of these sites is especially harmful for watercourses due to the leaching of suspended solids into streams and lakes. Ikkelänjoki river basin, Kauhajoki, western Finland in 1982. Photo Raimo Heikkilä.

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Environmental impacts of mire utilization

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Introduction

In Finnish waters, the main growth-limiting nutrient is typically nitrogen. Also phosphorus may be the limiting factor. Other factors important to the water quality are acidity, humic substances and suspended solid particles. Mires are the main primary source of dissolved organic matter to Finnish runoff waters. Mires also contribute largely to the acidity of runoff (Laine & al. 1995).

Mires affect the quality of water which reaches them, be it rain water, surface water or ground water. Mire vegetation and also peat take up nutrients and other elements which are then partly accumulated in the peat. So mires act as sinks of inorganic elements.

The leaching of total nitrogen from boreal forested catchments is not very high compared to for example tropical streams (Mattsson & al. 2003). Most of the total nitrogen is organic, and the concentrations correlate strongly with total organic carbon. Because of this, export of total nitrogen is greater from mire dominated catchments (Saukkonen & Kortelainen 1995, Finér & al. 1997). However, the concentrations of total nitrogen are low compared with the amount of nitrogen in the peat, although Mattsson & al. (2003) found a strong correlation between total organic carbon and total nitrogen, indicating that the losses of organic nitrogen are associated with leaching of humic substances.

The amount of ammonium nitrogen is related mainly to precipitation. The deposition of inorganic nitrogen increases with increasing precipitation, and the water flow through the soil is faster. Both phenomena can increase ammonium and nitrate export (Mattsson & al. 2003).

The leaching of total phosphorus is usually quite low in unmanaged boreal catchments (Mattsson & al. 2003, Finér & al. 1997). The export of both total phosphorus and phosphate was greater in mire-dominated catchments of Finér & al. (1997), whereas Mattsson & al. (2003) found no correlation between the export of phosphorus and the extent of mires. The concentration and export of total phosphorus is correlated with TOC, however, which indicates that losses of organic phosphorus are associated with losses of humic substances (Mattsson & al. 2003).

The amount of suspended solids in unmanaged catchments is mostly very low (Ahtiainen & Huttunen 1995, Mattsson & al. 2003), indicating low erosion. Thus, almost all total organic carbon (TOC) must be dissolved, and very little of it is in a solid form. Also, only a small amount of the nutrients is associated with suspended solids (Mattsson & al. 2003).

Dissolved organic carbon is formed in the decomposition of biomass, in mineral soils as well as in mires. In mineral soils it is retained by mineral particles, and in mires it is leached in the surface runoff (Laine & al. 1995). Concentrations of DOC are usually relatively high in Finnish brooks (Finér & al. 1997, Mattsson & al. 2003) compared to results from other pristine areas. Mires are the main contributor of DOC to surface waters in Finland (Kortelainen 1993, Kortelainen & Saukkonen 1998) as well as elsewhere (Hope & al. 1994). However, the same area of mire in the catchment results in lower DOC concentrations in the north (Kortelainen 1993, Mattsson & al. 2003). This may be associated with slower decomposition in the north as well as with different climatic and hydrological conditions (Mattsson & al. 2003).

Effects of forestry drainage

Hydrology

Forestry drainage has effects on catchment hydrology directly. Also the improved tree growth affects the hydrological features. In the first phase, water table lowers rapidly and the dynamic storage grows (Verry 1988). The faster decomposing of the peat partly compensates this, because the porosity and water storage co-efficient of the peat diminish. The effects of ditches are strongest immediately after the drainage and weaken gradually. The maintenance of ditch-network also has hydrological effects as well as tree cutting and soil preparation for regeneration.

The annual runoff is increased by forestry drainage in all cases. In most cases, the reduction of evaporation is the main factor for this (Verry 1988). The increase is biggest in the first years after drainage (Seuna 1981). The runoff will decrease to the original in 15-20 years if the tree growth is improved. The spring peak runoff is increased if the drainage area is situated in the upper part of the catchment, which is usual. Restricted drainage especially in the low parts of the catchment may even decrease the peak runoff of large catchments, because it causes asynchrony in the peaks from different parts of the catchment. Summer peak runoff is usually increased by the drainage. Especially high momentary peaks are pronounced, because the increased water storage does not have as rapid an effect as the fast runoff to ditches (Seuna 1981).

Normal forestry drainage will strongly increase the low runoff, especially in flat terrain and if the ditches reach permeable mineral soil under the mire. This effect may last for decades (Verry 1988, Sirin & al. 1991).

New, improved methods of water protection in peatland forestry include buffer zones, sedimentation basins and several other techniques (Joensuu 1999). These may somehow protract the runoff to the streams. The use of water protection techniques of forestry drainage as well as peat mining in flood control is very limited, however. Sedimentation ponds and buffer zones are too small for large scale water retention. In addition, they cannot be used in water protection, if excess water is stored in them (Rantakokko 2002).

Clearing of the ditches will further increase the low runoff. It does not affect very much the peak discharge, however. Complementary drainage, on the contrary, will diminish the water flow resistance considerably, and therefore it increases peak runoff (Ahti & al. 1995).

Fig. 1. Erosion in a glaciofluvial sand formation in Karvia, Pohjankangas, western Finland in 1986. Tapani Sallantaus (190 cm) as a scale in a ditch leading the waters of an adjacent drained mire to a nearby lake. During the first spring flood after ditching the collecting ditch in sand soil eroded to form a 10 metres wide and 3 metres deep channel. Altogether about 100 000 cubic metres of sand was washed in the lake. Photo Raimo Heikkilä.

Hydrochemistry

The suspended sediment discharge is the most usual and also the most radical environmental problem of mire drainage (Laine & al. 1995, Ahtiainen & Huttunen 1995, Seuna 1982). The material from ditches is greatest during the digging, but also afterwards floods remove solids. The total load is not usually measured, because rough material is carried near the bottom of the ditch, and is not caught in the sampling (Heikkilä 1999). Local erosion may be pronounced, if ditches reach the mineral soil under the peat, and if this soil is fine-grained. In such cases, the annual leaching of suspended solids is ten to hundred times more than the load from drainage areas in which ditches do not reach the mineral soil (Seuna 1982, Ahtiainen & Huttunen 1995). Ditch network management often leads to the same magnitude of load, because the ditches reach the mineral soil even easier than in the first drainage, after decades of peat compression and decomposition (Ahti & al. 1995). In the streams the mass of solid particles is gradually moving downwards, until it reaches a lake or sea, where it is permanently deposited. There are often sediment layers in the discharge point of ditches, and large deltas may be formed there (Heikkilä 1999).

The usual procedure of the forestry drainage is to direct waters from mineral soils past the mire that they previously entered. The processes, which affected these waters in the mire, are not functioning any more, or they are functioning only partly in the ditches. This water contains thus less dissolved organic carbon, and it is less acidic. Inorganic nutrients of the water are not retained in the mire, as before. Drainage areas become thus ombrogeneous, even if there may be lots of nutrients in the peat layers.

Usually the amount of DOC increases immediately after the ditching, as the static water storage is emptying. After this, the amount of dissolved organic carbon from drained mires is not markedly greater than from natural mires.

The amount of total nitrogen in the runoff water increases after forestry drainage, although it is always small compared with the nitrogen stores of the peat (Kenttämies & Saukkonen 1996). Also the concentrations from old drainage areas are greater than from natural mires (Joensuu & al. 2001, Mattsson & al. 2003). Especially the amount of ammonium is high. It comes from the anaerobic parts of acid peat, where no nitrification occurs. If water is afterwards neutralized, part of the ammonium changes to free ammonia, which is poisonous for example for fish (Kenttämies & Saukkonen 1996).

The increase in phosphorus concentrations is related to the erosion of mineral soil from drainage area. The phosphorus which is released in the decomposition of the peat is effectively taken up by plants. Dissolved phosphorus which is directly utilized by organisms does not leach significantly from unfertilized drainage areas. If there are deeper peat layers rich in iron and phosphorus in the mire, however, and ditches reach these, concentrations of both elements may increase significantly.

Effects of the fertilization of peatlands

Phosphorus leaching from fertilized peatlands has caused considerable deterioration in water quality of catchments in Finland. Although in many studies it has been difficult to separate the effects of drainage and fertilization, it is obvious that phosphorus from peatland fertilization has been a big problem in catchments, second only to the leaching of suspended solids from drained mires. Easily soluble phosphorus fertilizer was used 1977-1988 in the fertilization of drained mires. This leaches very effectively from the peatlands, and the leaching continues for a long time. In six years, 20 % of the used phosphorus had leached to the waters of the studied catchment (Saura & al. 1995). Most of this was in the form of phosphate, which is readily usable for organisms, and therefore especially harmful in waters (Saura & al. 1995). The characteristics of drained mires effect the retaining of phosphorus, even if the reasons for differences are not well known (Jarva & al. 1995). Most problematic are sites which suffer from phosphorus shortage because it is easily leached from the peat.

Nitrogen is not usually a minimum factor in drained mires (Laiho & al. 1999). Fertilization with NPK is required in drained ombrotrophic sites (Paavilainen & Päivänen 1995), if they are to be maintained. Nitrogen in fertilizers is in the form of ammonium and nitrate. Of these, ammonium is effectively retained in the peat. Usually, the increased leaching of nitrogen is observed in the first year after fertilization, and after two years the concentrations are at the same level as before. The amount of leached nitrogen is 4-20 % of the nitrogen in the fertilizer (Saura & al. 1995, Lundin & Bergquist 1985).

The use of fertilizers decreased significantly from 1970’s until the beginning of 1990, after which the use of especially PK-fertilizers in peatlands has increased (Kenttämies & Saukkonen 1996). In the new fertilizers, phosphorus is in slowly soluble form, which is supposed to diminish leaching to watercourses. The latest results show, however, considerable leaching of phosphorus from areas fertilized with these, too (Lyytikäinen & al. 2003).

Peat mining in the former Vuorenneva mire in Alavus, western Finland. Peat mining destroys the mire ecosystem completely. Large amounts of nutrients and humic substances are leached into watercourses. Photo Raimo Heikkilä.

Effects of peat mining on hydrology and water quality

Sediment, nutrients, organic matter and iron are leached to water systems from peat mining areas. Even if the total load from them is quite insignificant nationwide (Ministry of the Environment 1999), it can have significant effects locally. Mining sites are also concentrated in some regions, and negative effects also concentrate in some watersheds. Site preparation for peat mining and the mining itself cause radical changes to the mire nature. Intensive effects on environment continue through the whole mining process, in contrast to drainage for forestry, the effects of which usually wear off gradually. The effects of peat mining on catchment hydrology and hydrochemistry are easier to study than the effects of forestry, because the effects are strong and localized. Ecological effects are difficult to demonstrate, however, and the studies of them are few.

Site preparation for peat mining takes years. In the first phase, few ditches are dug for preliminary drainage. After the peat has dried and consolidated, a dense network of ditches is dug. Also subsurface drainage is possible, if peat does not contain lots of wood. The drainage is meant to be ready for the whole mining. Vegetation is removed, and the site is levelled and profiled.

The hydrological effects of peat mining are quite well known. These effects in turn affect strongly runoff water quality.

During the site preparation the low runoff as well as total runoff increases markedly, as the static water storage empties partly (Sallantaus 1983, Burt & al. 1990). This runoff is also from deep peat layers, in contrast to natural surface and acrotelm runoff. During the mining phase, the water storage loses about 2 000 mm of water. The evaporation does not increase even though uppermost peat layer is turned over now and then. Actually, removal of the vegetation decreases the evapotranspiration as well as the drying of the peat. Most of the storage water must then depart as runoff (Sallantaus 1986). In the preparation phase, 600 mm decrease in the water storage is possible (Johansson & Olofsson 1985). In old sites total runoff is near the natural runoff (Kløve & Bengtsson 1999). In the mining phase peat is removed, and the remaining peat consolidates. Thus the water storage capacity decreases in old mining sites, and marked peaks of high runoff are possible (Sallantaus 1984).

The amount of suspended solids increases markedly during peat mining (Sallantaus 1984). Ditch network is dense and the ditches are deeper than in forestry drainage. Also deepening and clearing of field ditches must be done annually. Mining area is free of vegetation, and so the whole surface is easily erodable. In old mining sites there is typically surface runoff over the whole surface, which increases erosion. However, the ditches are usually not steep, and they are not dug into mineral soil. The leaching of organic suspended solids is about 300 kg $ha^{-1}a^{-1}$. The main problems occur during intense runoff peaks.

Main part of the organic matter is transported in dissolved form (Kløve 1997). Because waters from natural mires contain lots of dissolved organic matter, slight increase in concentrations due to the drainage does not usually mean much. In the beginning of the peat mining total runoff is markedly greater than from natural mires. Even the same concentrations of dissolved organic matter increase the load in the catchment (Sallantaus 1986). The acidity of runoff water is closely connected with dissolved organic matter. Peat mining does not have any acidifying effects on watercourses.

The increase of suspended solids in runoff waters increases the amount of total nitrogen, respectively. Most of it is in organic form, however, and not readily available for organisms. During the site preparation there is only a minor increase in the amount of inorganic nitrogen in the form of ammonium (Sallantaus 1986). Increase in the runoff increases the ammonium load in the catchment, however. Kløve (1997) observed increase in the loads of total nitrogen as well as ammonium and nitrate from a peat mining site during first years of mining. It is evident that soil tillage and removal increases the decomposition of organic matter which results in increased nitrogen mobilization and leaching (Kløve 1997, Bridgham & al. 1991). Some results indicate that in base-rich peat mining areas considerable amounts of nitrate leach during peak runoffs (Sallantaus 1983). Heikkinen (1994) observed that a peat mining area which was only 2 % of the catchment accounted for almost all the ammonium and half of the nitrate transport.

Phosphorus is not easily retained in the peat physically or chemically, and most of it is in organic form. In the decomposition of the peat during the peat mining part of this phosphorus is mobilized and leaches to the waters. In peat mining areas of low nutrient status the concentrations of phosphorus are only slightly higher than in natural mires. In the areas with higher natural phosphorus content, load can be much greater, however. Loads from areas under preparation are almost 10-fold compared with areas which are not used (Leijting 1999), or with loads from natural catchments (Mattsson & al. 2003). During the actual peat mining, the average load is 5-fold compared with natural mires (Leijting 1999).

Effects of mire drainage on aquatic ecosystems

Knowledge of the ecological impact of the load from forestry in aquatic ecosystems is poor compared to the knowledge on hydrological and hydrochemical effects. Some studies show marked short-term and long-term effects on organisms in catchments affected by different forestry practices. Mire drainage has significantly deteriorated water quality and habitat structure of headwater streams, and thus contributed to the impoverishment of benthic macroinvertebrate communities. These communities in turn have a great impact on the structure and function of downstream communities (Vuori & al. 1998).

Primary production in small brooks increases after ditching or supplementary ditching, although the reaction may be retarded. Also algal biomass increases radically, and in the first year after ditching it may be 100-fold. Even after 11 years the biomass was still 3-fold compared to the original situation. This increase is explained by the total nitrogen content of the water. Also the algal flora changes after ditching. In a brook which was separated from the drainage area by a protective zone, the primary production and algal biomass still increased in the first year, but they decreased soon to the initial level (Holopainen & Huttunen 1998)

Effective drainage and fertilization of mires may change the trophic state of a lake quite dramatically from oligotrophic to eutrophic, as shown in the diatom flora in palaeolimnological studies. Anoxia in the lake bottom leads to continuous phosphorus escape from sediments, as shown in sedimentary phosphorus anomalies. Also blooms of blue-green algae have been recorded. Narrow protective zones provide little shelter from the material inflow (Turkia & al. 1998). The typical brown-water lake phytoplankton composition does not change noticeably after forest fertilization, however, although phosphorus concentration increases. Extra nutrients are either utilized by bacteria or transported out of the lake (Lepistö & Saura 1998).

Drainage and clearing of brooks have marked effects on the habitats of trout (*Salmo trutta*). Especially the spawn is sensitive to water quality. Most harmful for this stage seems to be sand, which is eroded from drainage areas and cleared brooks. In some catchments, where drained mires on easily erodible sands dominate, erosion poses a definite threat to endemic populations of trout (Jutila & al. 1995).

A little stream Hukanluoma in the upper reaches of the river Isojoki in Kauhajoki, western Finland, hosted a very good trout population up to the beginning of 1970s. Forestry drainage caused the leaching of sand into the stream. The stone and gravel bottom was covered by sand and deep points were filled, which changed the stream unsuitable for trout. Photo Raimo Heikkilä.

Water protection methods and possibilities

Forestry

Finnish government has set strict goals for water protection by the year 2005. The non-point loads of nitrogen and phosphorus from forestry should be at least 50 % smaller than in the year 1993 (Ministry of the Environment 1999).

To achieve these goals, recent water protection methods should be applied very effectively. Also new, improved methods are needed. Even so, the goals are difficult to achieve, if the economical situation is good and activities high (Kenttämies 2003).

Peatland forestry contributes greatly to the water pollution caused by forestry. Although the drainage of natural mires has practically ceased, substantial increase of ditch maintenance is needed (Maa- ja metsätalousministeriö 1999). The maintenance has been largely neglected, which is beneficial for the water protection, but not for the tree growth. Fertilization of peatland forests was minimal in 1993, but has increased since then, which increases especially the phosphorus load in waters.

Usually different forestry practices are taking place in the same watershed simultaneously. The protection measures should therefore be able to take care of loads from all these activities. There are several widely used methods, e.g. digging breaks, cleaning breaks, buffer zones, sedimentation basins and overland flow areas, which are used in peatland forestry. An important part of the water protection is the non-management of drainage areas which are not profitable or not yet in the need of management (Saarinen & Silver 1992, Lauhanen & al. 1995, Saarinen 2003). Restriction of fertilization to sites which really need it reduces costs and also the load to the waters. Also the amount of fertilizer might be reduced, and even more slowly soluble fertilizers used (Lyytikäinen & al. 2003).

The use of overland flow fields (or other percolation areas) is the primary water pollution control method used to reduce loads from forestry. An overland flow field is an area covered by vegetation, where runoff from forestry is conducted. The runoff on overland flow areas is cleaned through physical, chemical and biological processes. The effectiveness of these areas depends on many characteristics and may change in the course of time. The main factor determining the effectiveness is the size of the field compared with the area of the catchment (Sallantaus & al. 1998, Lyytikäinen & al. 2003). Best fields are on thick peat, they have a thick cover of mire vegetation, and the surface is even. If the field is big enough, it will retain most of suspended solids, and the effectiveness may even improve after some years of overflow (Lyytikäinen & al. 2003). Part of the phosphorus is retained with suspended solids. Also soluble phosphate phosphorus may retain in big fields, but there are also times when it leaches considerably (Sallantaus & al. 1998, Manninen 1999). In areas of intensive phosphorus fertilization, the fields are not big enough to retain big loads of leaching phosphorus. Inorganic nitrogen retains quite effectively in big fields, at least some years after construction. Dissolved organic matter does not decrease, neither do the amounts of nitrogen and phosphorus which are retained in this fraction. Too small fields do not contribute substantially to the water quality improvement in catchments (Lyytikäinen & al. 2003).

Sedimentation basins are widely used in forestry. They are dug into the ditches in places where the water flow would slow down. The main effect of them is to retain suspended solids. The basin will eventually fill up, though, or floods may remove the sediments. Dissolved organic matter will not be deposited in the time it is in the basin. Also fine solid soil particles may not be deposited. For nutrient retention, other methods should be used in connection with sedimentation basins (Ahti & al. 1995).

Buffer zone between the ditch and watercourse catches suspended solids and nutrients. In this case the forestry ditching is not profitable. Sikarämäkkä mire in Kauhajoki, western Finland in 1982. Photo Raimo Heikkilä.

Buffer zone is an undrained area between a water body and a forestry area. Physical, chemical and biological processes of the zone retain nutrients and suspended solids as in any natural area. Drained mires do no act as buffer zones as such, but they can be restored. The characteristics of the zone, e.g. vegetation, slope etc., and its width cause considerable variation in the effectiveness of buffer zones.

Peat mining

Suspended solids, nutrients, organic matter and iron are leached to water systems from peat mining areas. Phosphorus and nitrogen load caused by peat mining is only about 1% of the total load to water systems in Finland. It can have a significant effect on water quality locally, however. According to the Finnish Government, there should be a decrease of nitrogen and phosphorus load of at least 30 % from peat mining by the year 2005 from the 1993 level (Ministry of the Environment 1999). To achieve this goal, new water protection methods have been developed.

In general, water protection management of peat mining areas is easier than in forestry. The same mining site is used for a long time. Constructions can be used all of this time, and the maintenance is easily done. Also the profit per hectare is much greater than in forestry, and water protection does not endanger the profitability of the business.

The basic combination used nowadays is field ditch structures, small sedimentation ponds and large sedimentation basins. Also overland flow areas and chemical treatment of the water are used. Field ditch structures and small sedimentation basins are to remove sediments and nutrients in them. Different structures reduce the load of suspended solids by 64-97 % (Heikkinen & al. 1995). In large sedimentation basins, 30-40 % of the remaining particle load is deposited (Selin & Koskinen 1985). During peak runoff, this basic method is not effective, because sedimented solids are resuspended from sedimentation basins (Sallantaus 1983, Selin & Koskinen 1985). Soluble nutrients and dissolved organic substances cannot be reduced by this combination of methods.

An overland flow area is a natural mire area, through which waters from the peat mining area are led. This is possible in about 50 % of the peat mining areas, mainly in northern Finland. Overland flow areas remove suspended solids as well as dissolved organic substances and nutrients. Overland flow areas function best in the summer. During spring and autumn floods, the cleaning efficiency is probably less, and part of the nutrients absorbed in the area may even be leached away. The lifespan of an overland flow area is about 10 - 15 years. On an average overland flow areas reduce the load of suspended solids by 50 %, while the reduction of total phosphorus and nitrogen is 40 %. The reduction of ammoniacal nitrogen is 70 % and of phosphate phosphorus over 50 % (Savolainen & al. 1996a).

Chemical water treatment is based on chemicals which precipitate the dissolved nutrients in the water, so that they can be removed by sedimentation. Mean reduction in the load is 50 - 91 % for suspended sediment, 48 - 86 % for total phosphorus, and 1 - 34 % for total nitrogen. The most visible change has been the clarification of water, which is due to the precipitation humus and iron. Of the soluble inorganic nutrients, the method removes phosphate, but the decrease in nitrogen is less, and the concentration of inorganic nitrogen may even increase due to the treatment. Chemical water treatment is an expensive method for controlling water pollution and it is thus economically profitable only in areas of over 200 ha (Kløve 1997, Savolainen & al. 1996b).

Sediment leaching from peat mining areas is heaviest at peak flows, e.g. during snow-melt in the spring or heavy rainfall in the summer. Peak runoff control aims at conducting the sediment leaching to deposit in the ditch network (field and cross ditches). This can be done by constructing pipe dams in connection with the sedimentation basins or in cross ditches. The damming of water in the ditches reduces the flow velocity, so that sediment is deposited on ditch beds. In this method there is no erosion of ditches. Control structures reduced the peak flow rates which reduces the annual load of suspended sediments by 95 %. Sedimentation ponds are still needed in connection with peak runoff control (Kløve 1997).

Artificial floodplains are similar to sedimentation basins, but they are significantly larger and shallower basins covered by vegetation. Part of the peak runoff from peat mining areas is conducted to an artificial floodplain, when the capacity of sedimentation basins is not enough. In artificial floodplains the absorption of fine-grained particles, which settle poorly, is intensified. The functioning of an artificial floodplain is based partly on sedimentation and partly on biological and chemical processes. Even 76 % removal of suspended solids has been observed (Kløve 1997).

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Peatlands and global change – the Finnish case

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Introduction

Peatland ecology and palaeoecology - Grounds for global change studies

One third of the present 34 Mha Finnish land area has developed into peatlands during the Holocene. After the Second World War much of these resources have been reclaimed for forestry, agriculture, and energy production. Supported by State, an extensive ditching campaign took place mainly in 1950-80's, resulting in forest drainage in 5.7 Mha of peatlands. Furthermore, about 0.7 Mha of peatlands has been reclaimed for agriculture. Due to the drainage, the area of pristine peatlands diminished dramatically, mostly in Southern Finland, underlining the need for peatland protection. In research, boreal mires have received attention by plant ecologists, palaeoecologists and applied ecologists due to the many-fold faces of peatlands.

A considerable part of Finnish peatland research has been motivated due to land use: To find best ways to manage the hydrology and nutrient regimes of peatlands in order to ensure adequate forest growth on the drained peatlands, or to create an ecological moisture-nutrient classification based on phytososiology and indicator species (Cajander 1913, Laine & Vasander 2005; for a thorough review on research for peatland forestry, see Paavilainen & Päivänen 1995). The concept of mire complex types (cf. Ruuhijärvi & Reinikainen 1981, Ruuhijärvi 1982, Ruuhijärvi 1983) has created a scientific framework, fully applicable in more recent studies on ecosystem dynamics. Peatlands also form a vast palaeoecological archive, as sediments consist of subfossil remains of plants and other life forms once inhabiting the now sedimented former peat surface layers. In climate change studies, knowledge in plant ecology, ecohydrology (Laine & Vasander 1996) and palaeoecology combine in ecosystem response studies over varying time scales. Research on peat macrofossils (Väliranta 2005) and many other palaeo-proxies have contributed e.g. to models aiming to describe the atmospheric interactions due to landscape paludification (Väliranta & al. 2006, Weckström & al. 2006) and mire complex development (Korhola & al. 1996, Alm & al. 1999a, Alm & al. 2004, Alm & al. 2006).

Global greenhouse gas question

As northern peatlands form a major terrestrial organic carbon (C) store (Gorham 1991, Tolonen & Turunen 1996,Turunen 1999, Turunen 2003), the extensive drainage or peat extraction were feared to cause a loss of carbon bound in peat deposits due to the natural decomposition (Silvola & al. 1985), and due to peat energy use (Ahlholm & Silvola 1990). Such an atmospheric feedback by the CO_2 release would further accelerate climate warming.

Already in 1990, well before the current climate policy developments, a major research programme was launched by the Academy of Finland – SILMU (Finnish Research Programme on Climate Change, Roos 1996). The concerns were heard and the questions asked at that time included: How the peatland ecosystems and carbon stored in peat would react under changing climate? Has forest drainage resulted in carbon losses or gains due to new tree growth? How large are the greenhouse gas emissions from peatlands? SILMU gathered a group of peatland scientists, from biologists through forest scientists to hydrologists and microbiologists, and an ecosystems ecological approach on peatland carbon balance issues was adopted to study the flux dynamics of CO_2, CH_4 and N_2O (Silvola & al. 1992, Martikainen & al. 1993, Alm 1997, Regina 1998, Nykänen 2003) both in pristine and drained peatlands. Common study sites were employed by as many of the groups as possible. Gas exchange studies launched during SILMU have continued and expanded into fields concerning lakes and lake associated wetlands (Huttunen & al. 2003, Juutinen 2004, Larmola 2005), restoration ecology (Tuittila 2000), and agricultural peatlands (Maljanen 2003). Dynamic modelling of methane fluxes (Kettunen 2002) followed a period of extensive collection of data.

Methodological developments

Photosynthesis in mire plants had earlier been observed in laboratory conditions (Silvola & Hanski 1979, Silvola & Aaltonen 1984), making path for new methodological developments. The first soil-atmosphere gas flux has been soil respiration, i.e. the combined outcome of respiration of below-ground parts of autotrophic organisms and heterotrophic organisms belonging to the chain of decomposers of dead organic matter. Employment of IR absorbance sensors rather than soda lime chambers allowed for monitoring of more dynamic processes than before. Impacts of peatland drainage were studied by Silvola & al. (1985, 1996ab). In addition to soil respiration, SILMU researchers needed to observe the key greenhouse gas fluxes *in situ*: Net uptake of atmospheric carbon dioxide (CO_2) in photosynthesis and the simultaneous release of CO_2 in autotrophic and heterotrophic respiration (Silvola & al. 1992, Alm & al. 1997). Further, the release of methane (CH_4) was associated with the same vegetation and microsite types (Saarnio & al. 1997, Nykänen & al. 1998). The methods available at that time for mire scientists were based on the use of dynamic chamber (Silvola & Hanski 1979) for measuring soil CO_2 emission and static chamber (Crill 1991) for measuring CH_4 fluxes or CO_2 exchange (Figure 1). In wintertime, a snow gradient method (Sommerfed & al. 1993) was employed (Alm & al. 1999b, Saarnio & al. 2003). Chamber techniques allowed for studies on the scale of microsites, i.e. within hummock, hollow and lawn communities. Micrometeorological energy balance and flux measurement techniques, introduced to peatland research in collaboration with Finnish Meteorological Institute, allowed continuous measurements at the level of the whole mire site type (Hyppönen & Walden 1996, Alm & al. 1999c, Aurela & al. 2004). The different ecosystem scales and concepts adopted, and still maintained, show that the links between the Finnish mire research tradition and the ecological interpretations of gas exchange results are evident.

The newly gathered gas exchange data formed tools for estimating the annual carbon balance. Most of the exchange of organic carbon occurs in gaseous form, but a significant amount of organic matter may leave the system dissolved in water (Kortelainen & Saukkonen 1994, Sallantaus 1992). Winter efflux were found important components of the annual C balance; the carbon losses during winter may constitute 10–30% of the growing season net carbon gain in the boreal zone (Zimov & al. 1993, Alm & al. 1999c). Methane release alone, during the long boreal winter is significant, consisting 5–33% of the annual total (Dise 1992, Alm & al. 1999b).

Chamber measurements give gas exchange values in the specific conditions during the chamber closure only. These instantaneous flux rates, sensitive to peat moisture conditions, or to solar irradiation and temperature changing in seconds or hours, must be expanded over night and day. A regression-based transfer function for CO_2 exchange was defined by Alm & al. (1997, 1999c), following the approach of Silvola & Hanski (1979), and for CH_4 by Saarnio & al. (1997). Later, new generations of physiologically based transfer function models have been developed (Kettunen 2000, Tuittila & al. 2003). The response function approach requires that a complete time series of appropriate environmental factors with one hour resolution is made available at each study site. Such regressions are valid only for the given site and range of environmental factors. Ultimately, the transfer function estimates for each hour are integrated into a seasonal sum that forms the site's seasonal gas balance. Wide and detailed data set may allow the development of more advanced process models for different C fluxes.

Fig. 1. Carbon dioxide exchange measurements by Sanna Saarnio on the hollow surface of Haukkasuo bog (60°47'N, 26°54'E) in Anjalankoski. Photo Päivi Saari.

Responses of mires

The increasing atmospheric ozone (O_3) concentration is not yet a threat for mires

Effects of atmospheric O_3 concentration on mires have been studied in short- and long-term mesocosm studies in laboratory and out-door experiments. *Sphagnum* mosses turned out to be rather resistant for the increased O_3 exposure. Only some changes in membrane leakage or pigment content were observed in some species (Niemi &

al. 2002a). However, in the ultrastructure of mosses several changes like decrease in chloroplast area and in granum thickness and various changes in plastoglobuli and cell wall thickness depending on the species and the experiment were observed (Rinnan & Holopainen 2004). The structural changes may also indicate functional changes in mosses in the long-run.

Correspondingly, in vascular plants (*Eriophorum vaginatum*, *Vaccinium oxycoccos* and *Andromeda polifolia*) various changes in number and size of plastoglobuli, amount of chloroplast and starch and thickness of cell wall were observed depending on the other growing conditions. Dwarf shrubs seemed to be more sensitive to O_3 exposure in the cool, autumn conditions than in summer. In the whole ecosystem level, carbon gas fluxes showed increase in the rate of respiration and CH_4 release (Rinnan & al. 2003). Production and oxidation potentials of CO_2 and CH_4 did not seem to change but instead the aerenchyme of *E. vaginatum* became narrower under the highest O_3 exposure. As the number or biomass of aerenchymal shoots has often been observed to correlate positively with the CH_4 efflux (Saarnio & Silvola 1999, Greenup & al. 2000, Niemi & al. 2002a), the increase in CH_4 efflux under the highest O_3 exposure was surprising. The result probably indicates that the CH_4 transport capacity from soil to the atmosphere was not the limiting factor for CH_4 release from that *Eriophorum*-dominated mire ecosystem.

In the first look, the recent long-term out-door experiment with the average exposure of 60 ppbv indicates no dramatic changes in vegetation or C gas exchange under raised O_3 exposure (Sanna Saarnio, personal interpretation). The detailed analyses of the results are now in the hands of two PhD students (Sami Mörsky [Kuopio] and Jaana Haapala [Joensuu]). The highest O_3 concentrations used in the earlier studies, 100-200 ppbv, can cause some alterations in the structure and function of mire plants but the background concentrations in Finland are fortunately still much lower. The current background concentrations elsewhere in Europe are also lower, 20-40 ppbv (Fowler & al. 1998) but they are predicted to increase at about 0.1 ppbv a^{-1} (NEGTAP 2001). The increasing O_3 concentration is thus so far a local threat for ecosystems.

UV radiation is a threat withdrawing

A few out-door experiments, either in mesocosms or in field, have been conducted to see effects of the increased UV-B radiation on mire ecosystem. *Sphagnum* mosses seemed to be more sensitive than vascular plants to the increased UV-B exposure. Actually the increase in the amount of carotenoids and chlorophyll content, membrane leakage and decrease in capitulum dry mass were more pronounced in the experiment with cooler and more cloudy weather and thus lower UV radiation exposure than in sunny summer with higher exposure (Niemi & al. 2002b & c). In her PhD thesis (Niemi 2003), Riikka Niemi (currently Rinnan) speculated that the damages were repaired more quickly in warmer temperature and therefore the symptoms were more clearly visible after the cooler summer, although the exposure was smaller. In contrast to *Sphagnum* mosses, vascular plants showed responses only after a high exposure (Niemi & al. 2002c). Thirty percent increase in the erythemally weighted UV radiation decreased the leaf cross-section and aerenchymatous space in *Eriophorum vaginatum*. Further, this reduction in the ecosystem level led to a significant decrease in the rate of photosynthesis and CH_4 release, and also the rate of respiration tended to decrease. The recent UV experiment in a northern aapa mire with a 46% higher UV dose than the ambient exposure, indicates that even after longer exposure the changes in wet surfaces might remain rather small (Sanna Saarnio, personal interpretation). These results are, however, now under a careful perusal by the above-mentioned PhD students, and the final results will be revealed in near future.

Fig. 2. A UV exposure field currently working on Halssiaapa mire (67°22'N, 26°38'E) in Sodankylä. Photo Jaana Haapala.

Stratospheric O_3 depletion, caused mostly by anthropogenic emissions of NO_x and chlorine and bromine compounds, has led to an increase in the amount of solar ultraviolet radiation reaching the Earth surface. Future scenarios indicate that in boreal and subarctic regions (60-90°N) we will be exposed to the maximal UV dose in the 2010-20's, after which the stratospheric ozone hole starts to recover (Taalas & al. 2000). In the spring, the UV dose might at worst be increased by 90% compared to the 1979-92 conditions, but on the annual level the increase will remain 14% at maximum. Thanks to the good international compliance with the Montreal Protocol and its Adjustments and Amendents the accumulation of ozone-depleting gases has slowed down and even begun to decrease (UNEP 2002). Thus, this threat will hopefully be passed without serious consequences for boreal mire ecosystems.

N deposition may eutrophicate and thus enhance C cycling in the long-run

Jyrki Jauhiainen has grown several *Sphagnum* species in laboratory at different N levels (0, 1, 3 and 10 g N m^{-2} a^{-1}). Effects seemed to be species specific. Ombrotrophic species growing on hummocks (*S. fuscum*, *S. rubellum*) were more efficient in the uptake of NH_4^+ than species growing in wetter microsites (*S. cuspidatum*, *S. magellanicum*, *S. papillosum*, *S. pulchrum*, *S. fallax*) and their N concentration in capitulum increased more than that in the other species under raised N supply (Jauhiainen & al. 1998). Correspondingly, only species with narrower niche benefited from the N addition, or even suffered from the highest dose, whereas the indifferent *S. angustifolium* did not response to the supplied extra N (Jauhiainen & al. 1994, Jauhiainen & al. 1999). The conclusion was that ombrotrophic species like *S. fuscum* will suffer most if the N deposition increases.

It is worth to remember that in the field, the change in the nutrient load will probably lead to changes in vegetation community. In a three growing seasons experiment with 3 g N m^{-2} a^{-1}, *S. papillosum* seemed to become more common at the expense of *S. balticum* (Saarnio & al. 2003) and in a six years experiment with 3 or 10 g N m^{-2} a^{-1}, the coverage of *Eriophorum vaginatum* had increased compared to the control plots

(Nykänen & al. 2002). In the first field experiment mentioned, N addition was not reflected in the rate of photosynthesis or decomposition processes in the ecosystem level whereas in the latter experiment, the increase in the aerenchymal transport capacity enhanced the rate of CH_4 efflux, especially on the originally ombrotrophic surface with low *E. vaginatum* cover. In addition, the increase in the amount of N rich litter may further accelerate the decomposition processes in the long run.

During the preceding decades, the median N deposition has been about 0.6-0.9, 0.4-0.6 and 0.1-0.3 g m^{-2} a^{-1} in southern, central and northern Finland, respectively (Järvinen & Vänni 1990). As elsewhere in Europe, during the last decades N deposition has decreased, especially in southern Finland (Soveri & Peltonen 1996, Ruoho-Airola & al. 1998). Thus the current atmospheric load does not seem to lead to a quick eutrophication in mire ecosystems. Instead, the use of mires as a buffer zone between the managed forests and water courses may form a more serious eutrophication threat for wetlands.

Rising the atmospheric CO_2 concentration strengthens the C fluxes

According to the laboratory studies of Jauhiainen & Silvola (1999) and Jauhiainen & al. (1999) with different *Sphagnum* species, as well as a field study of Saarnio & al. (2003) with mire ecosystems, CO_2 uptake of mire plants increases under raised CO_2 supply. In the long run, the original response fades when the plants acclimate on their growing concentration (Jauhiainen & Silvola 1999). The increased CO_2 uptake causes an increase in the amount of biomass and in the non-structural compounds like soluble sugars in *Sphagnum* tissues (Jauhiainen & al. 1999, Jauhiainen & Silvola 1999, van der Heijden & al. 1996). The higher CO_2 concentration also increases and widens the optimal water content for photosynthesis in *Sphagna* (Jauhiainen & Silvola 1999). The increase in the C uptake rate is also seen as an increase in the C gas losses, both in the rate of respiration and CH_4 release (Saarnio & al. 1998, Saarnio & Silvola 1999, Saarnio & al. 2000, Saarnio & al. 2003). However, the increase in CH_4 efflux has been much lower than that observed in experiments on temperate or subtropical conditions (Dacey & al. 1994, Hutchin & al. 1995, Megonigal & Schlesinger 1997). In wet years, C accumulation increases, whereas in dry and warm years more C is lost under the raising atmospheric CO_2 concentration (Saarnio & al. 2003).

Further, the increasing atmospheric CO_2 concentration will affect indirectly via climate change. In Finland, the annual mean temperature and precipitation are projected to rise by 1-3°C and by 0-15 %, respectively by the 2020's (Jylhä & al. 2004). The current atmospheric CO_2 concentration is nowadays over 375 ppmv and there are not any signs about the retardation in the rate of the increase (Houghton & al. 2001, CDIAC 2004) as the anthropogenic emissions are still increasing. Current attempts (Kyoto Protocol, EU legislation) to prevent CO_2 emissions have not yet been successful. It is thus obvious that this atmospheric change will affect the functions of boreal mire ecosystems far in the future.

Drought in boreal mires

Climatic warming and redistribution of precipitation may have critical consequences on mire hydrology (Houghton & al. 1996). Current climate models for high northern latitudes predict warming during the late autumn and winter, and increased precipitation and soil moisture especially in the wintertime. Summer droughts may also become more frequent in a warmer climate, with a predicted dropdown of water table by about 20 cm (Roulet & al. 1992). Such changes in ecohydrology may cause disturbances in vegetation communities. The communities, adapted to prevailing conditions, may turn towards a new species dominance, as suggested by a recent field experiment in project AUTOPEAT (Tuittila & al. 2004). The final interpretations of mire vegetation responses to drought are still underway, however.

The lengthening of the snow-free period will probably increase the length of C uptake season in the spring as *Sphagnum* mosses and some vascular plants are ready for growth immediately after the snow melt. On the other hand, the release of C will also increase during warmer autumn periods. The net change in C storage might thus remain small, like was estimated for coastal tundras by Grant & al. (2003). As the annual C gas balance is especially sensitive to the growing season weather (Alm & al. 1999c, Saarnio & al. 2003), possible changes in the frequency of dry years will affect the rate of peat accumulation in future. Any modelling efforts in order to predict biogeochemical processes under climatic forcing would need a hydrological component (e.g. Weiss & al 2006) to guide the decomposition processes.

During dry climate phases, the frequency of forest fires may increase (Overpeck & al. 1990). Fires are considered to have had a drastic influence on boreal ecosystems during the Holocene, sustaining various forest structures and high biodiversity (Tolonen & Pitkänen 2004), but retarding peat accumulation. Biomass burning results in significant release of greenhouse gases CO_2, CH_4 and N_2O, but also e.g. aerosols and methyle halogenids (Cofer & al. 1997). The climatic impact of peatland fires thus forces both warming and cooling. Long term carbon accumulation rates, observed using geological methods range from 2.9 to 28.2 g m^{-2} a^{-1} (Tolonen & al. 1992, Tolonen & Turunen 1996). For example in Patvinsuo mire, the fires observed from charcoal layers in peat could have reduced the accumulation from the average 17.7 ±0.6 (SE) down to 9.2 ±1.0 (SE) (Pitkänen & al. 1999). Individual fires in Patvinsuo could thus have resulted in an average loss of 2.5 kg carbon m^{-2}.

Concluding remarks

Mires as an ecosystem, or single species inhabiting those ecosystems, seem to be responsive to changes in atmospheric chemistry and in the annual distribution of temperature and precipitation. This sensitivity makes northern mire ecosystems vulnerable even to early phases of the projected climate change. Because many of the factors, in control of the wetland carbon cycle, are subject both to short-term and long-term shifts in the atmospheric composition or climate, it is highly probable that there will be changes in the capability of peatlands to sequester atmospheric CO_2, and in the feedback processes, such as CH_4 efflux. Responses to the increase in the lower atmospheric O_3 concentration, UV-B radiation, N deposition and CO_2 concentration are various. After all these studies with single or a couple of experimental factors, the most interesting question raised is: what is the combined effect of all these atmospheric changes on boreal mire ecosystems?

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Ecosystem services provided by Finnish mires

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Introduction

Ecosystem services include production of all kinds of goods from nature. In excess, they include such life-support processes as pollination, climate regulation and ground water filtration (Daily 2000). Monetary valuation of these services has been very up-to-date policy in many connections, for example in the mitigation process of wetlands in the U.S.A. (Hoehn & al. 2003). There have even been some attempts to value globally services provided by all ecosystems (Pimentel & al. 1997, Costanza & al. 1997). The results have been heavily criticized, however. Market prices, by definition, indicate a value of a small change in the availability of a service. Also, even though attempts to value all kinds of ecosystem services have been made, the methods of valuing non-market services, especially contingent valuation method, are often considered not very reliable (Costanza & al. 1997). However, there are situations in which valuation is necessary. For example the permit process in the Finnish Water Act requires cost-benefit analysis of all the relevant functions and services of the area in which a certain activity is planned.

Mires are in many cases used in multiple ways. Therefore there is a considerable risk of doublecounting the services both in direct and indirect use values (Söderqvist 2000). For example, nitrogen fixation purifies water flowing through a mire, but it also – in reasonable limits – increases the growth of trees, and is therefore indirectly counted into timber production. Few of these services are included in gross national product. Also many of the services are difficult to identify, and their economical value is not straightforward. Therefore they tend to be underestimated in many contexts. Also many services of mires are included in the services of forests, and in such they are not valued in any detailed way. However, the importance of mires and activities based on them is increasing. The global climate change and the importance of carbon cycles are acknowledged, and in this connection, mires of the world and their future use are vital. Ever tightening regulations of water pollution (EU's Water Framework Directive, the 3rd Programme of Targets for Water Protection by the Finnish Government) require that several problems must be solved in peatland forestry and peat mining as well as in agriculture.

Ecosystem services can be classified in several ways. There are both material and non-material functions of mires, which both contribute to the human welfare (Joosten & Clarke 2002). For example production functions provide timber and peat for markets as well labour for people in areas of high unemployment. Aesthetic values of mires are non-material as such, but they may be also exploited commercially in tourism.

In Finland 30% of the territory is covered by mires with a high diversity of mire complex types, site types and species. They have in different times provided important ecosystem services for the inhabitants of the country. Originally the ecosystem services of pristine mires were used, but during recent centuries especially agriculture, forestry and peat mining have greatly changed the mire nature.

Material services

Production

Forestry

Economically, timber production is the most important use of Finnish mires. It is also the reason for the most extensive environmental changes in the mires of Finland. The first peak of drainage for forestry began in 1928 and lasted a decade. Ditches were dug with spade. Almost one million hectares of mires were drained before the Second World War (Hökkä & al. 2002). The mires were chosen carefully and were usually very well suitable for forestry. Typical sites for drainage were spruce swamps with substantial natural tree cover. The tree stands of these drained mires have developed well and the quality of wood is good (Keltikangas & al. 1986). Many of these sites have already reached the regeneration maturity. The second peak of drainage began in the late 1950's and continued to the end of 1980's. The original biological mire area in Finland was 10.4 million hectares. 55 % of this is drained for forestry (Vasander 1996). Half of the Finnish peatland forests are still young. About 25 % of the peatland forests are advanced thinning stands, and 7 % are mature for regeneration (Hökkä & al. 2002). Majority of the timber logged from drained mires comes from thinnings and is mainly pulp wood.

The value of timber is included in national calculations. It is based on the National Forest Inventories data, the latest available being the 8th (Hökkä & al. 2002). Forestry is practised almost inclusively in drained mires. Only loggings for domestic purposes are done in natural mires (Paavilainen & Päivänen 1995). One fifth of Finnish tree volume is in peatland forests, and 77 % of this is in drained sites. The annual growth in peatland forests is 17.4 million m^3 (Hökkä & al. 2002). The increase in growth is twofold compared with the situation in 1951-1953, when vast majority of the mires was still undrained.

The digging of ditches and the maintenance of drainage are additional costs compared with mineral soil forests. The money endowed by the state to the original drainage of private owners' mires is about 3.5 mrd FIM/1997 (Aarnio & Pajuoja 1997). In addition, considerable sums were used to the drainage of state-owned mires as well as those of companies. The profitability of timber production in peatlands is almost always lower than in mineral soil forests of the same trophic status, because of lower timber growth and higher management costs.

According to the 8th National Forest Inventory, 10 % of the drained areas are unsuitable for forestry. Most of these sites are so poor that they can not maintain tree stand. Especially in northern Finland unbalanced nutrient amounts may cause poor tree growth even in rich fens. Most of the incorrectly drained mires are situated in northern Finland (Hökkä & al. 2002). In southern Finland there are areas where up

Harjanneva mire in Kauhajoki, western Finland, 12 years after ditching for timber growth. The drained area was also fertilized. Severe night frost in early June has damaged the new growth of the young pines. Photo Raimo Heikkilä.

to 30 % of the ditchings are unprofitable (Heikkilä 1984). In the calculations of the carbon balance of Finnish peatlands it was assumed that 30 % of the drained area will cease to be used for forestry by 2100 (Minkkinen & al. 2002).

Maintenance of the ditches is essential to the timber production. The probability of poor ditch-network condition is 70-100 % if the drainage is older than 30 years. In practice, no maintenance measures are suggested before 20 years from drainage, even if this may be too long especially in northern Finland (Hökkä & al. 2000). The possible methods of maintenance are ditch cleaning, complementary ditching and the combination of both. The maintenance of ditch-network is shown to be profitable to private owners, at least with the state grant (Hytönen & Aarnio 1998). In the 8th National Forest Inventory, need for maintenance was recognized for 1.52 million hectares of peatlands. This work has been largely neglected until recently (Hökkä & al 2002). There is often need to log timber in connection with ditch maintenance. These loggings are usually not profitable, provided that enough timber is left to grow to maturity. This logging and later thinning, which is more profitable, bring about a good quality mature forest (Penttilä & al. 2002).

The mean volume of timber in drained peatland forests is 63 m^3/ha, which is much lower than in mineral soil forests (93 m^3/ha). In drained spruce mires of southern Finland there is almost as much timber as in mineral soil forests, whereas the volume is much less in northern Finland and in pine mires. Much of this volume is in small trees. The amount of saw log sized timber is 21 % of the total volume. In the mineral soil forests the proportion is 40 %. The amount of big trees is clearly bigger in drained mires than in undrained mires, however (Hökkä & al. 2000).

The quality of timber varies strongly from site to site. Wood properties of peatland *Pinus sylvestris* are generally suitable for pulp production, although the wood grown after drainage differs from wood grown in pristine conditions. For special pulp purposes peatland *Pinus sylvestris* is not well suitable (Varhimo & al. 2003). *Betula pubescens* is often abundant in drained peatland forests, where it will appear naturally (Hökkä & al. 2002), wanted or not. In some southern Finland sites it may produce saw timber, even if the quality is not high (Verkasalo 1997). In most cases, *B. pubescens* is more suitable for pulp wood. Peatland forests with mixture of conifers and *B. pubescens* are less profitable than pure conifer stands (Hynynen & al. 1997), but *B. pubescens* may be profitable for the regeneration of *Picea abies* (Niemistö 2000). The quality specifications for saw timber conifers vary according to the size. Small logs must be of better quality than big logs, and thus the criteria for timber from thinnings are very strict. 13 % of *Pinus sylvestris* and 22 % *Picea abies* from first commercial thinning include parts which meet these criteria. The proportion of good-quality saw timber in thinnings is lower than in mineral soil forests (Stöd & al. 2002). The volume of timber size trees in sites drained before 1965 is comparable to the mineral soil forests. Also the internal timber quality was satisfactory. Internal tree properties, as crookedness, lower the amount of saw logs as well as the relatively small stem size. The proportion of pulpwood is thus significant even in mature stands (Päivänen & Sipi 2002).

Special carefulness is needed in the logging of peatland stands as not to harm the ditches. Also the transport distances from the logging sites are in an average longer in peatlands than in mineral soils.

In most drained mires, nitrogen is, contrary to the mineral soils, usually not a minimum factor (Laiho & al. 1999). Fertilization with NPK is required in ombrotrophic sites (Paavilainen & Päivänen 1995), if they will be maintained. Phosphorus is usually abundant in peat. The solubility of it is slow, however, and in many drained mires phosphorus restricts the tree growth. Potassium pool in peatlands is small. It is sufficient for the tree growth as such, but loggings may cause leaching of potassium (Ahtiainen 1988). Simultaneously, the potassium binding into trees temporarily decreases (Laiho & al. 1999). It has been estimated that approximately one million hectares of nitrogen-rich drained mires suffer from deficiency of potassium in the late phases of rotation or after first loggings. Fertilizing with potassium and phosphorus should improve the timber growth in these peatlands (Kaunisto 1988, Silver & Saarinen 2001).

Early studies suggested an effective natural regeneration of drained mires (Kaunisto & Päivänen 1985). In most cases the surface was *Sphagnum*-dominated and moist, which is favourable for germination and seedling growth (Saarinen 1997). In old drained sites, the situation is not so good. Site preparation (rotavation or mounding) facilitates the regeneration, which remains very weather-sensitive, however (Saarinen 2002). Results of seeding of *Picea abies* are generally poor. The seeding of *Pinus sylvestris* varies greatly even if site preparation is done. Peat thickness and weather conditions are probable causes. Late frosts cause problems both in *P. sylvestris* and *P. abies* plantations. If *P. abies* is planted under a shelter of *Betula pubescens*, result is better. Biotic damage risks of young peatland forests are not very well known, but diseases and damage caused by animals may differ from problems in mineral soil forests. The profitability of many drained sites must be evaluated anew after the first tree generation is harvested. In borderline cases, especially if there might be problems in regeneration, the site is probably left out from active forestry use. There are also some cases in which the nature values of the site are remarkable, and the best use for it is protection (Saarinen 2003).

Agriculture and horticulture

The agricultural use of mires in Finland has a short history and minor scale compared with many European countries. Grazing and making hay in pristine mires has, however, been an activity used all over the country as soon as cattle farming was introduced. Even far-away fens were used to collect winter fodder in the absence of cultivated hay fields. This use ceased during the first half of the 1900's. The last marks of grazing and haymaking are still seen in the vegetation of fens and rotting remains of barns and structures for haypiles.

Actual mire cultivation began gradually. First references to occasional local mire cultivation are from the 14th century. In the 1600's the method of drainage and subsequent burning of mire surface spread in southern Ostrobothnia. Manure was mixed with the ash layer, and resulting crops were very satisfactory. The soil remained productive for some years, after which the peat was burned again. This method became a common practice in western parts of Finland. It destroyed the peat and nutrients were wasted especially in fens. Another soil conditioning method applicable in peatlands was the mixing of mineral soil to the surface peat, which was started in the 1700's. The amounts used in Finland were usually 200-400 m^3 per hectare. It was mixed to the peat by ploughing and harrowing. Both of these methods were in use until the beginning of the 1900's. At that time, the advent of liming and fertilization replaced earlier soil conditioning methods.

It has been estimated that 0.7-1 million hectares of mires have been turned into agricultural land. Most active eras for mire drainage for agriculture were the beginning of the 20th century, when the population growth was rapid, and the years after the Second World War, when land was needed to compensate land losses to the Soviet Union. Most of these fields were in use only for a very short period.

Peatland agriculture was an important part of national economy at a time. At the peak period, peat soils comprised 1/3 of Finland's cultivated area. Nowadays, new fields are not needed, and many old peat fields are set aside. It is estimated that about 200 000 hectares of peat soils remained in agricultural use in the late 1990's. This is 10 % of the arable field area in Finland.

Energy peat extraction

Finland is the biggest peat user and miner in the world. About 35 % of the known commercial energy peat is excavated in Finland (Joosten & Clarke 2002). Other major energy peat users are Ireland, Russia, Belarus, Estonia and Sweden. Most of the mined peat is used locally or regionally, and little is exported (www.turveteollisuusliitto.fi). The role of peat has been emphasized as one of few native energy sources in Finland. Also the social aspects are important – peat mining offers work in rural areas of high unemployment rates.

The annual amount of mined energy peat depends mainly on weather and varies greatly. In last two decades the amount has varied between 5 and 33 million m^3 annually. (www.turveteollisuusliitto.fi). In general, the amount of used peat has been quite stable in last years. The proportion of peat of all energy sources in Finland is about 6 % (www.motiva.fi).

Peat is recently mined in 60 000 hectares. In addition, about 100 000 hectares have been prepared or are reserved for peat mining (www.turveteollisuusliitto.fi). This is 1,6 % of Finnish mire area. The main problems of peat mining are increased CO^2 emissions, loss of large pristine mires, decline in water quality, dust and noise. Environmental impact assessment is required if the peat mining area is bigger than 150 hectares, and permission from Environmental Permit Authority is required.

Traditional extraction of litter peat for cattle in Vesineva mire, Jalasjärvi town, western Finland in 1982. This kind of utilization did not have a very strong influence on mire ecosystem, because the mire was not drained. Photo Raimo Heikkilä.

Horticultural and agricultural use of peat

At present, peat is used in agriculture as a soil improver and in manure treatment. In arable soils organic matter promotes the activity of micro-organisms and maintains soil structure and nutrient status. Especially clay and silt soils and on the other hand coarse sandy soils benefit from the addition of peat. In manure treatment slightly decomposed *Sphagnum* peat is used as a bedding material for cattle, pigs, horses and poultry. The use of peat first as livestock litter, which is then spread in the fields to improve soil, is most economical way of peat use in agriculture. Small amounts of peat are used in the storage of root crops and potatoes over the winter (Reinikainen 1996).

Weakly decomposed surface peat is used as a soil improver also in horticulture. Much more peat is used in greenhouse cultivation as a sowing, rooting and growing medium (Reinikainen 1996). In 1999, 2.4 million cubic metres of peat was mined for agriculture and horticulture. It corresponds to about 6 % of the global figure (Joosten & Clarke 2002).

Chemistry

Several organic compounds in peat are theoretically interesting for industrial use. Chemical conversion of peat has been studied by several organizations in the 20th century. Possibilities of peat wax and resin production in industrial scale were surveyed in the 1980's, but production costs have not yet been able to compete with products derived from mineral oil (Fagernäs 1996).

Thermochemical conversion methods include pyrolysis, hydrogenation and gasification. Also these methods have been studied in Finland. A peat coke factory using pyrolysis worked 1976-1988, but was closed as unprofitable. In the gasification, fuel gas or synthesis gas may be produced. Several small-scale gasifiers are used in energy production. Ammonia may be produced from peat by gasifying. An ammonia factory was established in 1988, but it is not operational due to the low market price of ammonia (Fagernäs 1996).

Peat textiles

Peat textiles are made from fibres of *Eriophorum vaginatum*. In the peat, these fibres have softened and are ready for use after a chemica or mechanical treatment. Peat fibre has been used in parts of Europe for a century, but in Finland peat textiles are new. Nowadays, peat fibre is used together with wool to make different warm textiles, both for industrial production and for art craft work (Pirtola 1996). There are some companies in Finland that make use of peat fibre, which is screened off in peat mills, because it is unsuitable for horticultural use. No statistics available, does not influence the amount of mined peat

Balneology

Peat balneology is quite new in Finland, although it has been known in continental Europe since the Roman Empire. Characteristics of peat types for balneological purposes were studied by Geological Survey of Finland and University of Turku from 1989 (Korhonen & al. 1991). Mainly well decomposed black peat is used, but the amount is very small (See Korhonen & Lüttig 1996, Joosten & Clarke 2002).

Recently several Finnish spas offer different sorts of peat baths. Also the use of local treatments has increased considerably in last few years. A typically Finnish application is the use of peat masks in sauna (Korhonen 1999).

The peat should be highly decomposed. Its quality should be tested beforehand, as the balneological characteristics of peats vary greatly. The mining of balneological peat is very suitable for small peat mining companies, which can take the special needs of peat users into account. The mined peat must be treated so that it does not dry out. It may be even mined manually (www.lehtopeat.com).

Wild plants, mushrooms and animals

Berry picking is usual in Finnish households. According to Saastamoinen & al. (2002), 60 % of households picked berries annually. Most of them were collected for domestic use. *Vaccinium vitis-idaea*, *V. myrtillus* and *Rubus chamaemorus* made up 90 % of the picked berries. Mires are not important for the picking of mushrooms.

The value of all wild berries and mushrooms sold to buying enterprises and industry varied from 30 to 141 million FIM (5.0 – 23.8 million €) in the period 1990-2002 (Malin 2003). The high annual variation in the yields seems to be a limiting factor for the commercial berry picking (Kangas 2001a). Commercial berry picking concentrates in the northern and eastern parts of Finland, in regions of high unemployment and low income. For most pickers, the income from picking is less than 1 000 FIM (170 €) annually. Few pickers earn more than 10 % of their income from commercial picking (Kangas 2001b).

Cloudberry *(Rubus chamaemorus)* is the most valuable berry in Finnish mires. Especially in northern Finland it is an important source of income. Photo Teemu Tahvanainen.

The most valuable mire berry is *Rubus chamaemorus*. The yield varies greatly annually, which causes problems for pickers and retailers. The proportion of *Rubus chamaemorus* of the total berry picking varied between 1 and 30 % in the period 1994-2001. The paid price per kg is higher in poor years, but it does not compensate the low amount for pickers. The total income varied between 2.5 and 26.7 million FIM (0.4-3.5 million €) in 1994-2001 (Malin 2002).

The use of *Vaccinium oxycoccos* has increased in recent years, but still the picked amounts are fairly low. A considerable amount of *Vaccinium oxycoccos* is also imported, but exact numbers are not known (Malin 2003). Other berries which are collected from mires are *Vaccinium uliginosum*, *Empetrum nigrum* and *Rubus arcticus*. Of these, *Rubus arcticus* is very valuable commercially. Its use is limited by usually low yields both in nature and in cultivation. The price in 2002 was 14 €/kg, but only 984 kg were sold (Malin 2003).

At present, mire plants are not collected for industrial purposes in Finland. Live *Sphagnum* moss is harvested commercially for horticultural purposes in North America, Australia and Chile (Joosten & Clarke 2002).

Extracts from several *Drosera* species are used in medicines, the main use being against asthma and bronchitis. *Drosera rotundifolia* is collected from the mires in Finland, and most of the yield is exported. The collected amount was 2 100 kg in 1994

(Galambosi & al. 2000a). To get one kilogram, 5 000 – 10 000 flowering individuals must be collected. The population density is not very high compared with cultivated beds (Galambosi & al. 2002b). Collection from natural mires is still more profitable than cultivation because costs are low. The regeneration of *Drosera rotundifolia* from seed is ensured, if 5-10 flowering plants are left per m^2 (Galambosi & al 2002a).

Drosera species suffer significantly from drainage of mires. The area needed for collecting has been so small that the collecting has not been hindered by drainage, however.

In Russia there is a long tradition to use many mire plants, e.g. *Menyanthes trifoliata*, for domestic medication and in medicine industry. Altogether 29 mire plant species, i.e. 10% of all used species, have been used for medicine industry in the Soviet Union (Елина 1993). This potential has not been studied for other mire plants than *Drosera* species in Finland.

Wild animals

There are 300 000 hunters in Finland, which makes the biggest proportion of population in Europe (www.riista.fi). The most important game animals are elk, tetraonids, hares and waterfowl. Of all the meat and furs, vast majority is used in private households.

Mires may be used directly for hunting, but their main value is as nurseries. Many game species favour mire margins, which are rich in food and offer good protection (Pirkola 1976). Numerous species of waterfowl nest in small ponds in mires. For example, up to 90 % of the population of *Anser fabalis* lives in mires. In northern Fennoscandia, palsa mires and lakes with mire shores are rich habitats for waterfowl (Haapanen & Nilsson 1979).

Ahonen & Leiviskä (1993) gave an estimate of the value of game in mires. The total value of mire animals (market value of meat and other products) was 43.7 million FIM (7.35 million €). This is 18 % of the total value of game in Finland.

Drainage for forestry is partly beneficial for tetraonids. Elk has been even a pest in young peatland forests. Fertilizing has further increased the attractiveness of drained areas (Ruuhijärvi & Ruuhijärvi 1980). Wet mires with lots of waterfowl have been mostly unsuitable for forestry use, and waterfowl have not suffered very much from forestry drainage. Instead, the building of large water reservoirs has been harmful to some species of waterfowl. Species like *Anser fabalis* do not find suitable habitats from the shores of reservoirs (Haapanen & Nilsson 1979).

Carrier functions

Water reservoirs

60 000 hectares of mires have been drowned in water reservoirs (Lappalainen 1996). The largest reservoirs, Lokka and Porttipahta, are situated in Lapland, while most of the others are situated in the Suomenselkä watershed area in Ostrobothnia, western Finland. The largest aapamire in Finland, Posoaapa, was drowned in Lokka reservoir, constructed in 1967, (Häyrinen 1972). Also in other reservoirs there were large mires, especially in Levalampi, western Finland. Building reservoirs on mires converts them from a source to a sink of CO_2 and increases the emission of CH_4 to the atmosphere (Joosten & Clarke 2002). Mire ecosystems disappear and are replaced by usually heavily regulated reservoirs. Also the reservoirs on mires have a negative influence on water quality. There is remarkable leaching of nutrients and mercury into watercourses (Verta 1990).

Infrastructure, waste deposits, landfills

Mires have not been popular areas for habitation. However, in many towns and cities also drained mire has been used as building ground. There are no statistics over the area used like this. The amount of mire area used for municipal purposes, as landfill areas and waste deposits is 2 000 hectares. There have been some 300 waste deposits on mires in Finland. The number of actively used deposits is decreasing, but the old waste deposits remain in mires. Roads have been constructed on 37 000 hectares of mire area (Lappalainen 1996).

Military exercises, defence

The ministry of defence of Finland has given its land property mostly to Metsähallitus, which is taking care of most of the state forests in Finland. So far the military exercise areas have been refugees for wildlife especially in mires, but now forestry is intensifying in these.

Transport, herding

Mires are used commonly for timber transport in wintertime when they are frozen. It does not have a significant influence on mire ecosystems. Recently hiking routes with wooden boardwalks have been constructed in mires especially in nature reserves. The amount so far is a few hundreds of kilometres. Mires are excellent routes for winter recreation. Cross-country skiing and snowmobile routes are often made on mires, because the terrain is mostly open and there are no steep slopes.

Mires have been used commonly for reindeer herding in the summertime in northern Finland, and earlier also for cattle grazing in the south. Nowadays their importance is declining while reindeer husbandry has more and more turned into feeding the reindeer inside fences

Regulation functions

Regulation of global climate

Deep concern about the global warming by increasing amounts of greenhouse gases in atmosphere has also emphasized the mires as important factors of natural carbon cycling. Use of mires as well as changes in climatic conditions may alter the carbon balance in several, partly unpredictable ways. They may also affect the carbon storage of mires (Alm & al. 2006). The value could be estimated on the basis of the trade of emission rights, taking into account the roles of the different forms of carbon bound in the mires and emitted from the mires in natural state and as a consequence of different ways of utilization. So far there is little data about it.

There are three components of carbon stores in mires: biomass, litter and peat. The amount of carbon in Finnish pristine mires has been intensively studied. Their total carbon storage is 2 257 Tg. Aapa mire zone contributes 85 % of this amount, because major part of undrained mires is in northern Finland. This knowledge has been used to calculate the total amount of carbon in boreal and subarctic mires (Turunen & al. 2002).

The use of mires affects their carbon stores. Peat from agricultural peatlands is constantly decomposing. Mined peat is either burned or used in horticulture, and the carbon is released quite rapidly into the atmosphere. The situation in mires drained for forestry is more complex. Some peat is decomposing, but the amount of litter is often increasing until an equilibrium is reached. This may take decades.

The role of mires in the future carbon balance remains unclear, as there are still uncertainties about the effects of global warming to the climate in Finland. Especially the amount and seasonal distribution of precipitation affect the carbon sequestration and peat decomposition.

Regulation of regional and local climates
In pristine mires the moist surface of the peat layer promotes heat exchange between the peat and the air above it. Mires in natural state do not have a significant influence on temperatures. After drainage the topmost peat layer is drier than in the natural state, and heat exchange through it is diminished due to the thermal insulation of rather dry peat inn summer. Therefore, during calm and clear weather at night the air over drained mires becomes strongly cooled, and an inversion layer often develops. By time, when the tree cover becomes more dense, the cooling effect is reduced, due to the shelter of the tree stand (Solantie 1999).

Especially in middle boreal zone, where mires are abundant, and the proportion of drained mires in general high, forestry drainage of mires has caused changes in regional climate. Short-term changes may be large, decreasing minimum temperatures both in winter and in summer markedly. In long term, winter minimum temperatures rise especially in the middle boreal zone, but summer minimum temperatures decrease. The rise in annual minimum temperature varies between 0,5 and 2,2 degrees in different vegetation zones, and the decrease in monthly mean temperature in the summer varies between 0,4 and 1,5 degrees (Solantie 1999). After logging the timber in peatland forests, the impact is similar or stronger than immediately after the drainage.

Regulation of catchment hydrology and hydrochemistry
In Finnish waters, the main growth-limiting nutrient is typically nitrogen. Also phosphorus may be the limiting factor. Other factors important to the water quality are acidity, humic substances and suspended solid particles. Mires are the main primary source of dissolved organic matter to Finnish runoff waters. Mires also contribute largely to the acidity of runoff. Mires affect the quality of water which reaches them, be it rain water, surface water or ground water. Mire vegetation and also peat take up nutrients and other elements which are then partly accumulated in the peat. So mires act as sinks of inorganic elements (Kondelin 2006). There is no data yet for the valuation of the roles of mires in the regulation of catchment hydrology and water quality. Neither is there data about the influence of mire utilization on it.

Non-material services

Non-material services cover a diverse range of benefits. Proxy functions include pleasant sensations, whose material advantages are not obvious. They may be consumed consciously, but often also unconsciously. Learning modifies them, but they may also have a genetic basis. Identity functions serve to identify person's position in the surrounding environment (Joosten & Clarke 2002). Non-material services are as important for human beings as material services, but their value has long been neglected in the context of nature utilization. Nowadays, however, many of these functions have also market value for nature tourism etc. Some non-material services are evaluated in political decision-making, but not all.

Proxy functions

All functions that satisfy social needs are included in this group. For example friendship, solidarity, respect and territorial needs are included as well as employment (Joosten & Clarke 2002). Right to work is as well a question of self-esteem and belonging as of direct income in Finland.

Helsinki University field course of mire ecology in Elimyssalo nature reserve in Kuhmo town, eastern Finland, in 1994. The aim was to give a multidisciplinary view on mires and mire conservation. Photo Tapio Lindholm.

Peat industry and forestry have been good employers in areas of traditionally poor employment. The employment policy has been taken into consideration in many cases of peat power plant planning. The amount of people in full-time job in peat industry is about 800 annually. Peak time employment in summer is 2 500 (www.turveliitto.fi).

Especially the mire drainage period from 1950's to 1980's offered opportunities to machinery companies of rural areas. The drainage has almost ceased. Management of the ditch network is much smaller than the amount of ditching in peak years. In 2002, forestry employed 21 000 people, and the amount decreases annually. As a whole, forestry and wood industry employed 3.9 % of the labour force in 2002, while the percentage in 1970's was still 10 %.

Several projects are concentrating in nature tourism and other activities in protected areas and wilderness areas. There are nowadays tourist companies concentrated on mire tourism at least in Teuravuoma in Lapland and in southern Ostrobothnia in western Finland. Bird tourism is an important form of tourism in mires.

Mires have often been regarded as remote and borderland sites, with which people do not have close connections. This may be changing, however, when people widen, deepen and strengthen the understanding of their own surroundings. There are recent cases, in which local people have been strongly against peat mining in their neighbourhood (Palviainen 1999). Recreation and aesthetic functions as well as identity functions (symbolisation, spirituality and existence functions) have in several connections been regarded as important forms of mire ecosystem services, but so far there is no data about the values of these functions. The situation is the same with educational (transformational) functions as well as bequest functions.

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Mire conservation and its short history in Finland

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Early stages

Scientists started to pay attention to the conservation of mires, especially rich fens, in Finland in the 1930s (Kujala 1939). The first law on nature conservation was given by the parliament of Finland in 1923, and it made it possible to establish nature reserves based on legislation. The first concrete proposals for mire conservation were made in the late 1940s, when the nature conservation committee of the Finnish Society for Forest Science (1948) suggested the completion of the network of national parks and strict nature reserves to compensate the reserves lost, located in the land taken by the Soviet Union as a consequence of the II World War. The leading societies for natural sciences joined the proposal. The proposal led to the nomination of a national park committee. On the basis of its proposals, strict nature reserves of Vaskijärvi, Häädetkeidas and Runkaus were established in 1956, with the aim to protect good examples of mires mainly for research purposes. In addition, valuable mires were also included in some other national parks and strict nature reserves establishes at the same time.

When clearing for agriculture and forestry drainage destroyed the most fertile mires, the need for the protection of rich fens, spruce mires and spring fens was emphasized already in the 1950s (Keltikangas 1955, Ulvinen 1961). Attention was paid also to the diminishing of raised bogs, and the conservation of best examples was proposed (Isoviita 1955, Aartolahti 1965). Among others, the special values of Torronsuo mire in Tammela and its scientific importance were emphasized. In 1960s the need for mire conservation was understood more widely than earlier, and the protection of mires was demanded to protect the fauna and flora of mires, for the needs of education and to protect watercourses (Söyrinki 1964).

Waking up in mire conservation

A real awakening for the preparation of mire conservation programmes happened more widely in the 1960s (Keltikangas 1965, Ruuhijärvi 1965, 1989, Raitasuo 1965, Häyrinen 1965a,b). A committee nominated by the Finnish Nature Conservation Association and Finnish Peatland Society prepared a plan for the protection of mires in state owned land in southern Finland (Häyrinen & Ruuhijärvi 1966). Another part for northern Finland was ready in 1969 (Häyrinen & Ruuhijärvi 1969). Altogether these plans covered more than 200 mires in an area of almost 450 000 hectares. Also localities on the level of national parks or strict nature reserves were proposed in the plans. The plans were mainly based on the regional studies of Ruuhijärvi (1960) and Eurola (1962). Thus, in addition to the evaluation of typical mire complexes, regional features of mires were taken into account.

Metsähallitus (National Board of Forestry), responsible for most of state land, decided around 1970 to protect most of the mires proposed for conservation by its own decision as reserves of different levels, which was very important for the preserving of Finnish mires. At the same time it was understood that protecting mires in state land is not enough to preserve mire diversity, especially in southern Finland, but conservation must be extended also to privately owned land (Häyrinen & Ruuhijärvi 1968, Keltikangas 1969, Ruuhijärvi 1970). Mire conservation became more and more urgent due to the wide **forestry improvement programme** (MERA) including intensive forestry drainage.

Also the state started to prepare the development of Finland's network of national parks and strict nature reserves in the 1970s by establishing committees for environment protection (1973) and for national parks (1974-76). The ecologically and biogeographically very good proposal of the National park committee (Tallgren & al. 1976:88) included many of the most valuable mire systems, which were proposed to be protected as national parks or strict nature reserves. In addition, numerous smaller mires were proposed to be protected as mire reserves. Due to large areas proposed to be protected, the proposal was strongly opposed by land owners and forestry organizations, and the government of Finland in 1978 decided to establish only a part of the reserves proposed. However, most of the national parks and strict nature reserves important for the conservation of mires were established, because their value for forestry was low.

The pioneer of Finnish mire conservation, Urpo Häyrinen in Koivusuo mire in Ilomantsi, easternmost Finland, in 1979. Part of the mire was protected as a strict nature reserve, but a large eccentric bog part was decided to be used for peat mining. Photo Pekka Salminen.

National programme created a solid basis

Simultaneously with the National park committee's work, the preparation of a National mire conservation programme was going on. At first, in the unit responsible for nature conservation in the ministry of forestry and agriculture, information about the most important pristine protected mires and mires worth protection was compiled as the basis for conservation planning. In this basic material was included all the previous data about mires and mire conservation Altogether this data consisted of about 1200 areas and approximately 700 000 hectares of mires, largely also in privately owned land. Conservation in private land was problematic, because the nature conservation administration did not have tools to protect private lands. The only way was to negotiate with the land owners to make voluntary decisions for conservation, because there was not adequate funding for the compensation of economical losses. State funding for forestry drainage of mires continued, and nature conservation value were not taken into account when deciding about the state support. Forestry legislation only later prevented the use of state funding for the ditching of mires to be protected.

In the 1970s also regional land use plans based on the legislation for building were compiled, including regionally important areas for conservation and recreation. In practice, these plans did not gain much, and pristine mires were not seen as important among those who wanted to utilize mires. Also the system to make these regional land use plans true was not adequate, and for example it could not prevent the land owners to make ditching on their own expenses.

Despite their deficiency, regional land use plans were important, because they included many new mire conservation sites especially on private land. They added to the knowledge about mires to be protected among planners, and created a basis for the protection of many mires later included in the National mire conservation programme. The mire conservation year 1976 raised the awareness about the urgency and problems of mire conservation, and probably influenced on getting more understanding for mire conservation.

Due to the problems of mire conservation, it was important that the ministry of forestry and agriculture established a mire conservation working group to compile a national mire conservation programme, which was prepared in two parts in 1979 and 1981 (Häyrinen 1972b, Heikkinen & Kosonen 1976, Raitasuo 1976, Haapanen & al. 1977, Salminen 1977, Haapanen & al. 1980, Maa- ja metsätalousministeriö 1981, Ruuhijärvi 1978, Salminen 1978, 1980). In the creation of the conservation programme, best mire biological expertise of Finland was used. The goals to protect mire complexes, site types, bird fauna and vascular plant flora were taken into account, attempting also to obtain as good regional coverage and representativeness as possible. Finnish topographic maps (scale 1:20 000) were surveyed, and mires were analysed using aerial photos. The available resources were, however, very limited in relation to the very intensive ditching of mires for forestry at the same time.

The main goal of mire conservation in the 1970s was to protect in the first place the most valuable undisturbed pristine mire complexes. Also numerous small mires valuable for the conservation of flora were included in the programme. The first lists of threatened mire site types and vascular plants of mires were prepared. In addition to the whole country, also regionally threatened sites and plant species were taken into account. A scoring system for the evaluation of the conservation value of rich fens was developed (Kaakinen & Kukko-oja 1981).

In the decisions of mire conservation programmes by the government of Finland (1979 and 1981), 600 mires covering altogether 500 000 hectares were included. Together with earlier decisions about national parks and strict nature reserves, about 7 % of Finnish mires were protected. The decisions meant that state authorities were not allowed to plan or perform activities, which would damage the conservation values of the mires included in the programmes. The very small nature conservation administration in the ministry of forestry and agriculture as well as provincial administration, had a lot of work in informing about the programmes, controlling different activities and in negotiations with land owners, and ditching of mires to be protected could not be completely prevented. The situation became better in the 1980s, and state resources for nature conservation grew in connection with the establishment of the ministry of the environment in 1983. Also the legislation for the supporting of forest improvement finally in 1987 prevented state funding for the ditching of mires included in the conservation programmes.

Pirjatanneva mire in Alavus, western Finland was agreed to be used for peat mining in the EYR contract in the 1970s, but because it was not destroyed yet in the 1990s, it was protected in the Natura 2000 programme. Photo Raimo Heikkilä.

Peat mining and nature conservation

The utilisation of mires for fuel peat mining increased significantly after the so-called energy crisis in 1973. The ministry of trade and industry established a working group to fit together the **needs for energy production and nature conservation**, and it prepared in 1978 a contract (so-called EYR contract) about which mires would be protected and which were to be used for fuel peat extraction. This contract between different interests was crucial to get the mire conservation programme accepted by the government. In the contract also some regionally valuable mires were decided to be protected, even though they were not included in the national mire protection programme.

It must be pointed out that some mires, which in the 1970s were agreed to be used for peat mining, have later been agreed to be protected, e.g. Pirjatanneva mire in Alavus, western Finland, Kilpisuo mire in Karstula, central Finland, Lääväsuo mire near Oulu, Käärmeaapa in Simo, southern Lapland and Kilpiaapa in Pelkosenniemi, central Lapland. The preservation of them was important for later conservation projects, e.g. the preparation of Natura 2000 programme since 1995. The worst loss for peat mining in Ostrobothnia in the EYR contract, Karhusuo mire in Pudasjärvi has been protected through a provincial land use plan. Also water legislation and environment permit processes have protected some valuable mire areas, most important of them being the Vuotos mires in central Lapland (Lindholm 2003).

The situation with peat mining has changed in the 2000s also due to new legislation about land use and construction, and national land use principles on the basis of the new law. In regional planning, in some provinces peat mining has been directed into new mires, less valuable for nature conservation. Old reservations for peat mining in regional land use plans have been removed, and these mires have been reserved for nature conservation. For example in Northern Ostrobothnia around Oulu city, new peat mining areas have been directed to at least partly earlier drained mires. In new pristine valuable mires, no new peat mining areas have been opened since the 1990s. In addition, the legislation about environmental impact assessment from 1994 with later amendments has made the position of nature conservation better in connection with peat mining. In the environment permit processes based on the legislation about environment protection, biodiversity impacts are nowadays taken into account. This has also safeguarded valuable pristine mires.

Other conservation programmes supported mire conservation

The government of Finland ratified in 1984 a national conservation programme for herb-rich forests. In northern Finland also small but valuable rich fens, forest mires and spring fens were included.

The bird sanctuary wetland conservation programme, ratified by the government in 1982, is important for the conservation of flooded mires.

In the law for the conservation of wilderness areas in Lapland (1991), large areas were protected, including also wide mire areas.

The conservation programme for old-growth forests in northern Finland (1996) is important while it protects especially the networks of small mires, forest mires and thin-peated pine mires, which were not very well represented in the mire conservation programme, due to the emphasis for large mire complexes. There are a lot of undisturbed ecotones of mires and forests in the old-growth forest reserves. Altogether more than 100 000 hectares of mires were protected in the decision for the conservation of old-growth forests.

Complementary proposal for mire conservation in 1995

Complementary mires supporting the national mire conservation programme were searched during the 1980s by studying new maps and aerial photos and intensive field inventories. Especially the rich fen studies of H. Heikkilä in the southern half of Finland (H. Heikkilä 1987, 1991) were important. Inventories of threatened species in whole Finland have markedly added to the knowledge about mires.

On the basis of new data, a list of additional mires proposed to be protected was compiled (R. Heikkilä 1994). It includes 520 mires, covering altogether 120 000 hectares. As a mean, the mires are much smaller than in the mire conservation programme, but also numerous large valuable mires were found in the survey, especially in Ostrobothnia, northern Savo, Kainuu and southern Lapland.

New legislation for nature conservation and forestry

The new nature conservation law (1096/1996) and forestry law have been applied since the beginning of 1997. It made nature conservation planning as an official task for environment administration and gave new ways for conservation. The law also made true the goals and applying of the habitats directive of European Union in Finland. Also it gave a duty to monitor the state of natural biotopes and species. The most comprehensive analysis has been made concerning threatened species. The third updated evaluation was prepared in 2000. Good basic knowledge of the conservation status of different biotopes, including mire site types, has been obtained on the basis of the 8th and 9th nationwide forest inventories conducted by the Forest research institute, as well as the representativity analysis finished in 2000 in Finnish Environment Institute. In addition, information about the conservation level of species and habitats has been compiled in connection with the preparation of Natura 2000 programme.

Forest legislation protects some ecologically important key biotopes, e.g. springs and spring fens as well as fertile forest mires by steering land use and informing the land owners about the key biotopes. Nature conservation law protects the most valuable black alder swamps. A problem in conserving the key biotopes is their small area, defined also in forest law.

Professor Rauno Ruuhijärvi showing *Impatiens noli-tangere* to students in the largest black alder swamp in Finland, Mallasranta mire in Pälkäne, southern Finland, in 1981. This habitat is protected by nature conservation law. Photo Raimo Heikkilä.

In the mappings of the key biotopes according to forest legislation, 14 700 hectares of open or sparsely tree covered mires, 2 800 hectares of rich fens and 1 900 hectares of fertile forest mires were found. Until the end of 2004, a little more than 100 hectares of black alder swamps have been found in the inventories.

As a specially protected species according to nature conservation law, the peregrine (*Falco peregrinus*) protects numerous mires in Northern Ostrobothnia and Lapland from peat mining.

Natura 2000 network has added protected mires

The preparing of Finnish Natura 2000 network is being finished, and the EU commission has already accepted Finland's proposal for the network. Meanwhile the status of Natura 2000 areas has become better, even though they already have nationally been protected by the Natura 2000 sections of nature conservation law. In the network belong among others, some 1500 areas, which include habitats of bogs or aapamires.

Numerous earlier non-protected mires were included in Natura 2000 network. Especially the representativity of rich fens and fertile forest mires improved. Also many earlier protected areas were extended. Among the new mire reserves there were

180 mires proposed for conservation by R. Heikkilä (1994). This has meant an addition of 25 000 hectares in the area until 2001. After that new mires have been protected, e.g. in connection with the regional land use plans. Especially the inclusion of Vuotos mires in Lapland is international important for the threatened fauna and flora of the mires as well as for the diversity of habitats.

The mire formation succession series in the Bothnian Bay coast is a globally unique phenomenon, which is not included in nature reserves or conservation programmes so far in the form of continuous time series. Finland has a global responsibility for the conservation of land uplift phenomena. Therefore the protection of the last preserved more or less complete succession series in Hailuoto, Kuivaniemi and Siikajoki is extremely important. These areas in Hailuoto and Siikajoki were included in Natura 2000 network, but the very important series in Kuivaniemi is not yet protected.

Conservation programmes are implemented – evaluation of threatened habitats is going on

Successful damming of a ditch in Haapasuo mire reserve in Leivonmäki, central Finland in 1991, has raised the water table on the level of mire surface. Päivi Mattila as a measuring stick. Haapasuo was drained for peat mining and became later an object for the testing of ecological restoration. Nowadays restoration is mainly filling the ditches not only damming. Photo Tapio Lindholm.

Only a part of the mires included in the national conservation programme have been established as nature reserves according to the nature conservation law. So far, 173 state owned mire areas, included in the programme, have been formed as nature reserves, covering altogether 414 000 hectares (Hokkanen 1994). In addition, numerous mostly small private owned mires have been established as nature reserves with a decision of provincial administration, later by regional environment centres. Altogether more than 90 % of the area included in the programme has been acquisited for the state to be protected. The total area has risen to 630 000 hectares, and only for 23 000 hectares the protection has not yet been implemented. Rather commonly also mineral soil areas around the mires have also been acquisited to ensure the preservation of hydrological units. The resources for implementing conservation programmes and the resources in nature conservation administration have become many-fold during two last decades. Implementing the programmes has proceeded effectively after a financial programming by the government in 1996.

A new view in evaluating mire conservation is the assessment of threatened habitats, started in 2004. A three years survey is based on three levels: mire site types, mire mesotope level (mire complex types, mire systems and primary succession series of mires) and mire landscape types. On the basis of the results it is possible to evaluate the future additional needs for mire conservation and direct the resources for non-adequately protected mire habitats.

Conservation situation

As a total, 1,13 million hectares of mires have been protected in Finland, i.e. almost 13 %, which mainly consists of the national mire protection programme, national parks and strict nature reserves, old-growth forest conservation programme and wilderness areas.

In mire conservation there are remarkable differences regionally and with mire site types. The conservation level of forest mires in the southern zones of concentric and eccentric bogs is very low, 0,5 %. Excluding Lapland, the conservation level of other rich or intermediate mires is very low also. In addition, the successional series in land uplift coast as well as small-scale mosaics of mires and forests, characterised by forest mires and pine mires, in southern and central Finland have not been adequately protected. In many cases the boundaries of mire reserves have been drawn very tightly, and they do not include the whole mire complex, and in many cases they cannot prevent the drying effects of ditching in the surroundings.

Threats for mires at present

According to the most recent evaluation of threatened species in 2000, 67 species of mires are nationally threatened in Finland, mostly in rich fens. The committee for the monitoring of threatened species has compiled a list of species, for the conservation of which Finland has an important international responsibility. 48 of these species live in mires, and 16 of those are threatened in Finland. Six of the species also belong to the appendix II of Habitats directive, and on in the appendix I of the Bird directive.

During latest years, the change in the state of mires has become slower. Maintaining of ditches and supplementary ditching, however, still continue to change the habitats suitable for mire fauna and flora, and produce nutrient load in watercourses. Fuel peat mining changes mire nature locally and regionally.

Challenges for development

There are still serious shortcomings in mire conservation (Aapala 2001a). Recent surveys and research have shown that the whole diversity of mire nature has not been protected adequately. The definition of mire complexes and defining their boundaries has not been satisfactory. The definition of mire system containing several mire complexes has been presented in Finnish mire studies only recently (Tolonen & Seppä 1994, R. Heikkilä & al. 2001). Especially mire margin habitats, valuable for biodiversity, like forest mires and rich fens are underrepresented in mire reserves (Aapala 2001b). Also regionally mire conservation is not even. Especially in the zones of bogs, where land use has been intensive for a long period, and most of the land privately owned, mire conservation is not comprehensive. In the aapamire zone a problem is the hydrological dependence of mires on their surroundings. Many protected aapamires have dried due to ditching in their drainage basins (Eurola ym. 1991, Aapala ym. 1994, Keränen ym. 1995, Aapala & Lindholm 1999). In addition, knowledge of mires in the aapamire zone has recently increased especially in connection with the inventories of threatened species.

About 41 000 hectares of the mires included in the national mire protection programme have been drained, mainly by the own activities of land owners. It is almost 10 % of the whole programme. Most of the ditching has been done in western Finland, in the provinces of Satakunta and Ostrobothnia.

Especially in southern Finland restoration of drained mires is an important tool for the protection of the diversity of mires. So far, mires drained for forestry have been restored almost only in state owned nature reserves. The need for restoration in the nature reserves maintained by the Natural Heritage Services of Metsähallitus has been estimated to be a little more than 20 000 hectares. By the end of 2005 altogether almost 13 000 hectares had been restored.

Even though drained mires are restored mostly in nature reserves, the restoration of unprofitably drained mires would support the state of mire biodiversity also outside nature reserves, and would be favourable to prevent the floods and nutrient releases, probably increasing due to climate change. The monitoring of the ecological consequences of restoration is a big challenge.

The hydrological conditions of protected mires should be evaluated, and methods to ensure the undisturbed status must be developed to safeguard the mires, which do not form hydrological entities within their present boundaries.

The planning, implementing and guidance of ditch maintaining should be developed to take into account biodiversity. In areas with nature values maintaining of ditches should not be done. The hydrology of unprofitably drained poor mires should be restored especially in areas adjacent to nature reserves. It is important to apply new methods for conservation, based on voluntary activities of land owners, to preserve mire habitats outside nature reserves.

Peat mining must be directed into mires already drained e.g. for forestry or agriculture. According to recent research it increases greenhouse gas emissions less than taking pristine mires in peat mining, which slows down the climate change.

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Ramsar areas in Finland

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Introduction

The Convention on Wetlands or Ramsar Convention provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. It is said that this convention is the oldest intergovernmental treaty on nature conservation, signed in Ramsar, Iran, in 1971.

The Ramsar Convention takes a broad approach in determining the wetlands, which are defined as:

“areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres”.

Wetlands “may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands”.

As a result of these provisions, the coverage of the Ramsar Convention extends to a wide variety of habitat types, including rivers and lakes, coastal lagoons, mangroves, peatlands, and even coral reefs.

In addition there are man-made wetlands such as fish and shrimp ponds, farm ponds, irrigated agricultural land, salt pans, reservoirs, gravel pits, sewage farms, and canals.

The official name of the treaty – The Convention on Wetlands of International Importance especially as Waterfowl Habitat – reflects its original emphasis on the conservation and wise use of wetlands primarily to provide habitat for water-birds.

Wetlands of the World

Wetlands occur in every country, from the tundra to the tropics. The World Conservation Monitoring Centre has suggested an estimate of about 570 million hectares (5.7 million km^2) – roughly 6% of the Earth’s land surface – of which 2% are lakes, 30% bogs, 26% fens, 20% swamps, and 15% floodplains.

A global review of wetland resources submitted to the Conference of the Parties to the Convention on Wetlands in 1999, while affirming that “it is not possible to provide an acceptable figure of the areal extent of wetlands at a global scale”, indicated a ‘best’ minimum global estimate at between 748 and 778 million hectares. The same report indicated that this “minimum” could be increased to a total of between 999 and 4,462 million hectares when other sources of information were taken into account.

UNESCO serves as Depositary for the Convention, but its administration has been entrusted to a secretariat known as the “Ramsar Bureau”, which is housed in the headquarters of IUCN–The World Conservation Union in Gland, Switzerland, under the authority of the Conference of the Parties and the Standing Committee of the Convention.

The first obligation under the Convention is to designate at least one wetland for inclusion in the Ramsar List and to promote its conservation, including, where appropriate, its wise use. Selection for the Ramsar List should be based on the wetland’s significance in terms of ecology, botany, zoology, limnology, or hydrology.

There are presently (November 2005) 147 Contracting Parties to the Convention, with 1522 wetland sites, totaling 129 million hectares, designated for inclusion in the Ramsar List of Wetlands of International Importance.

Meetings of the contracting parties are being held every third year. Just recently the 9th meeting of the contracting parties (COP9) was held in Kampala, Uganda 8.-15.11. 2005.

Original Finnish Ramsar list

In 1974, immediately after the convention had entered into force, Finland designated 11 sites for the Ramsar list. In line with the original basic idea, the ecological selection criteria of the sites were based on the ornithological value of the sites, exclusively. Administratively most of the sites already were protected areas. The original list of these 11 sites included 6 archipelago areas along the coastal areas (about which two on autonomous Åland Islands) and 2 shallow bays with reed-beds along the south coast of Finland and 3 mire and bog areas.

Each of the designated three mires represented the most important breeding area for water-birds and waders of the region in question. The sites were Patvinsuo Mire connected to Suomujärvi Lake in Northern Karelia (land area 86 km^2), Martimoaapa-Lumiaapa Mire complex in Ostrobothnia near Gulf of Bothnia (74 km^2) and Koitilaiskaira Mire and forest complex in Lapland (317 km^2).

One can notice that the designated mires of original Finnish Ramsar list were chosen as representative examples of the geographical distribution of typical mires with rich avifauna. As an indicator of the rich variety of the mire and bog habitat types in Finland, this listing was far from satisfying. Later on, after changing the selection criteria for Ramsar sites, to comprise other ecological criteria, such as vegetation types and habitats in parallel with bird fauna, Finland started the process of re-designation of new sites into the list.

Wetlands of Finland

Thinking of the original Ramsar target in ensuring the habitats of wetland bird species, Finnish wetlands are extremely important. They have provided, together with the neighbouring countries, most of the yearly production area of the wetland birds in the northern Europe. Thus our wetlands greatly contribute in ensuring the future of the bird production in Europe, and they represent a large variety of different mires and other kinds of wetland types.

The amount of the original wetland area, mires of Finland, has been evaluated as one third of the whole land surface, which makes a bit more than 100 000km^2. Forestry drainage largely affected Finnish mire and bog areas in the latter half of the 20th century. In addition, large areas of mires have been taken for peat mining, mainly for fuel and horticulture peat. Today, nearly half of the original mire area (40 000 km^2) still remains more or less in the natural state. However, mire habitats with thin peat layer like swamp forests, springs and spring fens, transition mires and especially bog woodlands are quite rare habitats compared to their original amount. As a matter of fact we have in Finland very few, if any, mires, which have been completely preserved in their natural state. Most of the protected mire and bog areas are lacking some parts of their original natural richness, namely the transition types of the natural mire types towards the surrounding genuine forest types. On the other hand, most of the economic activities, which have been described above, have been directed on less valuable mire and bog areas, whilst it has been possible to protect the richest large wetlands. This is due to the national mire protection programme.

At the moment, a lot of recovery measures are being conducted on Finnish mires to enhance the original habitats of the most valuable wetlands. At present, management plans and efforts of restoring many important mire areas have been financed under the EU LIFE/Nature fund. There are several restoration projects already terminated or still going on nearly everywhere on the Finnish mire and bog protection areas. A lot of monitoring studies on the ecological recovery of the lost habitats are under way.

Mires of the Finnish Ramsar list

After the ecological criteria for the selection of the sites for the Ramsar list had been changed and they had become more comprehensive, the ministry of the environment started completing the Ramsar list. This work was based on ecological inventories of wetland types, which were carried out for national nature conservation purposes in 70’s. These inventories comprised mires and bogs on one hand (resulting in the mire protection programme) and shallow lakes and coastal marine bays rich in nutrients, reed-beds and luxuriant vegetation (resulting in the bird-water protection program) on the other hand.

However, not until after joining in European Union in 1995 and in connection with the implementation of EU Natura 2000 network did Finland start to complete the second designation of the Ramsar list. In 2004, 38 new sites were designated. At the same time the sites of the old designation of 11 sites were renewed with remarkable enlargements and new boundaries.

Teuravuoma Ramsar site in northern Finland with aapa-mire and shallow water-body. Wooden paths allow walking on wet areas without damaging the vegetation. Photo Seppo Vuolanto.

Table 1. Ramsar areas in Finland. Areas important for mire conservation are marked with an asterisk.

PROVINCE OF SOUTHERN FINLAND	ha
1. Bird Wetlands of Hanko and Tammisaari	55 196
2. Lake Läppträsket	199
3. Vanhankaupunginlahti and Laajalahti Bays	508
4. Porvoonjoki Estuary – Stensböle	958
5. Söderskär and Långören Archipelago	18 219
6. Pernajanlahti Bay	1 143
7. Aspskär Islands	731
* 8. Torronsuo National Park	3 093
9. Lake Kutajärvi Area	1 051
*10. Valkmusa National Park	1 701
11. Lake Kirkkojärvi and Lupinlahti Bay	649
12. Kirkontura -Vilkkiläntura Bay	194
13. Siikalahti Bay Area	682
	84 324
PROVINCE OF WESTERN FINLAND	
14. Lake Kirkkojärvi Area	305
15. Bird Wetlands of Vanajavesi Area	702
16. Kvarken Archipelago	63 699
*17. Kauhaneva-Pohjankangas National Park	5 510
*18. Levaneva Mires	3 343
*19. Pilvineva Mires	3 667
*20. Salamajärvi National Park	9 261
21. Bird Wetlands of Lapväärtti	1 224
22. Vassorfjärden Bay	1 537
	89248
PROVINCE OF ÅLAND	
23. Lågskär – Björkör Archipelago	5 300
24. Signilskär – Märket Archipelago	22 566
	27 866
PROVINCE OF EASTERN FINLAND	
25. Bird Lakes of Rantasalmi	1 109
*26. Suurenaukeansuo-Isosuo Mires and Lake Pohjalampi	1 640
27. Bird Lakes of Rääkkylä and Kitee	1 227
28. Lake Sysmäjärvi	734
*29 Patvinsuo National Park	12 727
30. Lakes Heinä-Suvanto and Hetejärvi	1 224
	18 661
PROVINCE OF OULU	
31. Krunnit Islands	4 436
32. Bird Wetlands of Haapavesi	3 616
33. Bird Wetlands of Hailuoto	6 512
34. Liminganlahti Bay Area	12 275
*35. Bird Wetlands of Siikajoki	2 696
36. Lakes Aittojärvi and Kongasjärvi	703
*37. Veneneva – Pelso Mires	12 039

*38. Olvassuo Mires	27 073
*39. Oulanka National Park	29 390
	98 740
PROVINCE OF LAPLAND	
*40. Martimoaapa-Lumiaapa-Penikat Mires	14 086
41. Kainuunkylä Islands	1 005
*42. Riisitunturi National Park	12 461
*43. River Luiro Mires	12 345
*44. Teuravuoma-Kivijärvenvuoma Mires	5 788
*45. Koitelainen Mires	34 400
*46. Lemmenjoki National Park	285 990
*47. Sotkavuoma Mire	2 602
*48. Lätäseno-Hietajoki Mires	43 367
*49. Sammuttijänkä-Vaijoenjänkä Mires	51 749
	463 793
Total area	782 632

However, the second designation still is lacking 11 more sites, which were due to be included in the list. There is a procedure going on to designate these sites in the near future. In the final Ramsar list will be included 60 sites, presumably ready in 2006.

All of the Finnish Ramsar sites nowadays are included in the Natura 2000 ecological network of European Union. They enjoy the protection of Habitats and/or Birds Directives in addition to national protection scheme, which in most cases is based on the nature conservation legislation.

In the following, the reference is made to the list of mires of the whole 60 Ramsar sites, although not exclusively designated yet.

Mires are the dominant habitat types of the Finnish Ramsar list, amounting altogether to 9000 km² of the 11 260 km² included in the total list. Some of these sites consist of mires only, whereas other areas host several dominant habitats in combination, like lakes and sea areas, as well. In the southern part of Finland raised bogs are the prevailing mire types. In the northern part of the country aapa mires prevail, and in northernmost Lapland palsa mires are included in the list as a part of larger fell areas.

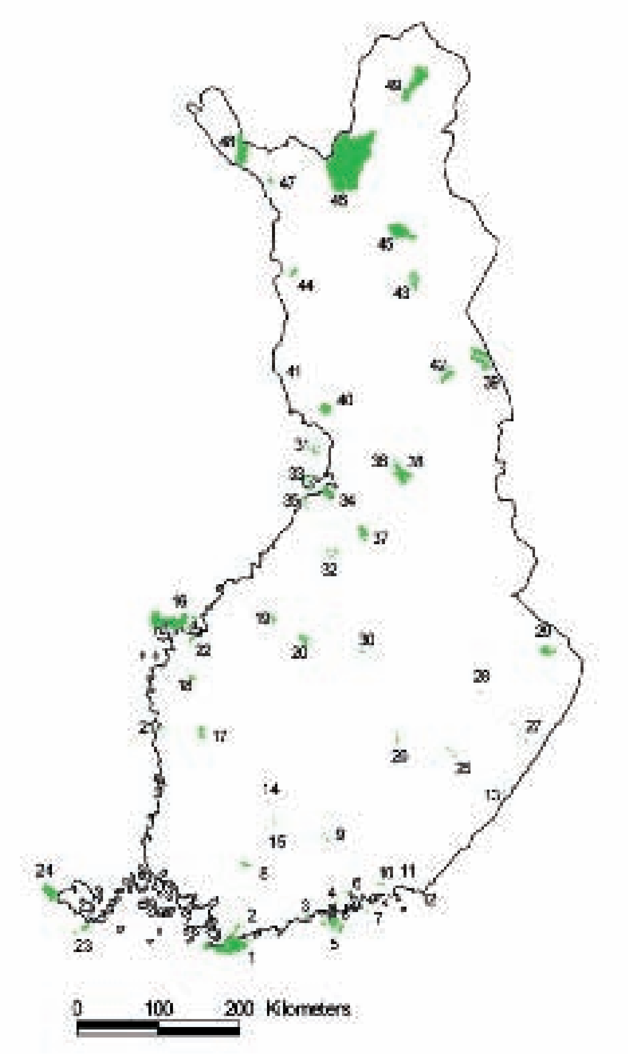

Fig. 1. Location of Finnish Ramsar sites. See Table 1 for the names of sites.

Large bog in Levaneva Ramsar area, Western Finland. The numerous bog pools are favourable for a rich bird fauna. Photo Hannu Vallas.

Southern and western Finland

In the provinces of Southern Finland and Western Finland the mire areas are relatively smaller than elsewhere, indicating either a younger succession history after the termination of the Ice Age and hilly terrains than other regions. The largest mire Ramsar sites in these provinces are Torronsuo National Park, southwestern Finland (mainly raised bog 31 km^2), Valkmusa National Park (south coast, raised bogs, 17 km^2) Kauhaneva-Pohjankangas National Park (western Finland, bogs and aapamires 55km^2), Salamajärvi National Park (aapamires and mosaic of mire and forest area, 93 km^2) and two large bog areas, Levaneva mire (33 km^2) and Pilvineva mire (37 km^2) along the main watershed between coastal and inland catchment areas.

Aapamire in Patvinsuo National Park . This mire is an example of sedge aapa massif. Wet flarks and low sedge fen strings form a mosaic, wich hosts a rich bird fauna. Photo Raimo Heikkilä.

Eastern and central Finland

In the province of Eastern Finland, the mires have evolved longer periods after the Ice Age, and their peat layer is thicker, and the sites are in general larger. The most famous mire areas also have a rich bird fauna, such as Patvinsuo National Park, (127 km^2), and Kesonsuo mire (21 km^2). The province of Oulu has many famous mire areas due to the low-lying terrain, like Veneneva-Pelso Mires (120 km^2), Olvassuo Nature Reserve (270 km^2). Oulanka National park on the Russian border is included in the Ramsar list, although it is mainly forested area (294 km^2), as it is hosting interesting and in Finland quite rare alkaline fen habitats on hill slopes and lowlands, mixed with forest areas.

Huge aapamires in Olvassuo Ramsar site. In the foreground a restored margin, which was drained in 1970. It is possible to watch birds in the mire from the tower, which has been built in the margin of the large open fen. Photo Hannu Vallas.

Lapland, the northern part of Finland

In the province of Lapland there are large Ramsar sites, which host a great variety of different moist habitats. In addition to true wetlands, in the Ramsar site of Lemmenjoki National Park (2860 km2) there is included large areas of dry hills with forests, and low arctic vegetation (fells). On the other hand, the designation of Urho Kekkonen National Park (including the famous Lake Sompio and Kemihaara mires, altogether 3098 km2) as a Ramsar site will presumably consist of the watercourses, as they host the most important population of the Pearl Mussel *(Margaritifera margaritifera)* in northern Europe. Large palsa mires are situated in the Sammuttijänkä-Vaijoenjänkä mire reserve (517 km2).

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Land birds on Finnish mires and their conservation status

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Introduction

In Finland mire ecosystems have changed much in recent decades. More than half of the original area of mires has been ditched mainly for forestry purposes especially in southern Finland. These changes have affected a lot on bird populations living in Finnish mires. Most bird species living in mires have decreased (Väisänen & al. 1998) and a lot of them are nowadays threatened (Rassi & al. 2001). Because in Europe mires concentrate much in the northern parts of the continent, Finland has an international responsibility in the protection of many bird species specialized on mires (Rassi & al. 2001). Many mire bird species are also listed in the Annex I of Wild Birds Directive of European Union and classified as threatened species in Europe by BirdLife International (BirdLife International 2004a and 2004b).

Many bird species occurring on mires are not actually specialized in such environment. On wet fens with open water there often breed e.g. water birds, gulls and terns. Open dry fens are often suitable habitats for many species mostly living on open farmland like Skylark (*Alauda arvesis*) and Whinchat (*Saxicola rubetra*). On bogs with growing trees many forest bird species are common. Forest species occurring also on pine bogs are e.g. Tree Pipit (*Anthus trivialis*) and Brambling (*Fringilla montifringilla*). The majority of the Finnish population of these species do not breed in mires and they could not be considered as real mire specialists.

Most of the mire specialists can also breed in other kind of habitats. E.g. Yellow Wagtails (*Motacilla flava*) and Meadow Pipits (*Anthus pratensis*) live also in farmlands and semi-natural meadows on sea shore and Golden Plovers (*Pluvialis apricaria*) are common on open fells (Väisänen & al. 1998). However the Finnish populations of these species concentrate on mires and changes in natural conditions on Finnish mires have affected much on their population trends.

Bean Goose (*Anser fabalis*)

The only waterfowl species specialized mainly in mires is Bean Goose. Its global breeding distribution is limited to taiga and tundra zones in Europe and Asia, the Finnish breeding *fabalis*-subspecies being an inhabitant of mires in taiga zone (Cramp

& Perrins 1977 – 94). In Finland Bean Goose is most abundant in the northern half of the country. In central Finland and northernmost Lapland the population is scarce. Bean Goose favours wet and large aapamires but the breeding sites are usually near the edges of mires on pine bogs and sometimes even in forests close to the mires (Väisänen & al. 1998).

Because its skulking habits during breeding season it is very difficult to estimate the population size of Bean Goose. It has been supposed that the Finnish population has decreased in last decades but direct evidence from censuses of breeding birds are lacking. Indirectly, the conclusion has been made from the decreasing numbers of geese resting on their migration in southern Sweden (Pessa & al. 2005a and 2005b). Locally no population trends have been observed e.g. in south-western Lapland (Rauhala 1994 and 2005) and Suomenselkä area in central Finland (Hutri & al. 1999), but in the province of Northern Savo in eastern Finland the population has decreased (Ruokolainen & Kauppinen 1999). In Finnish Red List, Bean Goose is classified as a near threatened species and because the high proportion of European population breeding in Finland, it is regarded as a responsibility species of Finland (Rassi & al. 2001).

Raptors

There are many raptor species using open mires for catching prey, but usually they breed in forests. Some of them may breed in small forest islands on open mires or sometimes even on pine bogs. E.g. Hobby (*Falco subbuteo*) often favours small forest patches in open mires for nesting (Väisänen & al. 1998).

The only Finnish raptor species specialized on mires are Hen Harrier (*Circus cyaneus*) and Peregrine (*Falco peregrinus*). Hen Harrier's global distribution is covering large areas across Europe and Asia (Cramp & Perrins 1977 – 94). The American subspecies *hudsonius* and *cinereus* are nowadays often kept as different species (Ferguson-Lees & al. 2001). During peak years of small mammals, Hen Harrier breeds in almost every part of Finland. Only in the southernmost Finland it is very rare even during those years. Normally it is most abundant in northern and central Finland. Originally Hen Harriers breed in Finland in bogs near the edges of open areas. They often breed also in agricultural landscape. Nowadays they occur often in clear-cut areas too (Väisänen & al. 1998).

For vole eating raptors like Hen Harrier, large fluctuations of numbers are typical. They also change their breeding areas with fluctuations of small mammals. Nowadays the vole cycles in Finland are not as regular as in the past, the peak years occurring more irregularly and not as often as earlier. That has caused a declining trend in the population size of Hen Harrier (Honkala & al. 2005). Because of that it is treated as a near threatened species in Finland (Rassi & al. 2001). In whole Europe its conservation status is unfavourable because it has depleted some decades ago (BirdLife International 2004a). In the scale of European Union it is considered as a declining species, too, and protected by the Wild Birds Directive (BirdLife International 2004b).

Peregrine has almost a cosmopolite distribution (Cramp & Perrins 1977 – 94). In Finland there are two main breeding areas, the bigger of them being in central Lapland and the other in the surroundings of the city of Oulu. Nowadays Finnish Peregrines live almost totally in large and wet aapa-mires (Väisänen & al. 1998). A few decades ago Peregrine was much more common in Finland. In addition to mires it bred also on steep cliffs in the entire country. In 1950s the population crashed in Finland and almost everywhere in Europe due to the use of pesticides in agriculture. After 1970s the number of breeding pairs has slowly increased, the Finnish population being nowadays at least 150 pairs (Ollila 2003). In whole Finland the numbers of Peregrines observed on migration have also increased (Lehtiniemi & Koskimies 2005).

Rimpineva mire reserve in Vuolijoki, central Finland is famous for a very diverse mire bird fauna. Photo Pekka Salminen.

Despite the increasing population trend, Peregrine is still treated as an endangered species because of the small population size (Rassi & al. 2001). European Union has protected Peregrine with the Wild Birds Directive (BirdLife International 2004b).

Grouse

Two of the five Finnish grouse species spend at least part of their yearly lifecycle in mires. Black Grouse (*Tetrao tetrix*) breeds in forests, but it uses open areas like mires as their leks (Väisänen & al. 1998). Willow Grouse (*Lagopus lagopus*) is a mire specialist living all year round in mires. In northern Finland, part of the Willow Grouse population lives also in sparse forests, especially in mountain birch forests (Väisänen & al. 1998).

Willow Grouse is a resident species of northern parts of Europe, Asia and North America (Cramp & Perrins 1977 – 94). Even on British Isles the species is locally common. The British subspecies (*L. l. scotica*) was earlier treated as a different species called Red Grouse (Magde & McGovan 2002). Unlike the other subspecies Red Grouse does not change its colour to white for winter, being reddish brown all the year. In Finland Willow Grouse is much more common in northern half of the country than in the south. Population changes are different in different parts of the country (Helle & al. 2003). Especially in the southern half of Finland the population trend has long been declining (Väisänen & al. 1998). It is classified as a regionally threatened species in southern Finland and even regionally extinct in the south-western coast of Finland (Ympäristöhallinto: Alueellisesti uhanalaiset lajit). In European Union the species is declining too (BirdLife International 2004b). One reason for the declining of Willow Grouse in southern Finland may be the scarcity of snow in many recent winters which makes the birds in their totally white winter plumage easy prey for predators.

Crane (*Grus grus*)

Crane's breeding range extends from western Europe to eastern Asia (Cramp & Perrins 1977 – 94). In Finland it is a quite common breeding species in mires, other wetlands and sometimes also on farmlands in whole country except northernmost Lapland (Väisänen & al. 1998). In Åland archipelago Crane is rare enough to be treated as a regionally threatened species (Ympäristöhallinto: Alueellisesti uhanalaiset lajit). It favours large open mires but sometimes it breeds also in very small patches of mires. During summer, in some large mire areas, in addition to breeding Cranes there gather also large flocks of young birds which are not yet nesting (Väisänen & al. 1998). Litokaira and Olvassuo nature reserves in northern Ostrobothnia are well known examples of such mires (Rajasärkkä 1994).

The Finnish Crane population has been increasing in recent years (Väisänen 2005) being 15 000 – 20 000 pairs at present (BirdLife International 2004a, Miikkulainen 2001). Same kind of trend has been observed also in most European countries within Crane's breeding range although the distribution is usually very patchy in these countries. Despite of the recent increasing population trend, the conservation status of Crane in Europe is still considered unfavourable, because of the large decline between 1970 – 1990 (BirdLife International 2004a). In European Union Crane is protected by the Wild Birds Directive (BirdLife International 2004b).

Waders

Waders form the most typical bird family in mires. Most waders are very audible and visible species which make them easy to observe. The diversity of waders on Finnish mires is high especially in the north (Järvinen & al. 1987, Järvinen & Väisänen 1978). In some northern mires waders form one quarter or even third of the total density of land birds. From the 26 mire specialist species (Table 1), 14 are waders. Most of these species occur also in other kind of open landscapes like agricultural land, shore meadows and fell heaths, but the majority of their populations lives in mires. Lapwing (*Vanellus vanellus*) and Curlew (*Numenius arquata*) are mainly farmland birds, but they are common in mires, too (Väisänen & al. 1998).

The global breeding ranges of most wader species breeding on Finnish mires are very northern (Cramp & Perrins 1977 – 94), and they are concentrated into north in Finnish scale too (Väisänen & al. 1998). Lapwing and Curlew are southern species in Finland, their global distribution being in the temperate and boreal vegetation zones from western Europe to eastern Asia (Cramp & Perrins 1977 – 94).

There are some wader species whose breeding ranges cover large areas of the boreal taiga and arctic tundra zones of Europe and Asia. Ruff (*Philomachus pugnax*) and Wood Sandpiper (*Tringa glareola*) are such species (Cramp & Perrins 1977 – 94). Also Snipe (*Gallinago gallinago*) and Whimbrel (*Numenius phaeopus*) have same kind of distribution, but their breeding ranges also extend widely to American continent. Their American subspecies are sometimes thought to be separate species (American Ornithologists' Union 2000 and 2002). Snipe breeds also widely in the temperate vegetation zone. Whimbrel's breeding range is very patchy in Siberia. In Finland, Ruff and Whimbrel are quite northern species, Wood Sandpiper and especially Snipe having a more even distribution (Väisänen & al. 1998).

Species	Trend	Threat	Resp	Dir	EU	SPEC	Biome	FIN min	FIN max	EUR min	EUR max	FIN-EUR %	EU min	EU max	FIN-EU %
Bean Goose *Anser fabalis*	- ?	NT	R					1500	2000	140000	140000	1 %	2300	3200	65 %
Hen Harrier *Circus cyaneus*	-	NT		D	Dec	SPEC 3		1500	3500	32000	59000	5 %	11000	18000	14 %
Peregrine *Falco peregrinus*	+	EN		D				120	150	12000	25000	1 %	7400	8800	2 %
Willow Grouse *Lagopus lagopus*	+ / -	RT			Dec			50000	120000	2100000	3300000	2 %	310000	680000	16 %
Crane *Grus grus*	+	RT		D	Dep	SPEC 2		15000	20000	74000	110000	20 %	46000	61000	33 %
Golden Plover *Pluvialis apricaria*	-			D	Dep	Non-SPECE		40000	80000	460000	740000	9 %	130000	240000	31 %
Lapwing *Vanellus vanellus*	0	RT			VU	SPEC 2		50000	80000	1700000	2800000	3 %	830000	1300000	6 %
Dunlin *Calidris alpina alpina*	?				Dec	SPEC 3		300	600	300000	570000	0 %	49000	85000	1 %
Broad-billed Sandpiper *Limicola falcinellus*	- ?	NT	R		Dec	SPEC 3		5000	15000	9200	22000	54 %	8000	20000	63 %
Ruff *Philomachus pugnax*	-	NT		D	VU	SPEC 2		10000	20000	200000	510000	5 %	51000	71000	20 %
Jack Snipe *Lymnocryptes minimus*	0 ?		R		Dep	SPEC 3	B	10000	15000	18000	70000	56 %	12000	19000	83 %
Snipe *Gallinago gallinago*	-	RT			Dec	SPEC 3		80000	120000	930000	1900000	9 %	300000	450000	27 %
Bar-tailed Godwit *Limosa lapponica*	+ ?	NT		D	EN		A	100	300	1400	7400	7 %	110	350	91 %
Whimbrel *Numenius phaeopus*	0	RT	R		Dec	Non-SPECE		30000	50000	160000	360000	19 %	40000	61000	75 %
Curlew *Numenius arquata*	-	RT	R		Dec	SPEC 2		35000	50000	220000	360000	16 %	160000	220000	22 %
Spotted Redshank *Tringa erythropus*	-		R		Dec	SPEC 3	A	10000	15000	19000	42000	53 %	15000	26000	67 %
Greenshank *Tringa nebularia*	0		R				B	30000	40000	75000	160000	40 %	46000	67000	65 %
Wood Sandpiper *Tringa glareola*	0	RT	R	D	Dep	SPEC 3		200000	300000	350000	1200000	57 %	250000	400000	80 %
Red-necked Phalarope *Phalaropus lobatus*	-			D			A	10000	20000	85000	220000	12 %	20000	45000	50 %
Short-eared Owl *Asio flammeus*	-			D	Dec	SPEC 3		2000	10000	58000	180000	3 %	5200	19000	38 %
Meadow Pipit *Anthus pratensis*	0				Dec	Non-SPECE		700000	1200000	7000000	16000000	10 %	4300000	7000000	16 %
Red-throated Pipit *Anthus cervinus*	-				EN		A	500	3000	1000000	3000000	0 %	800	3900	63 %
Yellow Wagtail *Motacilla flava*	-				Dec			250000	400000	7900000	14000000	3 %	1200000	2300000	21 %
Great Grey Shrike *Lanius excubitor*	0	NT			Dec	SPEC 3		5000	8000	250000	400000	2 %	240000	360000	2 %
Lapland Bunting *Calcarius lapponicus*	-						A	20000	50000	5800000	11000000	0 %	120000	450000	17 %
Little Bunting *Emberiza pusilla*	-							1000	5000	5000000	8000000	0 %	1000	5200	100 %

Table 1. Breeding mire specialist bird species in Finland. Columns are: Trend = recent population trend (+ = increasing, - = decreasing, 0 = stable + / - = trend is different in different parts of the country); Threat = present status in the Finnish list of threatened species (EN = endangered, NT = near threatened, RT = regionally threatened in some part of the country); Resp = international responsibility species of Finland (R); Dir = species included in the Annex I of the Wild Birds Directive of European Union (D); SPEC = species of European conservation concern (SPEC 2 = unfavourable conservation status, concentrated in Europe, SPEC 3 = unfavourable conservation status, not concentrated in Europe, Non-SPEC^E = favourable conservation status, concentrated in Europe); Biome = biome restricted species (A = arctic / tundra biome, B = boreal biome); FIN min & FIN max = minimum and maximum estimates of present Finnish breeding population in pairs; EUR min & EUR max = minimum and maximum estimates of present breeding population in whole Europe, including Greenland); EU min & EU max = minimum and maximum estimates of present breeding population in European Union; FIN-EUR % & FIN-EU % = the proportions of Finnish population from population of Europe (EUR) and European Union (EU).

Ruffs in Mayon the shore of a bog pool in Levaneva mire, western Finland. Photo Raimo Heikkilä.

Jack Snipe's (*Lymnocryptes minimus*) and Greenshank's (*Tringa nebularia*) breeding ranges lie on boreal taiga zone from Scandinavia to central Siberia (Cramp & Perrins 1977 – 94). Broad-billed Sandpiper's (*Limicola falcinellus*) distribution is also similar, although the details of its eastern parts are very poorly known (Väisänen & al. 1998). Jack Snipe and Broad-billed Sandpiper occur almost entirely in wet mires. Especially the latter is a bird of very wet and remote large mires, almost impossible to reach. Greenshank lives in many kinds of mires favouring edges of open mires and bogs with sparse trees. In Finland Jack Snipe and Broad-billed Sandpiper are northern species lacking from southern Finland as breeding species. Greenshank breeds in the whole country being rare in southernmost parts (Väisänen & al. 1998). Jack Snipe's and Greenshank's breeding is strongly restricted to the boreal biome (Heath & Evans 2000).

Golden Plover's breeding range extends from western Europe to central Siberia (Cramp & Perrins 1977 – 94). More than half of its global population is breeding in Europe (BirdLife International 2004a). In Finland it breeds in open mires in whole country and in the north also on fell heaths (Väisänen & al. 1998).

Three Finnish mire waders are mainly arctic species breeding in the tundra zone in Europe, Asia and America (Cramp & Perrins 1977 – 94). Dunlin (*Calidris alpina*) and Red-necked Phalarope (*Phalaropus lobatus*) are true holarctic species having almost continuous ranges through all three continents. Bar-tailed Godwit's (*Limosa lapponica*) breeding range extends only a little into Alaska, its main distribution being in the arctic Europe and Asia. In Finland Bar-tailed Godwit and the nominate subspecies of Dunlin breed only in northernmost Lapland, especially in palsamires and mires in open fells (Väisänen & al. 1998). Dunlin's southern *schinzii*-subspecies is a critically endangered bird living on coastal meadows of Bothnian Bay and it is not occurring in mires at all (Rassi & al. 2001). Red-necked Phalarope breeds on all kinds of wet mires in northern Finland and in small swampy ponds on shores and islands of the Bothnian Bay (Väisänen & al. 1998). Spotted Redshank (*Tringa erythropus*) has quite an arctic distribution, its breeding strongly being restricted in the arctic biome (Cramp & Perrins 1977 – 94 and Heath & Evans 2000). In Finland it breeds widely in wet mires of the boreal taiga zone (Väisänen & al. 1998).

Many of the wader species of mires have a decreasing population trend in Finland. The only possibly increasing species is Bar-tailed Godwit but its population size is very difficult to estimate reliably because it can change its breeding areas yearly (Väisänen & al. 1998). Very little is known also about the population trends of Dunlin's nominate subspecies (Väisänen & al. 1998). Lapwing, Whimbrel, Greenshank, Wood Sandpiper and possibly Jack Snipe are species with more or less stable population size in Finland in last 20 years, although in some parts of their Finnish breeding range, the trend could have been decreasing (Väisänen & al. 1998 and Väisänen 2005).

Broad-billed Sandpiper, Ruff and Bar-tailed Godwit are classified as near threatened species in Finland's Red Data Book (Rassi & al. 2001). Snipe, Whimbrel, Curlew and Wood Sandpiper are treated regionally threatened in southern parts of their Finnish ranges and Lapwing in northern Finland (Ympäristöhallinto: Alueellisesti uhanalaiset lajit). Many mire waders are Finland's responsibility species, because Finnish populations form quite great proportions of their global populations (Rassi & al. 2001). These species are Broad-billed Sandpiper, Jack Snipe, Whimbrel, Curlew, Spotted Redshank, Greenshank and Wood Sandpiper. In the scale of whole Europe or European Union every wader species specialized on Finnish mires is treated threatened or they are listed in the Annex I of Wild Birds Directive (BirdLife International 2004a and 2004b) (Table 1).

Owls

Most Finnish owl species breed in forests, especially in old-growth coniferous forests. The remaining old-growth forests form usually a habitat mosaic with mires, the largest areas of that kind being nowadays usually in nature reserves. Most of the owl species living in old-growth forests use small mammals as their main food item (Väisänen & al. 1998). They often use mires near their nesting sites for catching prey. This kind of owl species are e.g. Great Grey Owl (*Strix nebulosa*) and Tengmalm's Owl (*Aegolius funereus*). Because of their nocturnal activity the easiest way to become aware of the presence of forest owls in mires is to search traces of their hunting on snow cover in winter time.

The only owl species breeding in mires is Short-eared Owl (*Asio flammeus*) which also occurs often in open farmlands and clear-cut areas (Väisänen & al. 1998). It has a large global breeding range in almost whole Europe and the northern half of Asia (Cramp & Perrins 1977 – 94). It has a wide breeding range also in North America, and it occurs in Southern America, too. In Finland, Short-eared Owl has a similar distribution pattern to that of Hen Harrier (Väisänen & al. 1998). Also the population trends of these two vole eating specialists are similar, both having decreased (Honkala & al. 2005). The main reason for the decrease is the recent irregularity of vole cycles and the lack of peak years of small mammals.

Short-eared Owl has an unfavourable conservation status in Europe because of the large decline between 1970 – 1990. Therefore it is treated as a depleted species (BirdLife International 2004a). In the area of European Union it has decreased, being protected by the Wild Birds Directive (BirdLife International 2004b).

Passerines

Two most abundant birds on Finnish mires are Meadow Pipit and Yellow Wagtail (Väisänen & al. 1998). Both these species are common in open mires and sparsely tree growing bogs in the whole country, but they are especially abundant in northern Finland, the highest density of Meadow Pipit observed being over 70 pairs / km^2, but the density of Yellow Wagtail being usually slightly lower (Järvinen & Sammalisto 1976, Järvinen & al. 1987 and Väisänen & al. 1998). Both species occur in other kinds of open landscapes too.

Meadow Pipit's global distribution is highly concentrated in Europe, only southern and south eastern Europe being outside of it's breeding range (Cramp & Perrins 1977 – 94). More than three quarters of the global population is living in Europe (BirdLife International 2004a). Yellow Wagtail's global distribution is much wider than that of Meadow Pipit's, extending from the whole Europe through Asian continent to the westernmost parts of Alaska (Cramp & Perrins 1977 – 94). The racial variation is high in Yellow Wagtail. Globally 13 - 17 subspecies have been described, of which few have sometimes treated as separate species (Alström & al. 2003 and Dickinson 2003). Two subspecies occur in Finland. The dark headed subspecies *thunbergi* breeds in northern Finland. The southern half of the country is dominated by hybrids of subspecies *thunbergi* and *flava*, the latter in its pure form being quite rare in Finland (Väisänen & al. 1998).

No population trend has been observed in Meadow Pipit in Finland (Väisänen 2005). In recent years the Finnish Yellow Wagtail population has decreased especially in southern Finland, but the trend has not yet caused any national or local threat status for Yellow Wagtail in Finland. Both species have decreased in the scale of European Union (BirdLife International 2004b).

Red-throated Pipit (*Anthus cervinus*) and Lapland Bunting (*Calcarius lapponicus*) are extremely northern breeding species in Finland (Väisänen & al. 1998). Actually both of them are species of arctic tundra (Heath & Evans 2000), occurring in Finland mainly in open mires in fell region. There are scattered breeding observations in mires in the northern taiga zone, too, but the densities in mires in northernmost Lapland are manifold compared with densities in more southern mires. Especially the density of Lapland Bunting can be very high, exceeding 60 pairs / km^2 in some palsamires (Väisänen & al. 1998).

Globally Red-throated Pipit occurs in Europe, Asia and on a narrow belt in western Alaska. Lapland Bunting is common in arctic North America, too (Cramp & Perrins 1977 – 94). There are suggestions of decreasing population trends of both species in Finland but direct evidence from censuses of breeding birds are insufficient (Väisänen & al. 1998). The supposed decreasing trend of Red-Throated Pipit in Finland and Sweden has put the species in the list of endangered species in the European Union (BirdLife International 2004b). In the scale of whole Europe the species is evaluated as secure because the large populations living in Norway and Russia are thought to be stable (BirdLife International 2004a). Lapland Bunting is considered as secure in Europe.

Two passerine species in Finland are mainly specialised in sparsely pine growing bogs. Great Grey Shrike (*Lanius excubitor*) is more common of them, Little Bunting (*Emberiza pusilla*) being a rare breeder in northeastern Finland (Väisänen & al. 1998). Great Grey Shrike breeds also in other habitats like sparse mountain birch forests and clear-cut areas with scattered trees. It breeds in whole Finland but the density in southern Finland is extremely low. Even in its core area in northern Finland the density stays quite low (Väisänen & al. 1998).

Great Grey Shrike has a wide distribution with many subspecies across Europe, Asia, North America and even in North Africa (Cramp & Perrins 1977 – 94). The systematics of its complex subspecies group is at present under discussion, the southern races in Europe and Asia being recently split into a different species, Southern Grey Shrike (*Lanius meridionalis*) (Lefranc & Worfolk 1997), which have only twice been seen in Finland (Luoto & al. 2001, Ohtonen 2005). The nominate *excubitor*-subspecies' range is mainly limited in Europe. The range of Little Bunting covers large areas of the taiga zone from eastern Finland to the shores of Pacific Ocean (Cramp & Perrins 1977 – 94).

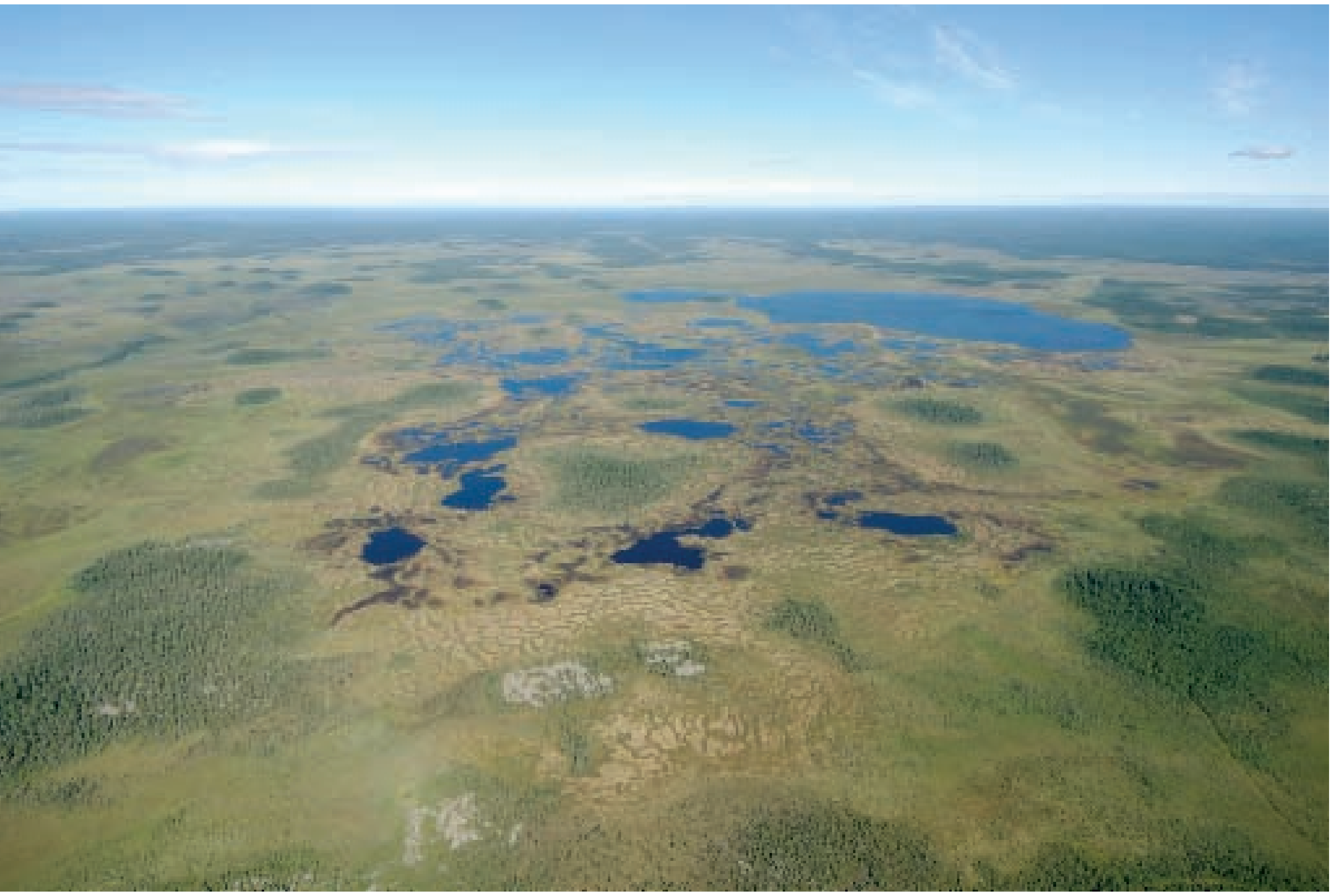
The number of breeding pairs of Great Grey Shrike has decreased steeply in 1980s, but after that no trend has been observed in Finland (Väisänen & al. 1998 and BirdLife International 2004a). Because of the declining trend in the past it is treated as a near threatened species in Finnish Red Data Book (Rassi & al. 2001). The population trend has been declining in past decades in whole Europe so that the species' conservation status is unfavourable in Europe (BirdLife International 2004a). Little Bunting became more abundant in Finland during 1980s, being a very rare breeder before that (Väisänen & al. 1998). However, since 1990s the population has decreased again. In spite of that it has no threat status in Finland and it has been evaluated as a secure species in Europe too (BirdLife International 2004a).

The present state and future of Finnish mire bird communities

All the mire specialist species occurring in Finland are nowadays somehow suffering (Table 1). Only two species, Peregrine and Crane are clearly increasing in Finland. In spite of that, their Finnish populations are treated threatened at least regionally, and in European scale they are threatened enough to be protected by Wild Birds Directive. Meadow Pipit is the only species whose population in Finland is stable and whose conservation status is favourable in whole Europe. Even it is however declining in the area of European Union. Some special attention must also be paid to Meadow Pipits in Europe because the global population strongly concentrates to the continent. Lapland Bunting and Little Bunting are the only two species which are not included in any list of threatened species (Table 1). However, both these species are at present decreasing in Finland. From the neighbouring countries around Finland, Little Bunting is a near threatened species in Sweden (Tjernberg 2000) and Lapland Bunting is included in the Red List of Karelian Republic (Hokhlova & Artemiev 2003).

More than half of the 26 mire specialists are included in the list of national or locally threatened species in Finland. 9 species are protected by the Wild Birds Directive of European Union. Over three quarters of the species are in the list of threatened species of European Union and half of them have unfavourable conservation status in whole Europe. Finland has a special international responsibility in protecting of 8 mire species.

Finnish nature reserve network covers on average about 10 % of the land area of the country. The area concentrates very much in northern Finland and especially in the northernmost Lapland, the proportion of protected area being very much lower in southern half of the country. Because many bird species of mires concentrate in the north, there are many species whose populations a great proportion breeds on nature reserves. In nine species the proportion of the nature reserve population is over half of the whole Finnish population (Virkkala & Rajasäkkä 2001). These species are Peregrine, Golden Plover, Dunlin, Broad-billed Sandpiper, Ruff, Bar-tailed Godwit, Red-necked Phalarope, Red-throated Pipit and Lapland Bunting. The distribution of all these species is very northern, only Golden Plover being quite common also in southern mires.



Martimoaapa mire in southwestern Lapland consists of large bogs, aapamires and shallow lakes, altogether covering 12 000 hectares. It has one of the richest bird faunas of Finnish mires. Photo Hannu Vallas.

Willow Grouse is the only resident species in Finnish mires. All the other mire specialists are migratory birds wintering in different locations around the world. In addition to the environmental changes in Finnish mires, changes in wintering areas may have strong effects on the bird populations in Finnish mires. The still continuing diminishing of Finnish mire area for e.g. peat mining causes threats for many mire birds. Global climate change may also cause unpredictable effects for Finnish mire birds both in their breeding grounds and in their wintering areas. All these things cause serious threats for mire birds and their future in Finland, and in whole Europe is not at all secure.

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A short introduction to the Finnish language

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How does Finnish relate to other languages?

The Finnish language, spoken mainly in Finland but also by people of Finnish origin in Sweden and other countries, belongs to the Fenno-Ugric group of languages, which is a part of the Uralian family of languages. Other Uralian languages include: Estonian, which is rather near to Finnish; Hungarian, which is very different from Finnish, with a fairly small number of related words; and several languages spoken in Russia, mostly by small ethnic groups.

The Uralian family of languages is possibly related to Indo-European languages (such as English, German, Swedish, Latin, Russian, Hindi, etc), but the relationship is highly debatable. The arguments are based on a few similarities which might, according to other scholars, be based on language universals, loanwords, or pure coincidences. – Note that some similarities in vocabularies are caused by relatively new loanwords which were taken into Finnish from Swedish due to strong cultural contacts (only very few words have gone in the opposite direction).

There are several structural similarities between Uralian and Altaic languages. However, linguists generally do not regard the undeniable typological similarities as evidence for common origin. See the Finno-Ugrian FAQ, section Language relationship, and sci.lang FAQ, section How are present-day languages related?

A language with suffixes

Both Uralian and Indo-European protolanguages had a relatively rich system of word flexion, e.g. about six cases for nouns. Typically Indo-European languages have developed towards a more analytic system where grammatical relations are expressed by word order, prepositions, and other auxiliary words rather than word flexion. On the other hand, in Uralian languages flexion has typically been preserved, and in part it has even expanded. Thus, for example, contemporary English has essentially just two cases (nominative and genitive), whereas Finnish has more than a dozen cases. Finnish has also a rich set of verb forms.

Thus, Finnish is a synthetic language: it uses suffixes to express grammatical relations and also to derive new words. To take a simple example, the single Finnish word talossanikin corresponds to the English phrase in my house, too. The suffix -ssa is the ending of the so-called inessive case, roughly corresponding to the English preposition in. The suffix -ni is a possessive one, corresponding to my in English. And the suffix -kin is an enclitic particle corresponding to the English word too (and the Latin enclitic -que). An example of verb flexion is kirjoitettuasi, which requires an entire sentence when translated into English: after you had written.

There are, however, some tendencies from synthetic to analytic expression in contemporary spoken Finnish. Thus, in free speech most Finns would rather say e.g. mun talossa (with mun corresponding to English my) than talossani, and verb forms like kirjoitettuasi usually only appear in written language – spoken language uses an analytic expression roughly corresponding to the English one.

Flexion uses suffixes only in Finnish. Originally the system was simply agglutinative: suffixes were "glued" to words by simple concatenation. (Compare this with e.g. the old Indo-European system of vowel alteration, which still lives in irregular verb flexion like in English sing : sang : sung.) However, due to various phonetic changes, in Finnish suffixes very often cause changes in the word root, causing phenomena which resemble flexion (e.g. juon 'I drink', join 'I drank'), and for several suffixes there are alternative forms. Typical changes in the base word include:

- final -i in nouns often (but not in new loanwords like grilli) changes to -e- in inflected forms, e.g. the genitive of kivi 'stone' is kiven (with -n as the genitive case suffix)
- final -nen (which is rather common in adjectives and occurs in nouns, too) in the singular nominative changes to -se- (or -s-) in other words, e.g. hevonen 'horse', hevoset 'horses'
- consonant gradation: double consonants kk, pp, tt are often (basically, before closed syllables) replaced by single k, p, t, e.g. the genitive of lakki 'cap' is lakin
- similar phenomenon for single consonants: single k, p, and t are often replaced by absence of a consonant, v, and d, respectively, e.g.laki : lain, lupa : luvan, katu : kadun.

For several suffixes, there are two alternative forms, because Finnish (unlike e.g. Estonian) has a phonetic feature called vowel harmony: in a non-compound word, the back vowels a, o, u do not appear in a word which contains any of the front vowels ä, ö or y, and vice versa. (Vowels e and i are neutral with respect to vowel harmony.) Thus e.g. the so-called inessive case suffix has two forms, -ssa and -ssä, so that e.g. the word kala takes the first form and kylä takes the second.

Suffixes are also used for word derivation. Another word formation tool is composition: glueing two words together. The following list of derived and composite words should give some idea of the mechanisms:

- talous 'economy', from talo 'house'
- taloudellinen 'economical'
- taloudellisuus 'economicality'
- kansantalous 'national economy', using kansa 'people, nation'
- kansantaloustiede '(study of) economics', using tiede 'science', which is derived from tietää 'to know'.

The word derivation tools have been used to produce names from Finnish ingredients instead of borrowing international words. For example, telephone is puhelin and university is yliopisto in Finnish. This approach was especially used in the 19th century when Finnish was consciously developed from the status of a language spoken by common people into a written, official (since 1863) and cultural language. Later international words have been adopted to a greater extent, so e.g. television is televisio in Finnish, but word formation has still been used e.g. for words like tietokone 'computer'.

However, Finnish has quite a lot of loanwords from several Indo-European (and other) languages, adopted during a long period of time. However, especially old loanwords are difficult to recognize, partly because they have been taken from the predecessors of contemporary languages, partly because they have been adapted to fit into the Finnish phonetic system.

Phonetics – simple or difficult?

Truly Finnish words – i.e. excluding newest loanwords – obey the following phonetic rules:

- consonant clusters are rare and never appear in the beginning or at the end of a word; thus, for example, Swedish strand has become ranta in Finnish
- they lack the sounds b, g, f, sh, which are typically replaced by p, k, v (or hv), s (or h), respectively; e.g. Finnish kahvi 'coffee' comes from Swedish kaffe, and English bacon is pekoni in Finnish
- a word usually ends with a vowel or a single consonant like n or s; words taken from other languages often have an i appended for this reason, e.g. the Swedish word kurs 'course' has been adopted in the form kurssi.

In spoken Finnish, final vowels of some words are often dropped out, which leads to forms not complying with the above-mentioned rules. E.g. kaksi 'two' often becomes kaks.

This means that loanwords may have undergone quite considerable changes. However, apart from these phonetic adaptations, Finnish tends to be a conservative language in the sense that words change very slowly. For example, linguists think that the Finnish word kala 'fish' is exactly the same as in the proto-Uralian language thousands of years ago, and the Finnish word kuningas borrowed from Germanic languages has remained almost unchanged through centuries whereas in the Germanic languages the word has changed quite a lot (English king, Swedish kung, German König etc).

You have probably now realized why Finnish words are rather long in the average: root words are long due to the conservativeness, suffixes and composition are used to derive new words, and suffixes are used for flexion.

The phonetic rules mentioned above make the language easy to pronounce in a sense. However, there are several difficulties if you try to learn Finnish and your native language is English, for example. Some vowel sounds, especially those denoted by "y" (corresponds to German "ü") and "ö", take some time to learn. The diphthongs such as "uo" (in e.g. "Suomi" 'Finland') might take even more time. Additional difficulties are caused by double consonants such as "kk", which should be pronounced basically as prolonged consonants. The difference between single and double consonants is very often distinctive; e.g., laki and lakki are completely different words, in pronunciation and meaning. Similarly, the length of vowels is distinctive two, and a long vowel is (almost) always written by doubling the vowel letter, e.g. "aa". On the positive side, the Finnish pronunciation rules are rather regular. It has even been claimed to be perfectly regular so that each letter always means one and the same sound and vice versa, but this is not quite true.

Word order expresses nuances

Word order is often said to be "free" in Finnish. The truth is that one can often change word order without changing the basic meaning of the sentence, but the emphasis or side meanings or style typically changes. Consider first the English sentence Pete loves Anna. If we change the word order to Anna loves Pete, we get a sentence with an entirely different meaning. Not so in Finnish: Pete rakastaa Annaa and Annaa rakastaa Pete both have the same basic meaning in the sense of speaking about Pete loving Anna. The case suffix -a in Annaa designates the grammatical object, no matter what the word order is. (If we wanted to say that Anna loves Pete, we would say Anna rakastaa Peteä.) In fact, in this case we could put the words of this sentence into any order, still speaking about Pete loving Anna, but with different purposes and different tones:

- Pete rakastaa Annaa. This is the normal word order, the same as in English.
- Annaa Pete rakastaa. This emphasizes the word Annaa: the object of Pete's love is Anna, not someone else.
- Rakastaa Pete Annaa. This emphasizes the word rakastaa, and such a sentence might used as a response to some doubt about Pete's love; so one might say it corresponds to Pete does love Anna.
- Pete Annaa rakastaa. This word order might be used, in conjunction with special stress on Pete in pronunciation, to emphasize that it is Pete and not someone else who loves Anna.
- Annaa rakastaa Pete. This might be used in a context where we mention some people and tell about each of them who loves them. So this roughly corresponds to the English sentence Anna is loved by Pete.
- Rakastaa Annaa Pete. This does not sound like a normal sentence, but it is quite understandable.

Peculiarities in grammar

Some specific grammatical features of Finnish:

- There is no definite or indefinite article. In speech, some pronouns or other words (e.g. yks(i) 'one', se 'it') are sometimes used in an article-like manner.
- There is no grammatical gender. Even the third person singular pronoun hän corresponds to both he and she. There is no direct counterpart of Indo-European passive verb forms. However, Finnish grammars often confuse things by calling some verb forms "passive" forms. These forms are actually forms that imply a personal (human) agent without specifying him, her, or them. E.g. the English expression was solved should not, in general, be translated by using the "passive" form (ratkaistiin) of the verb (ratkaista) corresponding to solve but by using a normal (active) form (ratkesi) of a distinct, although related, verb ratketa. The translation ratkaistiin would be correct if we knew that something was solved by a human being and not e.g. by a computer or by the course of events.
- The word expressing negation, corresponding to English not, behaves as a verb, inflected according to the subject person: en : et : ei : emme : ette : eivät, e.g. (minä) en lue = I do not read, (sinä) et lue = you do not read etc. This verb has imperative forms (meaning 'don't…'), but they are formed rather irregularly: älä, älköön etc
- Questions that require a yes or no answer are normally formed so that the verb is at the beginning and has the suffix -ko or -kö (e.g. Rakastaako Pete Annaa?). In answering such a question, the originally Finnish way (now often replaced by just kyllä for 'yes' and ei for 'no') is to say either the verb or the negation verb in an appropriate form, in this case rakastaa or ei.
- Ownership or possession expressed by the verb have in English is expressed by using verb corresponding to English be and putting the logical subject into a case ending with -lla or -llä. Thus, I have a dog is in Finnish Minulla on koira ("at me (there) is (a) dog").

Etymology of some Finnish words for mire

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Introduction

Finnish belongs to the Finno-Ugric part of the Uralic family of languages. Related languages are for example Karelian and Veps languages spoken in western Russia, Estonian, Saami languages spoken in an area stretching from Dalarna in central Sweden to the tip of Kola Peninsula in Russia, and further in the Middle-Europe, Hungarian. Other related languages are spoken in Russia (Mordvin, Mari, Komi, Udmurt, Mansi, Khanty) even beyond the Ural mountains. The vocabulary of Finnish language differs from Indo-European languages in many ways. Especially the old basic vocabulary is common Finno-Ugric or Uralic origin.

Already in prehistoric times people traveled and communicated with people speaking other languages, so not only goods and customs, but also words were changed. The oldest loanwords in Finnish are Proto-Indo-European, approximately 6000 years old. After that loanwords were acquired from old Germanic and Baltic languages (Latvian and Lithuanian are current Baltic languages). Also Russian and especially Swedish have had influence on Finnish language. Especially words describing nature have been adopted from Saami languages. Lately, following the global trend, English has left its marks also in Finnish language.

The Finnish written language is rather young, the literary tradition began in the 16th century. The written language is mostly based on the old dialects. The Finnish scientific language was created only at the end of the 19th century. At the beginning of the 20th century A. K. Cajander was one of the first university teachers who used Finnish in his lectures instead of Swedish, and his influence on the definition and use of Finnish mire terminology has been profound.

Language always reflects the environment it is used in, and as there are plenty of mires in Finland (almost 30 % of the land area), it is only natural that there are also plenty of words describing them. The etymology and history of fourteen words for mires will be described here. The words are: **aapa, aro, jänkä, keidas, korpi, letto, luhta, neva, palsa, pounu, rahka, räme, suo and vuoma**.

Scientific terms and dialect words

In Finnish standard language the general word for peatland or mire is **suo**. It is probably a very old word, but its etymology is not yet certainly known. It is known also in Karelian and in Estonian (**soo**). The name of the country Suomi has not been derived from the word **suo**, even though it has sometimes been used as an explanation. In dialects word **suo** has been commonly used, except in Ostrobothnia and North-Finland. In Ostrobothnia the general word for mire is **neva**. The main distribution area for the mire site type **neva** 'fen' is nevertheless in North-Finland, were the word **neva** has not been commonly used. **Neva** is known also in Karelian (**neva** 'water, water system') and in the dialects of Estonian, and the name of the river Neva, which runs from the Lake Ladoga to the Baltic sea through St. Petersburg city in Russia, has the same origin.

The general word for mire in North-Finland is **jänkä**. It has been borrowed from Saami language (jeaggi in North Saami). The Saami word **jeaggi** is an old Finno-Ugric word and has its´ equivalents in the furthest Finno-Ugric languages Komi, Mansi and Khanty. The word **jänkä** is not used in the Finnish mire site type classification. Neither is the word **vuoma**, which is a general word for mires in western Lapland. **Vuoma** comes from North Saami word **vuopmi** 'large mire area in river valley; forested, wide river valley'.

Scientific terms **aapa** and **palsa** are also loanwords from Saami. They are also used in written Finnish language. In northern Finnish dialects **aapa** (**áhpi** in North Saami) means both 'large, open mire' (Fig 1) and 'open sea'. The Saami word is perhaps loan from Scandinavian languages (cf. **hav**, 'sea' in Swedish). The word **aapa** has been adopted to international use meaning 'a minerotrophic, patterned fen'. The word **palsa** (**balsa** or **palsa** in North Saami), meaning 'a raised mound of peat with a frozen, permafrost core', is one of the most international Saami words. It is used in the same meaning for example in English, German and French. Another Saami loanword used in northern Finnish dialects is **pounu** (**bovdna** in North Saami) which in dialects means 'a large hummock on the mire'. The mire site type **pounikko**, derived from the word **pounu**, is an open bog with only some scattered trees and *Betula nana* and *Salix* spp. dominating the vegetation.

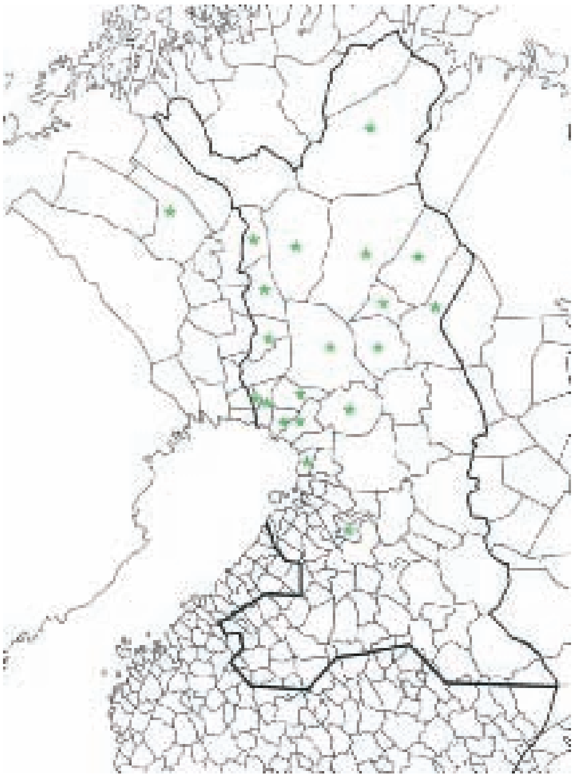

Figure 1. The distribution of word **aapa** (patterned fen) in the Finnish dialects. The aapamire zone according to Ruuhijärvi (1988).

Letto is a general word for mire, whose origin has probably been in the Häme region in southern Finland, but it has then spread to larger areas, even to North-Finland. In dialects **letto** means 'a quaking mire' or 'a sinking spot in a mire'. **Letto** has probably same etymology as verb lentää 'fly'. As a mire site type **letto** means a rich fen.

The Baltic loanword **luhta** (cf. **luksts** in old Latvian, 'a broadleaved (aquatic) plant or a wet lowland or shore meadow') belongs also to mire words. In standard Finnish **luhta** means 'a low-lying, wet meadow'. In dialects it can also mean 'a sedge'. As a mire site type **luhta** is characterized by limnogenic water from lakes or rivers. **Luhta** can be open or wooded and the vegetation is very diverse.

Rahka may be an old Germanic loanword, having same root as Swedish **drägg** 'sediment'. **Rahka** has several meanings in Finnish. In western dialects it means for example 'sediment', 'foam' and 'sweat'. **Rahka** meaning 'quark' has been adopted to standard language from the eastern dialects. In Ostrobothnia and Kainuu **rahka** means '*Sphagnum*' or 'peat' and in parts of southwestern Finland and Häme 'mire' or 'paludified land'. **Rahka** often forms part of the name of the mire in southwestern Finland, e.g. Kurjenrahka. **Rahka** forms part of the mire site type names, such as **rahkaneva** ('open *Sphagnum fuscum* bog') and **rahkaräme** ('*Sphagnum fuscum* pine bog').

Approximately half of the Finnish mires can be classified as **räme** ('pine mire', 'pine bog'). In standard language räme means 'dry mire with stunted pines and dwarf shrubs (e.g. *Calluna vulgaris*, *Empetrum nigrum*, *Rhododendron tomentosum*) growing on hummocks and *Sphagnum* species covering the ground layer'. In this case the description of **räme** as a mire site type is very similar. **Räme** is known also in Karelian language. **Korpi** ('spruce mire') in standard Finnish language means 'a dark, spruce forest' or a 'wilderness'. Also 'paludified forest' can be **korpi**. The word **korpi** is also known in Karelian and Estonian (**kõrb**). As mire site type **korpi** is forested spruce mire, with the field layer dominated by dwarf shrubs (e.g. *Vaccinium myrtillus*, *V. vitis-idaea*) and ground layer by *Sphagnum* species.

A very old Finno-Ugric word is **aro**. In Finnish dialects it means two, almost opposite types of sites: in west and north **aro** is 'wet, lowland area' and further east it means 'dry, poor area'. To the literary language **aro** came at the end of the 19th century meaning a 'dry, flat country (steppe)'. For the wetland terminology **aro** has been adopted only recently, meaning a seasonal wetland on well drained mineral soil (Laitinen & al. 2005). **Aro** wetlands are characterized by mainly treeless fen vegetation.

The word **keidas**, forming the first part of the term **keidassuo** ('ombrotrophic mire complex, bog'), has also several meanings. In modern standard language **keidas** means 'an oasis'. Use of the word **keidas** is very similar in dialects as it is in mire science: in North-Satakunta **keidas** means a mire, in South-Ostrobothnia 'a hummock on mire' or 'a high place on a mire' and further east 'an isthmus'. **Keidas** is an old Scandinavian loanword (cf. Swedish **skede** 'era, epoch').

Conclusions

As these mire words show, the meanings of the words are not always similar: the same word may mean different things in standard language and in dialects. When the word becomes a scientific or professional term, its meaning is defined as clearly as possible. As a special term meaning of the word may be much more narrow than in standard language. On the other hand only small part of the meanings of dialect words have been adopted to standard language.

The importance of mires is reflected in the fact that most of the Finnish mire words are original, not loanwords. In North-Finland words have been adopted from the indigenous Saami people, whose languages are also of Finno-Ugric origin. Other mire loanwords are rare, and those few are not only mire words, but have wider meanings.

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DOCUMENTATION PAGE

Publisher	Finnish Environment Institute			*Date* 7 / 2006
Author(s)	Tapio Lindholm and Raimo Heikkilä (eds.)			
Title of publication	**Finland – Land of mires**			
Publication series and number	The Finnish Environment 23 / 2006			
Theme of publication	Nature			
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Abstract	Finland – Land of mires is a textbook on mires and their ecology in Finland. Totally 27 separate articles of different topics are included in the book. The items dealt with in the book are the following: 1. Unsettled weather and climate of Finland. 2. Climate of Finland and its effect on mires. 3. Bedrock in Finland and its influence on vegetation. 4. The landforms of Finland. 5. Glacial and postglacial history of the Baltic Sea and Finland. 6. Postglacial history of Finnish inland waters. 7. Lake and river systems in Finland. 8. Interglacial and interstadial organic deposits in Finland. 9. Mire development history in Finland. 10. Regional distribution of peat increment in Finland. 11. Geobotany of Finnish forests and mires: the Finnish approach. 12. Ecohydrology of Finnish mires. 13. Ecological gradients as the basis of Finnish mire site types. 14. Mire plant species and their ecology in Finland. 15. Land uplift phenomenon and its effects on mire vegetation. 16. Palsa mires in Finland. 17. Cultural land use history in Finland. 18. The use of mires for agriculture and forestry. 19. Destruction of mires in Finland. 20. Environmental impacts of mire utilization. 21. Peatlands and global change – the Finnish case. 22. Ecosystem services provided by Finnish mires. 23. Mire conservation and its short history in Finland. 24. Ramsar areas in Finland. 25. Land birds in Finnish mires and their conservation status. 26. A short introduction to the Finnish language. 27. Etymology of some Finnish words for mire			
Keywords	Mire, ecosystem, land use, conservation			
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KUVAILULEHTI

Julkaisija	Suomen ympäristökeskus			*Julkaisuaika 7 / 2006*
Tekijä(t)	Tapio Lindholm ja Raimo Heikkilä (toim.)			
Julkaisun nimi	**Finland – Land of mires**			
Julkaisusarjan nimi ja numero	The Finnish Environment 23 / 2006			
Julkaisun teema	Luonto			
Julkaisun osat/ muut saman projektin tuottamat julkaisut				
Tiivistelmä	Finland – Land of mires on suomalaisen suoluonnon ja sen ekologian käsikirja. Kirja sisältää kaikkiaan 27 erillistä artikkelia eri aihepiireistä, jotka ovat: 1. Suomen epävakainen sää ja ilmasto. 2. Suomen ilmasto ja sen vaikutus soihin. 3. Suomen kallioperä ja sen vaikutus kasvillisuuteen. 4. Suomen maankamaran muodot. 5. Itämeren ja Suomen jääkaudenjälkeinen historia. 6. Suomen sisävesien jääkaudenjälkeinen historia. 7. Suomen järvi- ja jokisysteemit. 8. Suomen interglasiaaliset ja interstadiaaliset kerrostumat. 9. Suomen soiden kehityshistoria. 10. Turpeen kerrostumisen alueellinen vaihtelu Suomessa. 11. Suomen metsien ja soiden kasvimaantiede: suomalainen lähestymistapa. 12. Suomen soiden ekohydrologia. 13. Ekologiset gradientit suomalaisen suotyyppijärjestelmän perustana. 14. Suomen suokasvit ja niiden ekologia. 15. Maankohoamisilmiö ja sen vaikutus suokasvillisuuteen. 16. Suomen palsasuot. 17. Suomen maankäytön kulttuurihistoria. 18. Soiden käyttö maa- ja metsätaloudessa. 19. Suomen soiden tuho. 20. Soiden käytön ympäristövaikutukset. 21. Suomen soiden merkitys globaalimuutoksessa. 22. Suomen soiden ekosysteemipalvelut. 23. Suomen soidensuojelun lyhyt historia. 24. Suomen Ramsar-alueet. 25. Suomen soiden maalinnut ja niiden suojelun tila. 26. Lyhyt johdatus suomen kieleen. 27. Eräiden suomen kielen suota kuvaavien sanojen etymologia.			
Asiasanat	Suo, ekosysteemi, maankäyttö, soidensuojelu			
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PRESENTATIONSBLAD

Utgivare	Finlands miljöcentral			*Datum 7 / 2006*
Författare	Tapio Lindholm och Raimo Heikkilä (eds.)			
Publikations titel	**Finland – Land of mires**			
Publikationsserie och nummer	The Finnish Environment 23 / 2006			
Publikationens tema	Natur			
Publikationens delar/ andra publikationer inom samma projekt				
Sammandrag	Finland – land of mires är en textbok om myrarna och deras ekologi i Finland. Boken innehåller totalt 27 artiklar on olika temor, som är: 1. Finlands ostabil väder och klimat. 2. Finlands klimat och dess verkan på myrar. 3. Finlands berggrund och dess verkan på vegetationen. 4. Finlands jordformer. 5. Den postglaciala historien av Östersjön och Finland. 6. Den postglaciala historien av Finlands insjöar. 7. Sjö- och flodsystemer in Finland. 8. Interglaciala och interstadiala depositionerna in Finland. 9. Utvecklingshistorien av myrarna in Finland. 10. Den regionala utbredningen av torvavlagringen in Finland. 11. Geobotaniken av skogar och myrar i Finland. 12. Ekohydrologin av myrar i Finland. 13. Ekologiska gradienterna som grund av Finska myrvegetationstyper. 14. Myrväxterna och deras ekologi i Finland. 15. Landhöjningen och dess verkan på myrvegetationen. 16. Palsmyrar i Finland. 17. Kulturhistorien av markanvändningen i Finland. 18. Utnyttjandet av myrar i jordbruk och skogsbruk. 19. Undergången av myrarna in Finland. 20. Miljökonsekvenserna av myrarnas utnyttjande. 21. Finska myrarna och den globala förändringen. 22. Ekosystemservicen av Finska myrarna. 23.Myrskydd och dess kort historia i Finland. 24. Ramsar-områdena i Finland. 25. Fåglarna och deras skydd i Finska myrarna. 26. En kort inledning till det Finska språket. 27. Etymologin av några ord för myrarna in det Finska språket.			
Nyckelord	Myr, ekosystem, markanvändningen, myrskydd			
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Тематика публикации	Природа			
Части публикации/ другие публикации, вышедшие в рамках этого же проекта				
Резюме	”Финляндия – страна болот” – книга о болотах Финляндии и их экологии. В нее включены 27 отдельных статей по различным направлениям исследований. Тематика статей следующая: 1. Неустойчивая погода и климат Финляндии. 2. Климат Финляндии и его влияние на болота. 3. Материнские породы Финляндии и их влияние на растительность. 4. Формы рельефа Финляндии. 5. История Балтийского моря и Финляндии в ледниковое и послеледниковое время. 6. Послеледниковая история рек и внутренних водоемов Финляндии. 7. Озерные и речные системы Финляндии. 8. Межледниковые и межстадиальные органические отложения в Финляндии. 9. Развитие болот Финляндии. 10. Региональное распространение показателей скорости торфонакопления в Финляндии. 11. Геоботаника лесов и болот Финляндии: финский подход. 12. Экогидрология финских болот. 13. Экологические градиенты как основа для выделения типов болотных местообитаний в Финляндии. 14. Болотные виды растений и их экология в Финляндии. 15. Явление поднятия суши и его эффект на растительность. 16. Бугристые болота Финляндии. 17. История землепользования в Финляндии. 18. Использование болот для сельского и лесного хозяйства. 19. Уничтожение болот в Финляндии. 20. Воздействие утилизации болот на окружающую среду. 21. Торфяники и глобальное потепление – финский случай. 22. Экосистемные услуги, предоставляемые финскими болотами. 23. Охрана болот и ее история в Финляндии. 24. Рамсарские угодья Финляндии. 25. Птицы финских болот и их охранный статус. 26. Короткое введение в финский язык. 27. Этимология некоторых финских слов, обозначающих ”болото”.			
Ключевые слова	Болото, экосистемы, землепользование, охрана болот			
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This is a book about Finnish mires. There have been three reasons to make this book. Firstly: Finland really is a land of mires. We wish to tell the readers what are the Finnish mires and how they look like. This book is an attempt to answer a question how these mires are functioning and how they have developed. The oldest mires are about 11 000 thousand years in Eastern Finland. The youngest mires develop at present along the Bothnian Bay coast in the west. In the south, mires have some similarity to Central European mires, and in the north the mires are close to the Arctic.
Secondly: One third of the territory of Finland has been covered by mires and they have also been a target of very intensive land use. The history of land use and data on the nature conservation activities are presented in this book. The earliest use of Finnish mires has been to turn them into arable fields. In the 1900s there has been very extensive drainage for forestry. Also peat extraction, water reservoir construction, road construction and settlements have destroyed mires. On the opposite, especially during the second half of 20th century there have been several programmes to protect mires.
Thirdly: As a consequence of different activities in Finnish mires we have had a long and versatile tradition to study mires. This book gives an overview of the knowledge we have on our mires in Finland.

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