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Development History of Patvinsuo Mire, Eastern Finland

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Kansikuva: A bog with old dead pine trees on the edge of an aapa mire near to Nälämänpuro brook indicate rapid invasion of *Sphagnum fuscum* into a mire forest. Veli-Matti Väänänen.

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Abstract

Patvinsuo mire (63° 05'N, 30° 40'E, 150–170 m asl.) is an extensive aapa mire and eccentric bog system located at the southern limit of the middle boreal zone. According to ^{14}C datings, peat began to accumulated about 10500 cal. years BP, about 1000 years after the retreat of the Weichselian Land Ice.

The first vegetation communities were characterized by rich fen species (e.g. *Scorpidium scorpioides*) as indicated by macrofossil and chemical analyses. The rich fen stage was short and oligotrophic fen vegetation prevailed in most places, giving rise to ombrotrophic (bog) conditions over wide areas with good natural drainage. Only small areas have retained slightly mesotrophic vegetation (e.g. *Molinia caerulea, Trichophorum alpinum* and *Sphagnum subsecundum*). The initiation of the ombrotrophic bog stage began about 3500 years ago. The open-water flarks (rimpis), typical of the patterned string aapa mires, originated about 3000 cal. years BP.

Frequent mire fires have slowed vertical peat accumulation while promoting lateral peat expansion. The average rate of long-term carbon accumulation in Patvinsuo (9.2 ± 1.0 (SE) g m^{-2} yr^{-1}) was clearly lower compared to the average value for reference bogs and fens in southern and central Finland (17.7 ± 0.6 (SE) g m^{-2} yr^{-1}). The average rate of carbon loss in Patvinsuo mire system was 9.5 ± 1.0 (SE) g m^{-2} yr^{-1} and the mean carbon loss in an individual fire was estimated to be 2.5 kg m^{-2}. However, growth studies of eight *Sphagnum* species revealed high production figures. Recent carbon accumulation rates in the mire margins paludified after latest forest fires (60 to 240 years ago) were much higher compared to long-term rates of carbon accumulation in other parts of the mire. Carbon input into the mineral subsoil beneath the peat may be an additional carbon sink, which usually exceeds the amount of carbon in the ancient forest soil prior to paludification (on average 22 g of carbon m^{-2} yr^{-1}).

Keywords	Patvinsuo National Park, mires, bogs, peat, paleoecology, vegetation history, macrofossils, carbon accumulation, mire fires
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Tiivistelmä

Patvinsuo (63º 05'N, 30º 40'E, 150–170 m mpy) on keskiboreaalisen vyöhykkeen etelärajalla sijaitseva laaja aapa- ja keidassuoyhdistymä. Turpeen kertyminen alkoi ^{14}C-ajoituksien mukaan noin 10500 kalibroitua radiohiilivuotta sitten, noin 1000 vuotta mannerjäätikön vetäytymisen jälkeen viimeisen jääkauden lopulla.

Makrofossiilitutkimusten ja kemiallisten analyysien mukaan ensimmäisiä kasviyhteisöjä luonnehtivat rehevien nevojen lajit (esim. *Scorpidium scorpioides*). Useimmissa paikoissa rehevä suokasvillisuus korvautui lyhyen ajanjakson jälkeen oligotrofisten nevojen kasvillisuudella. Olosuhteet kehittyivät ombrotrofisiksi laajoilla alueilla, joilla luonnollinen valunta on hyvä. Lievästi mesotrofinen kasvillisuus on säilynyt vain pienillä alueilla (esim. *Molinia caerulea, Trichophorum alpinum* ja *Sphagnum subsecundum*). Ombrotrofiset rämeet alkoivat kehittyä noin 3500 vuotta sitten. Vetisiä rimpiä, jotka ovat tyypillisiä aapasoille alkoi muodostua noin 3000 vuotta sitten.

Suopaloja oli usein, ja ne hidastivat turpeen korkeuskasvua mutta samalla nopeuttivat suon sivusuuntaista laajenemista. Keskimääräinen pitkän ajanjakson hiilen kertymä Patvinsuolla (9.2 ± 1.0 (SE) g m^{-2} yr^{-1}) oli selvästi alempi kuin vertailuaineiston keski- ja eteläsuomalaisten rämeiden ja nevojen keskimääräinen pitkän ajanjakson hiilikertymä (17.7 ± 0.6 (SE) g m^{-2} yr^{-1}). Keskimääräinen hiilen hävikki Patvinsuolla oli 9.5 ± 1.0 (SE) g m^{-2} yr^{-1}, ja arvioitiin, että yksittäistä paloa kohti hiiltä poistui suosta 2.5 kg m^{-2}. Huolimatta matalasta hiilen kertymisnopeudesta kahdeksan *Sphagnum*-lajin kasvututkimukset osoittavat, että niiden tuotanto on korkea. Samoin nykyiset hiilen kertymänopeudet viimeisten metsäpalojen (60–240 vuotta sitten) jälkeen soistuneilla suon reuna-aluilla ovat paljon korkeammat kuin pitkän ajanjakson hiilikertymänopeudet suon muissa osissa. Hiilen kulkeutuminen turpeen alaiseen mineraalimaahan saattaa toimia myös hiilen nieluna (keskimäärin 22 g m^{-2} yr^{-1}), ja yleensä hiilen määrä turpeenalaisissa mineraalimaissa on suurempi kuin mitä se on ollut ennen soistumista.

Avainsanat

Patvinsuon kansallispuisto, suot, turve, paleoekologia, kasvillisuushistoria, makrofossiilit, hiilen kertyminen, suopalot

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Patvinsuo (63° 05'N, 30° 40'E, 150–170 möh) är ett vidsträckt komplex av aapamyrar och excentriska högmossar vid södra gränsen av den mellanboreala zonen. C14-dateringar visar att ackumuleringen av torv startade för ca 10500 kalibrerade C14-år BP, d.v.s. ca 1000 år efter att inlandsisen dragit sig tillbaka i slutet av den senaste istiden.

Makrofossilundersökningar och kemiska analyser visar att de första växtsamhällena karakteriserades av arter typiska för övergångsrikkärr (t.ex. *Scorpidium scorpioides*). Efter en relativt kort tidsperiod ersattes på de flesta ställen denna näringsrika myrvegetation av fattigkärrsvegetation. På vidsträckta områden med god naturlig avrinning utvecklades ombrotrofa (d.v.s. regn-födda) förhållanden för ca 3500 år sedan. Endast på mindre områden har en något näringsrikare övergångsfattigkärrsvegetation bevarats (t.ex. *Molinia caerulea, Trichophorum alpinum* ja *Sphagnum subsecundum*). Blöta flarkar, som är typiska för aapamyrar, började uppkomma för ca 3000 år sedan.

Myrbränder ägde rum ofta och ledde till att torvens vertikala tillväxt hämmades men å andra sidan till att myren snabbare bredde ut sig i sidled. Långtidsmedelvärdet för kolackumulationen (carbon accumulation, ”LORCA”) i Patvinsuo (9.2 ± 1.0 (SE) g m^{-2} yr^{-1}) var tydligt mindre än motsvarande värde för de tallmossar och fattigkärr i södra och mellersta Finland som utgjorde referensmaterialet (17.7 ± 0.6 (SE) g m^{-2} yr^{-1}). Medelvärdet för kolförlusten i Patvinsuo var 9.5 ± 1.0 (SE) g m^{-2} yr^{-1}, och kolförlusten per enskild myrbrand estimerades till 2.5 kg m^{-2}. Trots att hastigheten på kolackumulationen är låg, visar en tillväxtundersökning av åtta *Sphagnum*-arter att dessa arters produktion är hög. Likaså är värdena för den nuvarande hastigheten på kolackumulation i de kantområden av myren som försumpats efter de senaste skogsbränderna (60–240 år sedan) mycket högre än långtidsvärdena för hastigheten på kolackumulationen i övriga delar av myren. Transporten av kol till mineraljorden under torvlagret fungerar eventuellt också som en kolsänka (i medeltal 22 g m^{-2} yr^{-1}), och i allmänhet är kolmängden i mineraljord som befinner sig under ett torvtäcke större än mängden kol i jorden innan området försumpades.

Nyckelord

Patvinsuo nationalpark, myrar, torv, paleoekologi, vegetationshistoria, makrofossil, kolackumulation, myrbränder, skogsbränder

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Резюме

Болото Патвинсуо (63°05'с.ш., 30°40'в.д., 150–170 м н.у.м.) является крупной (более 6000 га) и сложной болотной системой, состоящей из нескольких эксцентрических верховиков и массивов аапа типа. Оно расположено у южной границы среднебореальной зоны в одноименном национальном парке. Согласно радиоуглеродным датировкам (С14) аккумуляция торфа началась на нем 10500 лет назад (возраст калиброван), примерно спустя 1000 лет после отступления ледника Валдайского оледенения. По данным ботанического анализа торфов первые растительные сообщества в наиболее глубоких депрессиях включали виды евтрофных болот (например *Scorpidium scorpioides*). Евтрофная стадия болота была короткой, затем длительное время на большинстве участков доминировала олиготрофная растительность. Только на небольших участках сохранилась растительность с участием мезотрофных видов (*Molinia caerulea, Trichophorum cespitosum, Sphagnum subsecundum*). Омбротрофная стадия на верховых массивах, входящих с эту систему, началась около 3500 лет назад. Обводненные мочажины, характерные для грядово-мочажинных аапа болот, возникли около 3000 лет назад. Частые лесные пожары обусловили низкую вертикальную скорость накопления торфа на болоте, при этом происходила его активная горизонтальная экспансия. Средняя многолетняя интенсивность аккумуляции углерода на Патвинсуо составляет 9.2 ± 1.0 г/м^2/год, что значительно ниже средних показателей для верховых и аапа болот южной и центральной Финляндии (17.7 ± 0.6 г/м^2/год). Средний уровень потери углерода на Патвинсуо составляет 9.5 ± 1.0 г/м^2/год, потери углерода при отдельных пожарах достигали 2.5 кг/м^2. Исследования прироста восьми видов сфагновых мхов показали их высокую продуктивность в настоящее время. Скорость аккумуляции торфа на окрайках болот, заболотившихся после последних лесных пожаров (60–240 лет назад) значительно выше по сравнению со средними многовековыми данными для других частей болота. Накопление углерода в реликтовых погребенных под торфяной залежью лесных почвах (до 22 г/м^2/год) существенно увеличивает общее количество связанного углерода.

Ключевые слова

Национальный парк Патвинсуо, болота, торф, палеоэкология, растительная история, макроископаемые, аккумуляция углерода, пожары на болоте, лесные пожары

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CONTENTS

1 INTRODUCTION

Mires serve as important indicators of environmental influences and an understanding of mire initiation and development may illuminate past changes in environmental conditions, especially climate. For example, raised bogs receiving their moisture and nutrients primarily from atmospheric inputs may be more sensitive to environmental fluctuations than surrounding upland sites (Barber 1981, Aaby 1986, Moore 1986, Foster & Wright 1990, Barber *et al.* 1994). As well, the accumulation of peat provides a stratigraphic record of past paleoenvironmental conditions and the influence of autogenic and allogenic factors. The abundance of macrofossils and their preservation within anoxic peat layers can provide direct information on past vegetation communities on a local and regional scale (e.g. Waren 1924, Brandt 1948, Tolonen 1967, Janssens 1983). Factors such as climate, geochemistry, topography and fire have significantly influenced the expansion, development and distribution of mire types (Foster & Jacobson 1990). The influence of autogenic and allogenic factors on mires has also caused carbon accumulation rates on local and regional scales to vary considerably during the Holocene.

The focus of this paper is to understand the development history of Patvinsuo mire system in eastern Finland. Through the use of paleoecological techniques, such as stratigraphic and macrofossil analyses, radiocarbon datings and chemical analyses from selected core profiles, the composition of plant communities present at different stages of development were reconstructed. The fire history and the effect of fires on the average long-term (apparent) rate of carbon accumulation (LORCA) were studied. Furthermore, carbon density and the LORCA in mineral subsoils beneath mires formed by paludification were studied through comparisons with adjacent forest sites with similar podzolic soils and topography.

2 GEOGRAPHIC SETTING

Mires are dominant landforms in North Karelia, covering about one third of the land area. In the North Karelian region (Figure 1; 62–63º N, 30º–31º30´ E), the climatic border area of southern boreal and middle boreal vegetation zones meet, resulting in a mixture of mire types (Ahti *et al.* 1968). In the southern portion of North Karelia, raised bogs are typical, while in the north, aapa mires and mixed systems of aapa mires and raised bogs are common (Tolonen 1967). The southern limit of aapa mires roughly coincides with the border between southern and middle boreal forest vegetation, which runs slightly north of the Koitajoki River system in Finland. The southern limit continues at about the same latitudes on the Russian side (Elina *et al*. 1984, Jelina 1985).

Patvinsuo National Park is located within one of the most continental areas in Finland in terms of thermal conditions, with cold winters and warm summers. The mean temperatures for January and July are –12.1°C and +15.8°C. The mean annual temperature is +1.5°C to +2.0°C and the effective temperature sum above a mean daily temperature of +5ºC is between 1 000 and 1 100 degree days. Duration of the growing season is about 150 days whereas the thermal winter is about 165 days. The annual precipitation amount is 650–700 mm with approximately 250–300 mm received as snow. The mean maximum thickness of snow is 65–70 cm and snow covers the open ground for about 170–180 days (Suomen kartasto 1987) (see also Table 3).

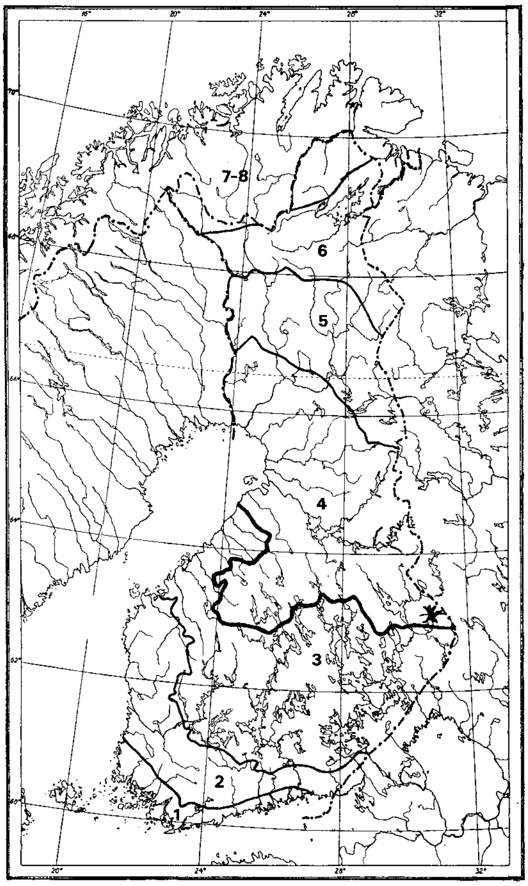


Figure 1. The Finnish mire vegetation zones (Ruuhijärvi 1982). Location of Patvinsuo (63°05′N, 30°40′E, 150–170 m asl) is marked with an asterisk. Ombrotrophic mires: 1. Plateau bogs, 2. Concentric bogs, 3. Eccentric and Sphagnum fuscum bogs; Minerotriphic mires: 4. Southern aapa mires (Pohjanmaa-type), 5. Main aapa mires (Peräpohjola-type), 6. Northern aapa mires (Forest-Lappland-type), 7. Palsa mires, 8. Orohemiarctic mires.

According to Punkari (1996), Patvinsuo National Park lies within a supra-aquatic area of Finland. The area remained above the highest shoreline during the Yoldia Sea and Ancylus Sea stages after the last deglaciation. The bedrock in Patvinsuo National Park consists granites, and sorted fluvioglacial sand deposits originating from the final stage of the last glaciation (about 10500 ^{14}C-years BP) underlie large areas of the mire system. At that time, the retreating margin of the icesheet remained stationary in the area, giving rise to a 200 km long ice-marginal formation that extends from Jaamankangas west of Joensuu to Lake Lieksanjärvi across the Finnish-Russian border into the east (Rosberg 1892, Lyytikäinen & Kontturi 1980). Fluvioglacial material is also present as eskers which run northwest to southeast in the eastern part of the park. Morainic soils also prevail as generally fairly coarse grained till. The forested hills that rise up to or over 100 m above the surrounding peatlands (the Rauvunvaara Hill 275 m asl.), are covered by morainic (till) material. Peat is the most common soil type around Patvinsuo National Park and mires cover more than 60 km^2 of the total area of the park (97 km^2).

3 MIRE FLORA AND VEGETATION

Patvinsuo National Park (63°05′N, 30°40′E, about 150–275 m asl.) is situated (Figures 1 and 2) in the border area between the ombrotrophic raised bogs (southern) and the minerotrophic aapa mires (northern). The mire vegetation of the park exhibits features common to both main mire complex types. In a very extensive mire system like Patvinsuo, the topographic conditions dictate the extent of alternating patches of aapa fens and ombrotrophic bogs, which are separated from each other by fairly distinct limits. The result is a diversely mixed complex of mire systems (see Figures 3 and 4).

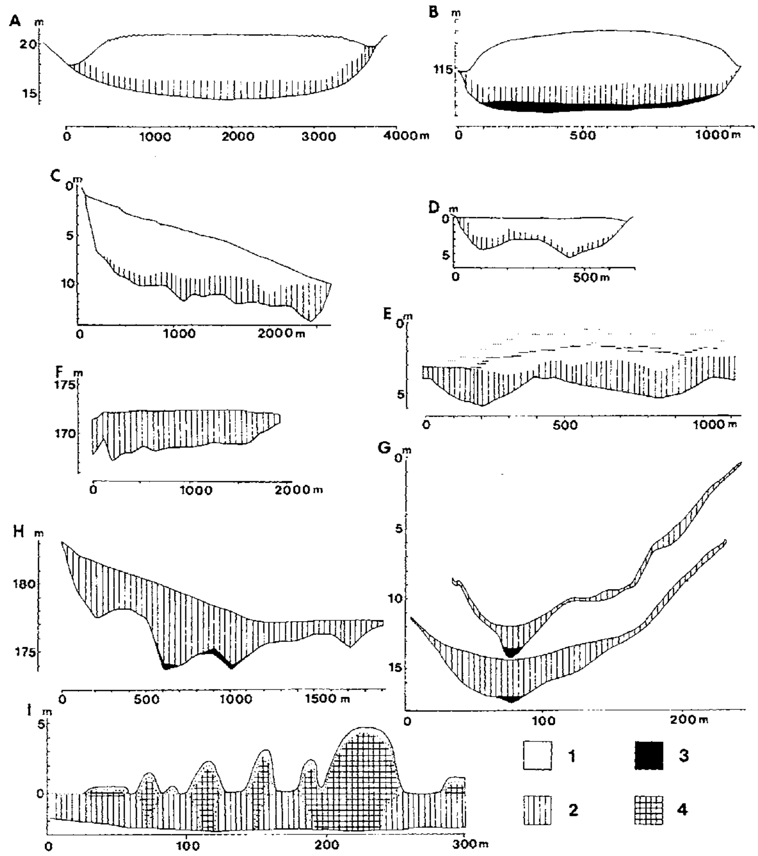


Figure 2. Profiles from Finnish mires representing different complex types from Ruuhijärvi 1983. A. Plateau bog, Munasuo, Pyhtää. B. Concentric bog, Kärjensuo, Tammela. C. Eccentric bog, Kirkkosuo, Kitee. D. Sphagnum fuscum bog, Kangasjärvensuo, Juva. E. Northern eccentric bog, Vuollasaapa, Sodankylä (hollow surfaces with solid lines, hummock surfaces with dotted lines). F. Southern aapamire, Ilajansuo, Ilomantsi. G. Sloping aapa mire, Nuolivaara, Posio. H. Main aapa mire, Parvavuoma, Kittilä. I. Palsa mire, Piera Marin jänkä, Inari. Key: 1. Ombrotrophic peat; 2. Minerotrophic peat; 3. Limnic sediments; 4. Permafrost.

Figure 3. An infrared air photo taken over the northeast part of Patvinsuo mire complex between Lake Suomujärvi and the Palosuihko mineral soil island based on photos taken in early summer 1986 by Finnmap Ltd. Ombrotrophic hummocks and kermis are visible in grey, brown and magenta, minerotrophic strings in light yellow or green or (if very wet) in blue or black. The boundary between bog and fen vegetation is usually very sharp. Location of study transects B and C are shown.

Figure 4. Oblique aerial photo over the southern aapa fen area, close to the bird tower within the Patvinsuo mire complex. At the base of the picture, the sharp boundary between the rain-fed bog (foreground, brown) and the minerotrophic fen (green) with water filled rimpis (flarks) and narrow and low strings (middle distance). Photograph by Prof. Rauno Ruuhijärvi in the early June 1980's.

The mire vegetation of the Patvinsuo area was studied in some extent by Tolonen (1967) and Kivinen and Tolonen (1972) and thoroughly by Leivo *et al.* (1992). The following description is mainly based on these sources. The term bog or raised bog refers to a mire (complex) in which the central part is covered by ombrotrophic (rain-fed) vegetation. Contrary to previous definitions, the main division is not based on topography. The profile of the peatland does not need to be convex. In fact, most of the bog complexes in North Karelia are concave in profile. The central parts of the aapa mires are covered by minerotrophic (fen) vegetation that receives extra nutrients from ground water or from water that is in contact with ground water. Hence, aapamires are also not defined based on topography. Marginal (upper) parts of an aapa mire complex are usually composed of ombrotrophic pine bog vegetation. The whole area is referred to as mixed complex *sensu* Tolonen (1967), where ombrotrophic pine bog vegetation covers about a half of the total area. This concept is disimiliar to a mixed mire, which is an aapa mire with ombrotrophic vegetation on the strings and clear minerotrophic vegatation at the lawn and/or the flark level(s).

Eccentric bogs of the Patvinsuo mire complex (Figure 5) mainly occupy the outer and upper parts of the mire basins. Ombrotrophic pine bogs with standing dead trees cover large areas of the northern part of Patvinsuo (south and southwest of Lake Suomunjärvi). Typical hummock vegetation consists of dwarf shrubs Empetrum nigrum subsp. hermaphroditum, Calluna vulgaris, Chamaedaphne calyculata, Vaccinium uliginosum and V. microcarpum. Further species include Eriophorum vaginatum and Rubus chamaemorus. The most common species in the bottom layer are Sphagnum fuscum, S. angustifolium and Cladonia rangiferina. Usually, the vegetation is completely ombrotrophic, although in places Carex pauciflora and Sphagnum papillosum are present. These species must be considered primarily as minerotrophic under conditions prevailing in North Karelia. Towards the inner parts of the basins, the mire surface is differentiated between wet mossy hollows and Sphagnum fuscum hummock ridges. Eriophorum vaginatum, Scheuchzeria palustris and Sphagnum balticum are dominant in the hollows.

Figure 5. Eccentric bog in the northern part of Patvinsuo mire complex. Rhynchospora alba-Scheuchzeria-Sphagnum balticum vegetation dominates the hollows, Empetrum-Chamaedaphne-Sphagnum fuscum pine bog on the peat ridges and Eriophorum vaginatum on the lawns and lowest hummocks. As charasteristic of aapamires of the middle boreal zone, the low strings are of lawn vegetation with, e.g. Carex lasiocarpa, Eriophorum vaginatum and Molinia caerulea dominating in the field layer and Spagnum papillosum in the bottom layer. More details in the text). Photo Pertti Huttunen, June 1975.

The aapa fen vegetation covers a somewhat larger area than the ombrotrophic vegetation present at the margins. A well-patterned string-flark complex prevails in the aapa mires. As opposed to bog vegetation where peat ridges are formed by relatively high hummocks, the string vegetation is composed mainly of lawn (carpet) communities elevated only slightly above the flark levels. The typical string vegetation is formed by *Carex lasiocarpa, Trichophorum cespitosum, Eriophorum vaginatum* and *Molinia caerulea* in the field layer and *Sphagnum papillosum, S. angustifolium* and *S. compactum* in the moss layer. The vegetation of the flarks (rimpis) is rather sparse in places and the most important species include *Carex limosa, C. laciocarpa, C. rostrata, C. chordorrhiza, Eriophorum angustifolium, Menyanthes, Scheuchzeria, Rhynchospora alba, Utricularia intermedia, Drosera anglica, Sphagnum fallax, S. majus, S. annulatum* var. *porosum, S. papillosum* and *S. balticum*. A northerly feature is the frequent occurrence of *Trichophorum cespitosum-Molinia-Sphagnum compactum* communities.

Spruce swamps are also found in the Patvinsuo area. In the most characteristic form, sedge spruce swamps and herb-rich spruce swamps occur along brooks. However in many places, the spruce swamps have been altered due to the rise in the water table caused by beavers. The spruce swamps are best preserved in their original form along the upper course of the brooks.

Usually ombrotrophic areas can be easily distinguished from minerotrophic vegetation both in the field and also from aerial photos, especially in infrared (Figure 4). In the northern parts of Patvinsuo there are localities where differentiation is impossible because the bog and fen elements are mixed together. In places, the morphology and physiognomy is characteristic of the eccentric North Karelian raised bogs, but there are a few aapa-fen species present, particularly in the hollows (for example *Carex lasiocarpa, C. rostrata* and *Menyanthes*). Obviously, the minerotrophic species are relicts and the mire is in the process of becoming entirely ombrotrophic, as illustrated by the fact that the moss vegetation is ombrotrophic.

4 MATERIAL AND METHODS

Nine representative transects were established in both eccentric bog and aapa mire systems and covered the deepest peat deposits and the marginal areas (Figure 6). Along these transects, levelling and determination of peat thickness were done every 25 m. As well, samples for stratigraphical and macrofossil analyses and peat chemical composition were obtained using a Russian peat sampler (50 x 500 mm). Samples were wrapped in plastic bags and kept in cold storage prior to analysis. For bulk density measurements, the uppermost 100 cm of peat profiles were sampled using a box-sampler (8.5 x 8.5 x 100 cm). A Russian pattern peat sampler (5 x 50 cm) was used for the deeper peat layers. The degree of decomposition was estimated in the field using the von Post's (1922) 10-grade scale (H1–10) and microscopically in the laboratory using the traditional method of Minkina and Varlygin (1939).

Macrofossil analyses were performed by two different methods. At the University of Joensuu, Finland (sites 24, 25, 29 and S650) macrofossil analysis was carried out from continuous peat columns cut into 5–10 cm thick slices. These subsamples (50 in total) were dried and pulverized (homogenized), treated with hot potassium hydroxide, stained with safranine and made into microscope slides according to Heikurainen and Huikari (1952). Plant remains, especially bryophyte and *Sphagnum* remains, were identified using a light microscope. Results were estimated by point count estimation (Clark 1982) and then changed to percentages. Amounts of unidentifiable vascular plant remains (indet non-mosses) were also estimated. Descriptions of the present vegetation was carried out from some of the sites (Appendices 1 and 2) with five one-m^2 quadrats made. The first quadrat was situated on sample site while other quadrats were situated around the first quadrat. In the analyses of the field and ground layers, cover percentages were used (scale +, ½, 1, 2, 3 ... 100). The areas of open water were also estimated. The arithmetic means of five one-m^2 quadrats were used for each site. In the interpretative text, western usage has been followed. Nomenclature follows Hämet-Ahti *et al.* (1998) for vascular plants and Koponen (1980) for Bryidae and Koponen *et al.* (1977) for Sphagnidae.

For the remaining 22 sites studied in Petrozavodsk, Russia the macrofossil analysis involved taking samples at 10–25 cm intervals. These subsamples (178 in total) were washed with a strong jet of water through a 0.25 mm mesh sieve, and the remaining residue was carefully transferred to glass tubes. Sedge and Bryales moss remains and other vascular plants were identified using a light microscope at 90–130x magnification. *Sphagnum* mosses were stained with methyl blue (5–10 %) before analysis. Identification of fine sedge roots and other vascular plant remains was aided through the use keys (Katz *et al.* 1977) and our own reference collection.

Results of macrofossil analysis were used to divide peats into three classes (based on Russian classification): ombrotrophic (verkhovoi), mesotrophic (perehodnyi) and eutrophic (nizinnyi; Elina *et al.* 1984, Lopatin 1973, Tjuremnov 1949). For example, the ombrotrophic class includes peat types consisting only of ombrotrophic plant fossils. The mesotrophic class includes *Sphagnum* mosses from both ombrotrophic and eutrophic peat classes. In the classification commonly followed by Finnish and other western mire scientists, the Russian concept ”eutrophic” comprises both eutrophic, mesotrophic and some oligominerotrophic species, while the Russian concept ”mesotrophic” roughly corresponds to western oligominerotrophic plus some mesotrophic species. The Russian ”ombrotrophic” concept is the same as the western definition.

As well, macrofossil analysis was used to determine peat types within and among the stratigraphic profiles of the representative transects. Peat types were determined based on the relative percentage of macrofossil remains and classified according to the dominant plant type within the peat. The decay resistance of different plant species was also considered (Elina *et al.* 1984, Tjuremnov 1949). For example, if the amount of woody macrofossils in a sample exceeded 15 %, the material woody was included in the peat classification (woody-*Carex*, woody-*Sphagnum* etc.). However, if the peat was formed by more than 40 % woody remains, it was classified as woody peat (*Betula* peat, *Picea* peat etc.). A peat type was described as herbaceous if over 25 % herb macrofossils were present. A grass-moss peat was used if the moss macrofossil remains constituted 35–60 % of the total number of macrofossils (*Eriophorum-Sphagnum*, *Carex-Sphagnum*). If the peat was formed by more than 60 % moss remains, it was classified as moss peat (*Sphagnum fuscum* peat, Bryales peat etc.).

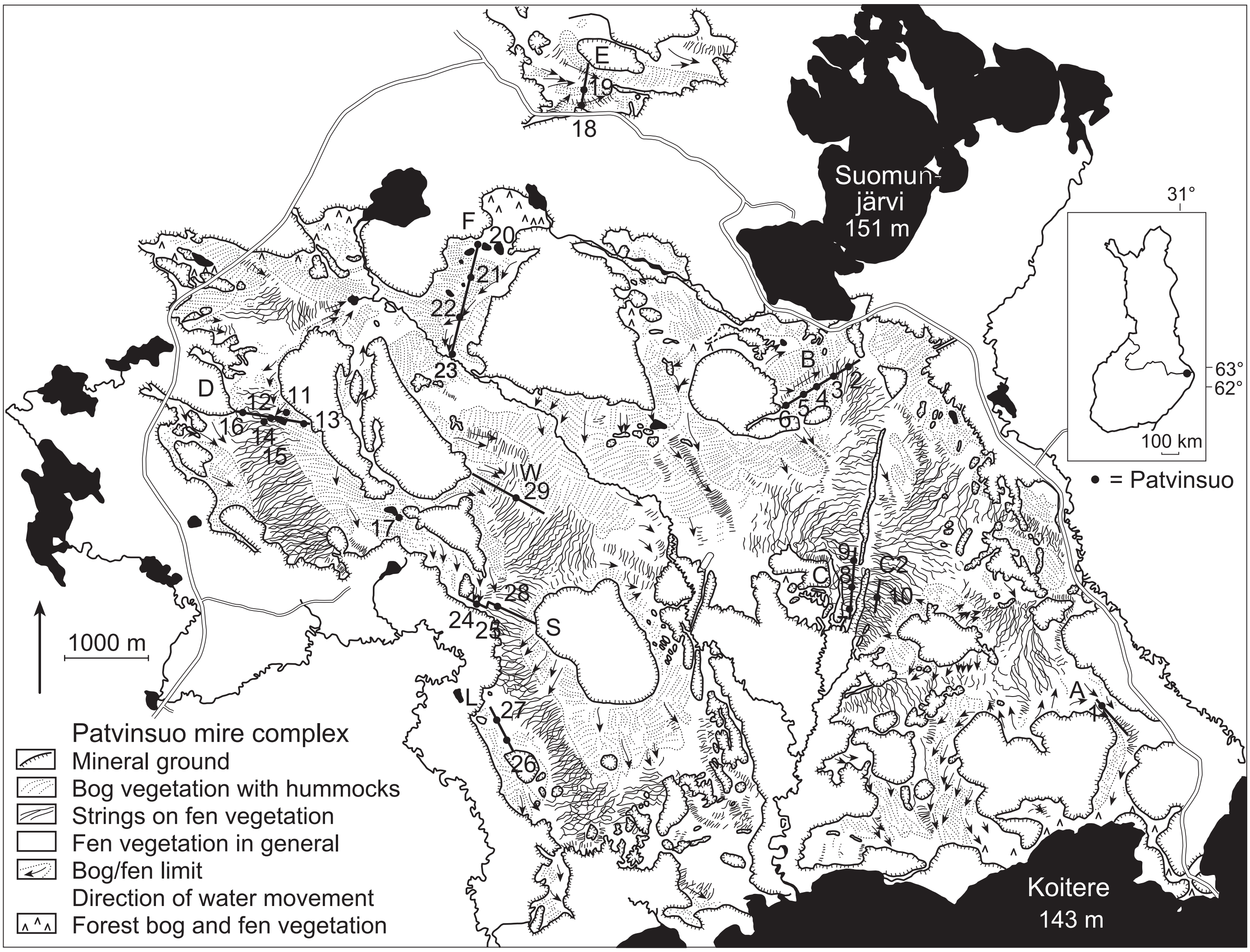


Figure 6. Patvinsuo mire system in eastern Finland. The nine transects are marked with lines (A–F, W, S, L), and the actual study sites with dots. (The line in the index map indicates the limit of the raised bog and aapa mire region.) The map of Patvinsuo is based on field observations and unrectified air photographs, resulting in scale errors (Kivinen & Tolonen 1972).

None of the studied peat columns was homogenous from the bottom to the surface regarding plant remains. The columns were comprised of peat types originating from different stages (called *phases*) during the peat growth. The 29 analysed peat cores contained between three to eight phases each, which were subjectively drawn on the basis of dominant and/or ”indicator” plant fossils. The phases are thus arbitrary entities, given only to facilitate the description of the development history of the given site. Whenever possible, the approximative age of the phases is given in the text, but most often it remains open due to the lack of dating.

In total, 30 radiocarbon ages were obtained from basal peat samples. Radiocarbon ages were determined at the Helsinki University Dating Laboratory (Table 1). The ages were converted to calendar years using CALIB 3.0.3 (Stuiver & Reimer 1993). The carbon content was estimated using the dry mass estimate of 0.5 and the correction for ash was made for all samples. Since it appeared that the near bottom peats at many sites were repeatly burnt, several radiocarbon datings were ”controlled” by pollen analyses by the authors Tolonen and Pitkänen. For the fossil pollen spectra, 100–300 AP were counted at 1–5 cm intervals starting from the peat/mineral soil junction. Approximate dating was obtained by comparison to the results in Tolonen (1967) and Tolonen and Ruuhijärvi (1976). The pollen diagrams are stored at the Department of Biology, University of Joensuu (Pitkänen), while one diagram has been published by Pitkänen *et al.* (1999).

Dendrochronological study of cross-sections of the dead Scots pines was carried out in the Saima Centre for Environmental Sciences, University of Joensuu. Tree-ring series were cross-dated against the chronology obtained from the region 63°05′–63°49′N, and 29°32′–30o50´E. In addition tree-ring counting was used to date the individual fire scars.

Subsoils of paludified mires and soils of adjacent forests with sorted sandy material were investigated in 1995. Samples for dry bulk density and carbon content analyses were taken using the Russian peat sampler. Extreme caution was used when obtaining subsamples for carbon content analysis to avoid impurities and contamination. Carbon was analysed using the LECO CHN-600 -analyzer at +1050°C. In marginal areas of the mire, charcoal layers were found between the mineral soil and peat. We used the age of the last fire as determined from historically known sources (Potinkara 1993) or from fire scars of mire pines to date the bottom peat of the marginal mire areas.

Table 1. Sample characteristics and the results of ^{14}C and pollen analyses of the Patvinsuo mire. Peat constituents: C = Carex, Er = Eriophorum, Eq = Equisetum, L = wood, Pr = Phragmites, S = Sphagnum, B = Bryales, H = degree of decomposition in von Post's (1922) 10-grade scale. Most probable age refers to the calibrated calendar years (Stuiver & Reimer 1993) from the conventional ^{14}C datings or datings obtained from the pollen stratigraphical marker levels (*) for Finnish North Karelia (Tolonen & Ruuhijärvi 1976).

Site	Sample depth, cm	Peat material	$\delta^{13}C$	^{14}C date, yr BP	Pollen date, yr BP	Most prob. date, cal. yr BP
1. A0	290–295	PrEqB,H3	–29.4	9 40±100	~ 9000	10030
A0	295–300	PrEqB, H3	–29.5	8130±150	~ 9000*	10030
2. B100	100–105	LErS, H8	–28.9	3120±100	~ 3 000	3390
B100	105–110	LErS, H8	–29.2	4970±100	~ 5500	5760
3. B400	145–150	ErS, H9	–	–	–	–
4. B600	160–165	LErS, H8–9	–28.8	6450±100	~ 7000	7410
B600	165–170	LErS, H8	–29.4	7020±120	~ 7500	7910
5. B800	115–120	ErS, H8–9	–	–	–	–
6. B1000	145–150	LPrC, H6–7	–	–	–	–
7. C200	45–50	C, H7–8	–	–	~ 4500	4280
8. C400	45–52	C, H7–8	–29.9	3840± 90	~ 4500	4280
9. C500	65–70	C, H7–8	–29.8	4060±110	~ 4500	4500
C500	70–75	C, H7–8	–28.4	6140±130	~ 5500*	7050
10. Lintu	65–70	C, H7–8	–29.7	3730±100	~ 5500*	6340
Lintu	70–75	C, H7–8	–29.5	4810±110	~ 7500*	8360
11. D550E	395–400	MnEqS, H6–7	–	–	–	–
12. D550W	295–300	EqC, H5	–	–	–	–
13. D900	285–290	CSB, H8	–27.6	8900±150	~ 9000	9910
D900	290–295	CSB, H3	–28.1	9510±180	~ 9500	10580
14. D400hum	95–100	ErC, H4	–	–	–	–
15. D400hol	140–145	C, H5	–29.2	7140±110	~ 7500	7970
D400hol	145–150	C, H5	–29.3	7960±150	–	9520
16. D100	95–100	LErS, H5–6	–29.1	4140±100	~ 4000	4850
D100	100–104	LErS, H6	–28.6	4710±100	~ 5000	5500
17. Pav	185–190	ErSC, H6–7	–28.6	7530±120	~ 8200*	9240
Pav	195–200	ErSC, H6–7	–28.9	7900±120	~ 8500*	9520
18. E200	290–295	SC, H4	–28.7	8980±120	~ 9000*	9970
E200	295–300	SC, H4	–27.5	8930±160	~ 9000*	9970
19. E400	240–245	CS, H7–8	–27.6	8350±140	~ 8500*	9420
E400	245–250	CS, H7–8	–27.9	8700±160	~ 9000*	9690
20. F50	315–320	EqLCB, H3–4	–	–	–	–
21. F400	260–265	LC, H6–7	–29.7	7650±100	~ 7500	8450
F400	265–270	LC, H6	–28.3	7430±130	~ 7500	8450
22. F800	290–295	EqB, H3–4	–26.2	9260±180	~ 9000	10280
F800	295–300	EqB, H3–4	–28.6	8730±120	~ 9000	10280
23. F1200	85–90	LErC, H8–9	–	–	–	–
24. K0	75–80	ErCS, H8	–29.1	4580±110	~ 5500*	6340
25. K100	95–100	ErCS, H9	–28.4	3770± 80	~ 7500*	8360
26. L–300	80–85	LSC, H8–9	–	–	~ 5500*	6340
27. L+100	95–100	ErCLS, H9	–	–	~ 8000*	9000
28. S600	55–60	SC, H7	–	–	~ 5500*	6340
29. W600	190–195	ErSC, H7	–28.8	7160±100	~ 8250*	9260

For the chemical analysis, samples were normalized by drying at +105 °C, and then were ground in a special stainless steel peat mill and ashed in muffel oven (+450 °C). The element content of ash was analysed using an atomic absorption spectrometer (Perkin Elmer AAS-1) after treatment with mineral hot acid solution, HF + H_2SO_4, in glass carbon crucibles. Phosphorus was determined colorimetrically according to Arinushkina (1970). Silica and sulphur were determined following fusion of the samples with Na_2CO_3 at +750 °C. The results were calculated per dry mass and per *in situ* volume (by means of the bulk density measurements of the same samples).

The production ecology of *Sphagnum* mosses was studied at different mire sites (along transects B, C, D, E) representing both bog and fen vegetation and various ecological conditions. The objective was to study the production ecology of *Sphagnum* through analyses of linear increment, annual productivity and biomass of different *Sphagnum* species in varying environmental conditions. The location of each *Sphagnum* species studied is listed in Table 2. *Sphagnum subsecundum, S. fallax,* and *S. papillosum* were classified as minerotrophic species while *S. compactum, S. majus, S. angustifolium, S. balticum* and *S. fuscum* were classified as ombrotrophic species. The phytomass, shoot density and the annual increment of eight *Sphagnum* species were determined in 1993–1995, enabling the production figures to be calculated.

Table 2. Sampling location of studied Sphagnum species along transects in Patvinsuo mire system.

Species	Location
Sphagnum subsecundum	Transect C-minerotrophic string flark mire with *Carex limosa* and *C. chordorrhiza*
Sphagnum fallax	Transect E-minerotrophic site with *Carex rostrata*
Sphagnum papillosum	Transect C-minerotrophic string flark site with *Carex limosa* and *C. chordorrhiza*
	Transect D-minerotrophic string flark site with *Eriophorum vaginatum*;
	Transect E-minerotrophic hummock site with *Carex rostrata*
Sphagnum compactum	Transect D-ombrotrophic ridge hollow site with *Eriophorum vaginatum*
Sphagnum angustifolium and *S. balticum*	Transect B-ombrotrophic hummock hollow site with *Andromeda polifolia* and *Eriophorum. vaginatum*
Sphagnum majus	Transect D-ombrotrophic flooded hollow with *Eriophorum vaginatum* and minerotrophic string flark with *Scheuchzeria palustris*
Sphagnum fuscum	Transect B-ombrotrophic ridge hollow site with *Andromeda polifolia, Eriophorum vaginatum* on ridges and minerotrophic hummock site with *Andromeda polifolia*

The modified ”cranked wire” method by Clymo (1970) as described by Lindholm (1983) was used to measure annual linear increment. In the autumn, several plots were selected and thread was tied around 50 *Sphagnum* moss species approximately one centimetre from the apex of the plant. After one year, the amount of moss above the thread was cut and the annual linear increment was measured. To calculate the weight increment of *Sphagnum* moss species, 100 one centimeter pieces of each *Sphagnum* species (with five replicas) and 100 living *Sphagnum* species with capitulum were weighed and dried. The amount of linear growth was then multiplied by the weight of the 100 one centimeter pieces to determine the weight increment of 100 *Sphagnum* moss individuals. The annual increment of 100 *Sphagnum* species was divided into the weight of 100 living individuals and the percent ratio of the annual production depending on the species biomass was calculated. The *Sphagnum* biomass was determined by dividing the *Sphagnum* moss species into living and decayed pieces. Visual identification of living pieces was conducted on 100 individuals of each of the eight *Sphagnum* species.

5 RESULTS AND INTERPRETATION

5.1 Production ecology of *Sphagnum*

Sphagnum mosses are important in the plant cover of mesotrophic, oligotrophic and ombrotrophic mires and can be characterized by the unlimited apical growth of stems and the permanent dying-out of the lower parts. Mosses begin to grow immediately after the snow melts and the linear growth increment depends on moss species, groundwater level, climatic conditions and nutrient content. Data on *Sphagnum* moss increments are applied by researchers as the criteria of the habitat estimation and thus, the degree of correspondence to habitat conditions. The annual increment of *Sphagnum* mosses in different geographical regions are presented in a number of publications (Clymo 1970, 1973, Grabovik 1991a, b, Ilomets 1981, Lindholm 1990, Lindholm & Vasander 1990, Moore 1989). The data published showed a significant variation in the annual increment of the same *Sphagnum* mosses in different regions. For instance, the increment of *Sphagnum* mosses in tundra and forest-tundra zones is obviously less than in the middle and southern taiga zones. Investigations also showed significant linear increment variations of different *Sphagnum* species within one plant community in separate years. Also, large variations in increment data were seen during one growing season in plant communities with differences in water-mineral regimes.

Sphagnum mosses have shown maximum increment growth under optimal temperature and humidity conditions (Grabovik & Antipin 1982, Grabovik 1991a, Maksimov 1982, Botch and Kuzmina 1984). In northwest Russia, *Sphagnum* mosses appear to have the largest amount of growth in May (Maksimov 1982, Boch & Kuzmina 1984). Data on linear increment growth and productivity of *Sphagnum* mosses in Finland is poor; however, information is available for several *Sphagnum* species from Suurisuo, southern Finland (Lindholm & Vasander 1990).

The linear increment of *Sphagnum fallax*, *S. papillosum*, *S. angustifolium*, *S. balticum* and *S. majus* determined in this study was insignificant and varied from data presented by Lindholm and Vasander (1990). The insignificant linear increments could be explained by the unfavourable weather conditions during the growing season (Table 3). Meteorological conditions between 1993 and 1994 varied and also deviated from the long term averages (Table 3). Biomass data for *S. balticum* and *S. majus* varied from 633 to 948 g m^{-2}, while *S. fallax* and *S. papillosum* varied between 421 to 884 g m^{-2}. The biomass of *S. fuscum* ranged between 666 to 827 g m^{-2}.

Table 3. Meteorological data from 1993, 1994 and long term averages (Ilmatieteen laitos 1991, 1994, 1995).

Year	Annual precipitation, mm	May-August precipitation, mm	May-August average temperature, °C
1993	665	314	12.1
1994	741	186	12.6
Average long-term data	644	267	12.8

According to Pjavchenko (1967), the annual production of *Sphagnum* consists of 30 % of the biomass. Results from Patvinsuo showed large differences in annual production amount based on habitat moistening. Annual production of *S. fuscum* was 17–38 % of its biomass, *S. fallax* and *S. papillosum* 15–46 % and *S. majus* 10–33 % respectively.

5.2 Successional trends of mire vegetation

5.2.1 Transect A

An oligotrophic tall-sedge fen occupies the study area in transect A (Figure 6). The present mire surface is sloping towards southeast with a gradient about 4/1000. The modern plant communities at site 1 (Figure 6) are composed of *Carex rostrata, C. limosa, Eriophorum vaginatum* in the field layer and *Sphagnum fallax* in the moss layer (Appendix 1). A thin detritus gyttja overlies basal sand indicating terrestrialization of shallow water bodies. *Carex* dominant peats characterize the peat strata (Figure 8). Phase I of site 1 can be described as a meso-eutrophic shallow water environment dominated by *Phragmites australis, Schoenoplectus lacustris, Equisetum fluviatile, Sphagnum squarrosum, S. teres* and *Menyanthes trifoliata* (Figure 7). Minor amounts of *Carex rostrata* (20 %) and *Calliergon* spp. (5 %) were also present. The basal grass-Bryales-peat was dated at 9040 ± 100 B.P (Table 1). Phase II is characterized by a decline in *Phragmites australis* from 50 % to less than 5 %. While *Menyanthes trifoliata* and *Equisetum fluviatile* also decline, both species remain at about 15 %. *Sphagnum squarrosum* and *S. teres* are not present in Phase II; however, *Carex rostrata* is the dominant species in Phase II at 40 %. Other *Carex* species like *C. lasciocarpa, C. limosa* and *C. chordorrhiza* also become present (10 %). *Betula pubescens* and *Scheuchzeria palustris* remains are also found in Phase II (15 %). The influx of *Carex* species and *Betula* indicate that the environment became more oligotrophic, possibly wet flarks. In Phase III, only minor amounts of *Phragmites australis* and *Equisetum fluviatile* remains are seen while *Menyanthes trifoliata* declined to about 10 %. *Carex* species are dominant in Phase III, especially *C. rostrata* (35 %), while *Scheuchzeria palustris* is also largely present (20 %). Minor amounts of *Sphagnum fallax* are found in this phase. An oligotrophic fen environment characterizes Phase III. Phase IV is dominated by a large increase in *Sphagnum fallax* (from 5 % to 70 %), while all other species decline to between 5–10 %. *Calliergon* spp. also reappears in Phase IV.

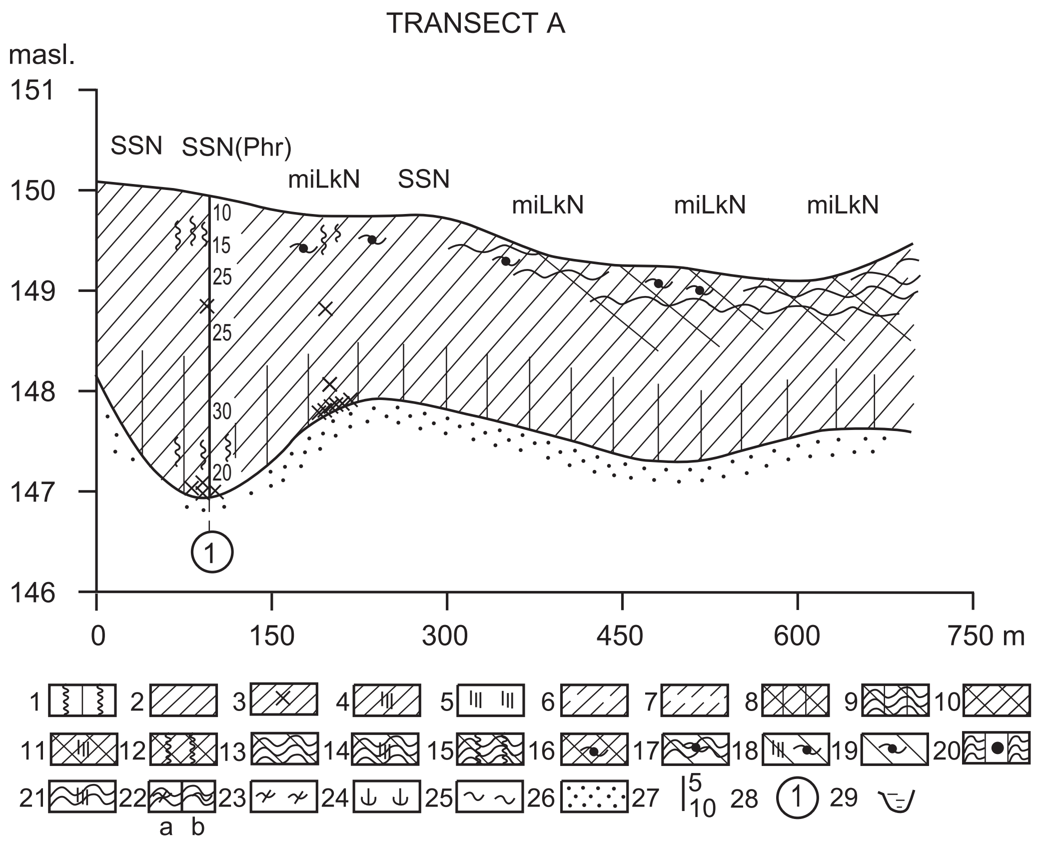


Figure 7. A cross-section of transect A, Patvinsuo. The profile shows the distribution of peat types. Explanation: Eutrophic peats 1–7: 1 = wood-reed, 2 = sedge, 3 = sedge-horsetail, 4 = sedge-Scheuchzeria, 5 = Scheuchzeria, 7 = Bryales (Scorpidium, Warnstorfia, Calliergon etc.). Mesotrophic peats 8–19: 8 = wood-sedge, 9 = wood-cottongrass, 10 = sedge, 11 = sedge-Scheuchzeria, 12 = sedge-reed, 13 = cottongrass, 14 = cottongrass-Scheuchzeria, 15 = cottongrass-reed, 16 = sedge-Sphagnum, 17 = cottongrass-Sphagnum, 18 = Scheuchzeria-Sphagnum, 19 = Sphagnum. Ombrotrophic peats 20–25: 20 = Pine-cottongrass, 21 = cottongrass-Scheuchzeria, 22 = cottongrass-Sphagnum (a = with Sphagnum fuscum, b = with hollow species of Sphagnum), 23 = fuscum peat, 24 = angustifolium peat, 25 = Sphagnum hollow peat. 26 = sand, 27 = degree of decomposition %, 28 = peathole no., 29 = water. The mire types are marked over the profiles using abbreviations. Explanation of abbreviations in Table 4.

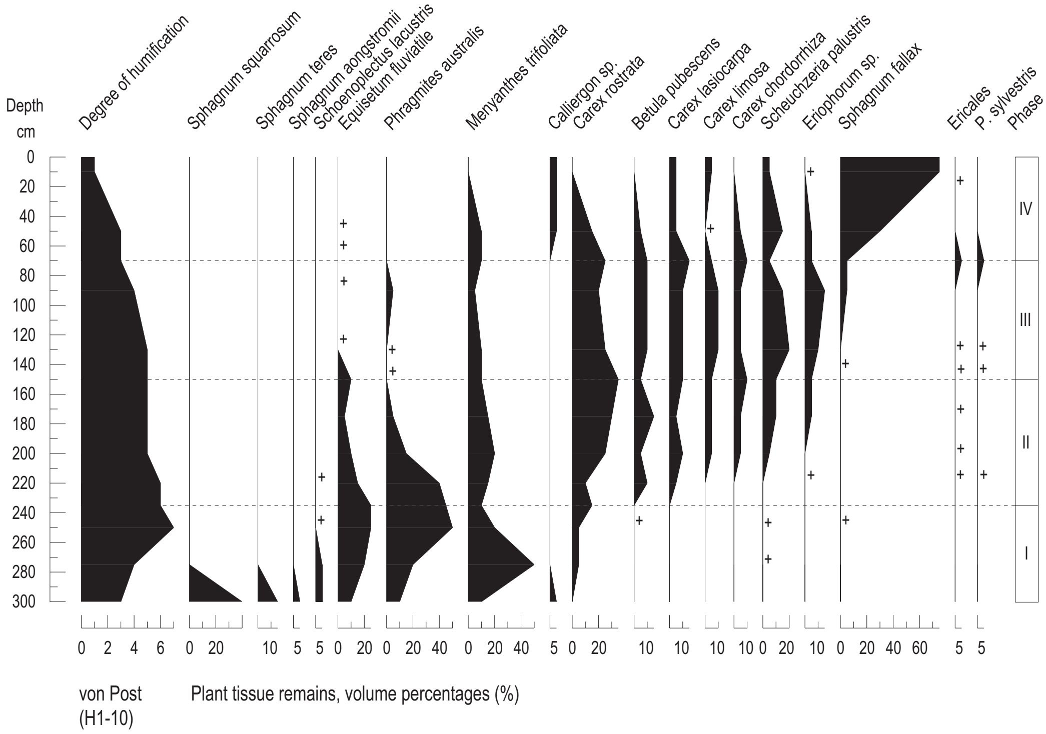


Figure 8. Macrofossil diagram for study site 1, transect A in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of humification is in von Post's (1922) 10-grade scale (H1–10).

Table 4. The following abbreviations were used for transects A–S to indicate the mire site types.

KaN	=	S*phagnum papillosum* fen
miLkN	=	minerotrophic short sedge fen
SSN	=	tall sedge fen
SSN(Phr)	=	tall sedge fen with reed (*Phragmites*)
ORiN	=	oligotrophic flark fen
meRiN	=	mesotrophic flark fen
RaLkN	=	± ombrotrophic short sedge fen with *Sphagnum fuscum*
OLkN	=	treeless short sedge (or cottongrass) bog
RaRiN	=	flark fen with *S. fuscum* hummocks
RaLkNR	=	mosaic of pine bog and ombrotrophic short sedge bog
KeR	=	ridge - hollow bog complex
KeR-KuN	=	ridge - hollow bog - hollow bog
RaR	=	*Sphagnum fuscum* pine bog
RaIR	=	tall shrub pine bog with *S. fuscum*
IR	=	tall shrub pine bog (ombrotrophic)

5.2.2 Transect B

The northern part of Patvinsuo mire is an ombrotrophic ridge-hollow pine bog (Figure 6; transect B). After a narrow minerotrophic lagg with some birches, willows and cottongrass, the transect runs over an eccentric bog with a general slope of about 1.4/1000. Bare mud bottom surfaces and surfaces with *Rhynchospora alba* are common in the middle part of the mire. Surrounding peat banks (kermi ridges) were up to one meter high at places.

The general stratigraphy of this eccentric bog is typical for North Karelian bogs (Tolonen 1967). Ombrotrophic *Sphagnum* and *Eriophorum vaginatum* peats prevail and the minerogenic strata restricted in the lower part of deposits are thin (Figure 9). *Equisetum* and limnic peats are missing and the whole mire basin was paludified from former dry heath forests. Paludification is evident in distinctly identifiable podzol horizons beneath the peat across the whole transect (Turunen *et al.* 1999). The lowest lying area was paludified first, over 7000 years BP and then advanced upslope according to the "law" of Gustavsson (1909). The mineral bottom of the mire is undulating with small separate depressions at 153–154 m asl. Paludification of the western part of the kettle (Figure 10A) started from widespread minerotrophic *Pinus sylvestris-Phragmites australis* communities (Phase I; 150–125 cm), which were confined to water tracks running from a small water body north of transect B to the southwestern part of the mire. In Phase II (125–65 cm), the percentage of *Eriophorum vaginatum* macrofossils greatly increased from around 10 % in Phase I to over 40 %. Inversely, the percentage of *Pinus* and *Phragmites* remains were reduced to 10 % and 20 %, respectively. The *Pinus* and *Phragmites* plant communities had a minerotrophic water-mineral regime despite the more stagnant and poor nutrient conditions. At 55 cm, the remains of minerotrophic species disappeared and the peat deposit was mainly composed of ombrotrophic *Sphagnum* species such as *S. fuscum, S. magellanicum* and *S. angustifolium.*

Paludification of the central part of the mire started about 7900 cal. years BP (site 4, Table 1). At study site 5 (Figure 10B), the bottom layer (Phase I; 120–100 cm) of the minerotrophic peat was composed of *Eriophorum vaginatum* and *Phragmites australis* macrofossils mixed with *Carex*, changing upwards into ombrotrophic woody-*Eriophorum* peat. The bottom layer also contained evidence of several fires occurring in the *Eriophorum vaginatum* and *Phragmites australis* community. From 80 cm to the peat surface, there was evidence of ombrotrophic paleocommunities dominated by *Sphagnum angustifolium* and *S. fuscum*.

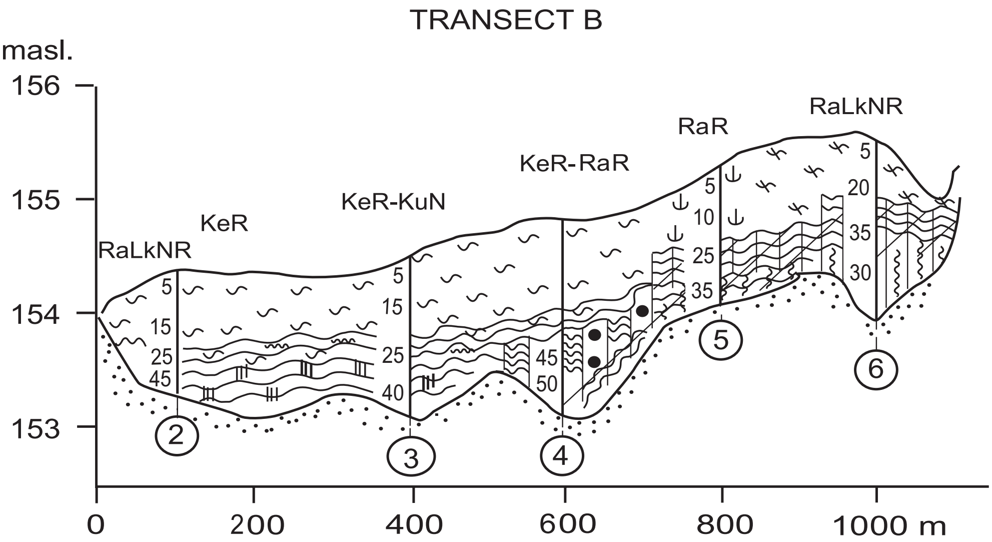
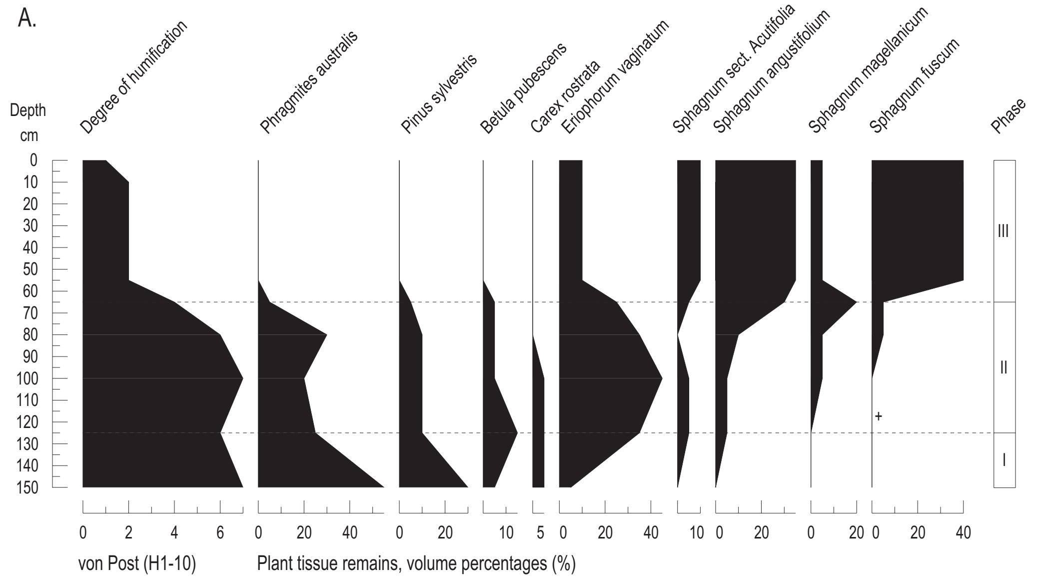


Figure 9. A cross-section of transect B, Patvinsuo. The profile shows the distribution of peat types. Explanation of symbols in Figure 7. The mire types are marked on the profiles using abbreviations. Explanation of abbreviations in Table 4.

The eastern section of the kettle (Figures 11A and 11B) was paludified later than the central parts, around 5700 cal. years BP. The first established communities were poor minerotrophic *Eriophorum-Scheuchzeria* mixed with *Carex rostrata* and *C. lasiocarpa*. During Phase II, *Carex* species disappeared quickly as the ombrotrophic stage of mire development became predominant around 3300 cal. years BP. Modern hollow communities in sites 2 and 3 are composed of moist *Scheuchzeria-Sphagnum* species (Appendix 2). Sites 2 and 3 both had visible fire horizons within the peat layers (135–150 cm). At the eastern margin of the kettle (Figure 11B), a short-term minerotrophic stage with *Carex* species became an ombrotrophic herbaceous *Sphagnum magellanicum* and *Eriophorum vaginatum* dominated stage, which later included both *Sphagnum majus* and *S. balticum*. In Phase III, *Sphagnum majus* (20-50%), *S. balticum* (20%) and *Scheuchzeria palustris* (20–55 %) communities dominated. *Sphagnum majus* gradually declined to less than 10 % while *Sphagnum balticum* increased from 20 % in Phase III to 90 % in Phase IV. *Sphagnum balticum* is dominant through Phase IV and comprises the main species in the modern vegetation community. Unfortunately, the stratigraphy of the hummocks was not studied, so it is impossible to reconstruct all the stages of the hummock formation.



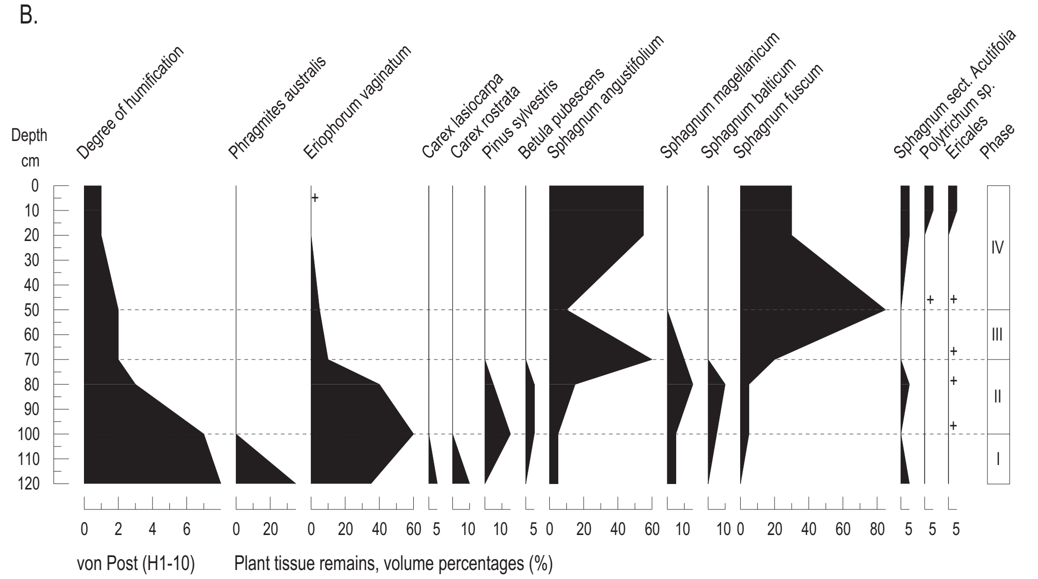
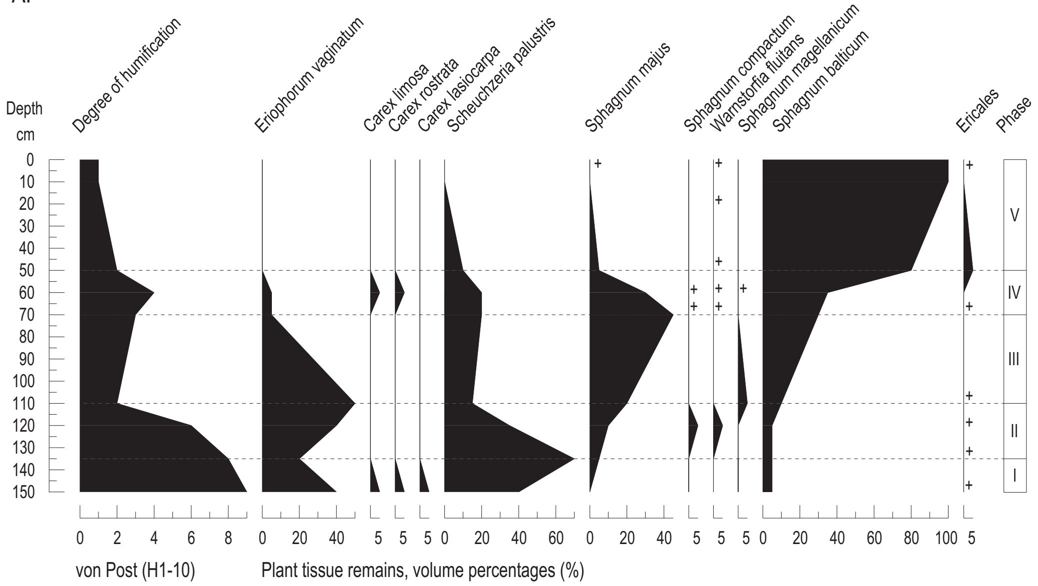


Figure 10. A) Macrofossil diagram for study site 6 and B) for study site 5, transect B in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of humification is in von Post's (1922) 10-grade scale (H1–10).

A.



B.

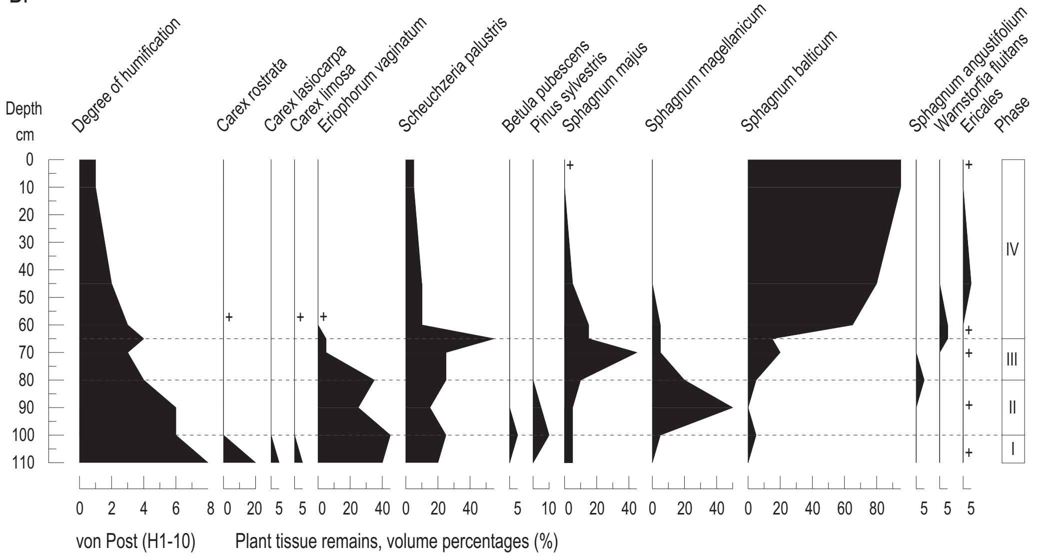


Figure 11. A) Macrofossil diagram for study site 3 and B) for study site 2, transect B in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of humification is in von Post's (1922) 10-grade scale (H1–10).

5.2.3 *Transect C*

The central part of Patvinsuo between Suomunsaari and Teretinniemi is occupied by a very wet, slightly mesotrophic flark fen (Figure 6, transect C). The aapa mire is comprised mainly of *Carex-Scheuchzeria* flarks (80–90 % of the mire area) with 10–20 % of the area dominated by narrow *Carex* and *Molinia* strings with *Sphagnum papillosum*. Further flora include *Utricularia intermedia, Viola palustris, Peucedanum palustre, Pedicularis palustris* and *Sphagnum subsecundum*.

The general slope of the fen is only about 0.95/1000 and at many places much less. Sedge peats dominate the stratigraphy of the very shallow fen (Figure 12) that initiated after the paludification of forest soil about 7000 cal. years ago. During the first 3000 years, mire fires recurred at about 100 year intervals. The initial community at site 7 was composed of *Carex rostrata* and *C. chordorrhiza* (Figure 13A) while *C. rostrata* and *C. cespitosa* were dominant (50–75 %) around site 9 (Figure 13B; Phase I). The presence of *C. cespitosa* is evidence of an alluvial community, as confirmed by a high ash content in the basal peat samples (25–69 %). The ash composition was mainly SiO_2 and Al_2O_3. Peat accumulation was possibly slow because of the good drainage and flow around the area. As well, decomposition products were intensively transported into an adjacent brook. The basal peat layer of site 9 was dated at 7000 cal. years BP and at 65–70 cm a date of 4500 cal. years BP was obtained. At site 9, Phase II vegetation is characterized by large percentages of *Carex cespitosa* (10–25 %) and *C. rostrata* (35–70 %) with minor amounts of *Equisetum fluviatile, Eriophorum* spp. and *Scheuchzeria palustris* (5 %). Due to the decrease in mineral and nutrient availability caused by water stagnation, the percentage of *Carex rostrata* declined in Phase III. However, *Scheuchzeria palustris, Carex chordorrhiza* and *C. limosa* increased forming the plant cover in the modern aapa mires (Figure 13B and Appendix 1). On low *Carex-Sphagnum* strings formed over the last 1000 years, *Sphagnum fallax* and *S. papillosum* have been most common, while on flarks *S. majus* and *S. annulatum* have spread and are most prolific.

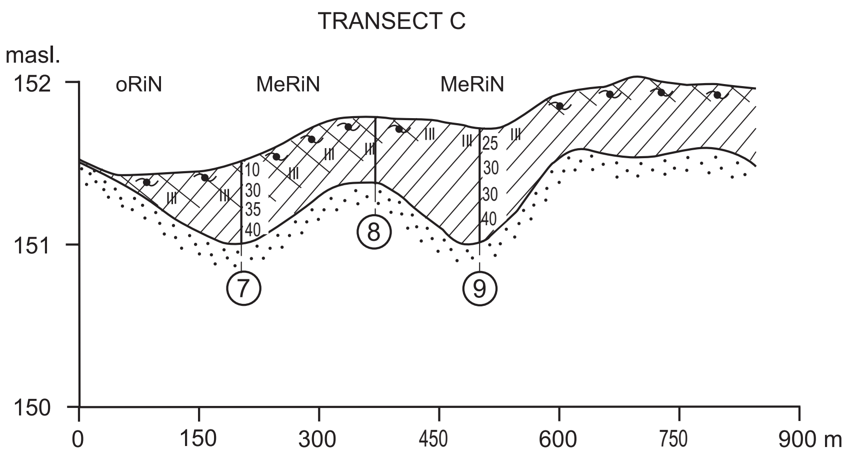


Figure 12. A cross-section of transect C, Patvinsuo. The profile shows the distribution of peat types. Explanation of symbols in Figure 7. The mire types are marked on the profiles using abbreviations. Explanation of abbreviations in Table 4.

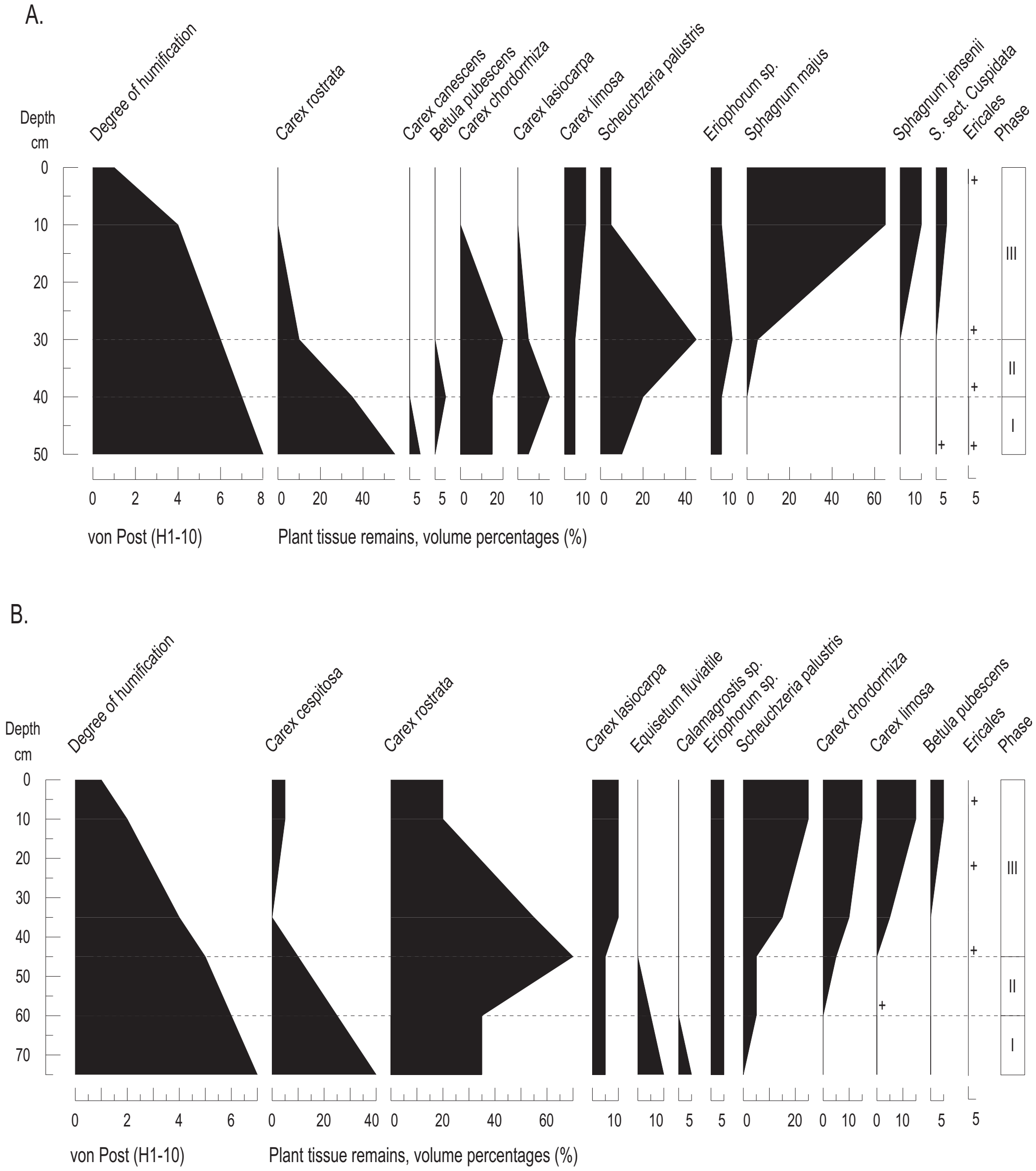


Figure 13. A) Macrofossil diagram for study site 7 and B) for study site 9, transect C in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of humification is in von Post's (1922) 10-grade scale (H1–10).

5.2.3.1 Transect C2

A flark fen occupies a vast area to the east of Teretinniemi (Figure 6; transect C2). The present vegetation at site 10 is formed by *Carex limosa*, *C. chorhorrhiza*, *Menyanthes trifoliata*, *Utricularia intermedia* in the field layer and *Sphagnum papillosum*, *S. angustifolium*, *S. annulatum* and *S. subsecundum* in the moss layer (Appendix 1). Following several fires, paludification began around 8000 cal. years BP. Peat accumulation has been extremely slow, with only 60–80 cm peat deposited. The slow peat accumulation is due to the loss of organic matter in repeated mire fires within the lower most 20 cm of the peat strata. Pioneer communities at site 10 were composed mainly of tall *Carex* spp. under the modern strings and under the flarks (Figures 14A and 14B, Phase I).

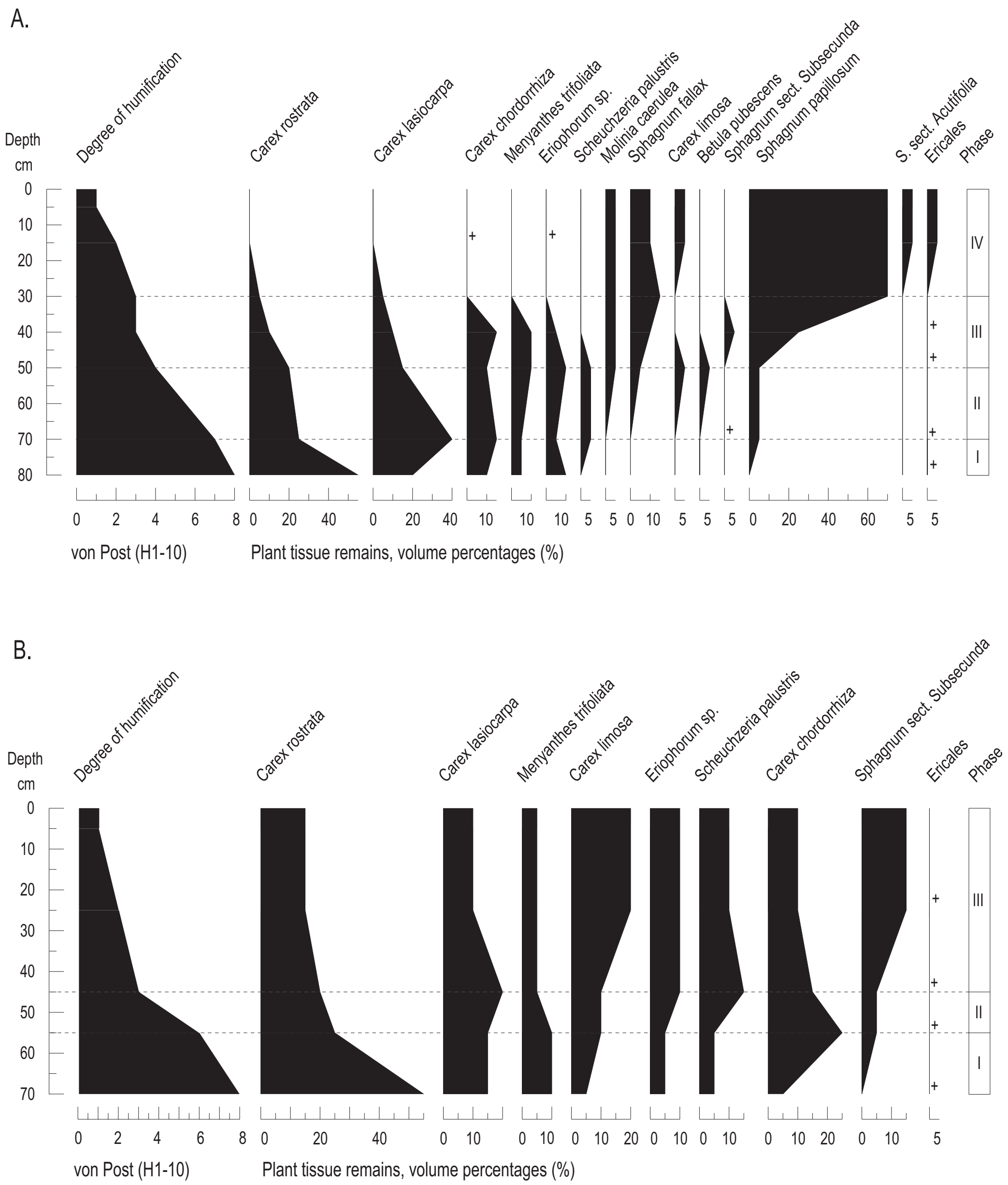


Figure 14. A) Macrofossil diagram for string in study site 10 and B) for flark in study site 10, transect C2 in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of humification is in von Post's (1922) 10-grade scale (H1–10).

Along the strings, *Scheuchzeria palustris* and *Carex* spp. declined after Phase II and were replaced by *Sphagnum fallax* and *S. papillosum. Andromeda polifolia* (included in the "Ericales" column of the diagram) and *Molinia caerulea* were minor elements of the vegetation community in Phase III. *Sphagnum papillosum* remains made up the majority of macrofossils (65%) in Phase IV with minor amounts of *Ericales* spp., *Sphagnum fallax* and *Molinia caerulea* (Figure 14A). In the flark communities, macrofossil evidence showed that more stagnant conditions became evident in Phase III with the increase of *Carex limosa, Eriophorum* spp. and *Sphagnum* sect. *Subsecunda.* At the same time, *Carex rostrata* and *C. lasiocarpa* declined to 10 % (Figure 14B).

5.2.4 Transect D

Lahnasuo occupies the western part of the Patvinsuo mire complex, and is comprised of a string-flark pattern characteristic of large aapa mires of the middle boreal type; strings are low and mainly covered by *Eriophorum vaginatum*, *Carex lasiocarpa*, *Molinia caerulea* and *Sphagnum papillosum*. Only the central and lower part of the basin is minerotrophic, with the wide margin and upslope parts clearly ombrotrophic (Kivinen & Tolonen 1972). The investigated transect runs across the middle part of the basin and the vegetation is a mixed minerotrophic, ombrotrophic flark fen with *Sphagnum fuscum* strings (compartment 962 in Leivo *et al.* 1992).

The mire stratigraphy and initiation were studied at six sites (Figures 6 and 15). The deepest kettles within the mire were filled with shallow water about 10500 cal. years BP and currently, a small relict pond fills the deepest part of the mire. The lacustrine stage was observed in the stratigraphic section sampled at the eastern shore of the small pond (Figure 6, site 11; Figure 16A). *Equisetum fluviatile* and *Menyanthes trifoliata* are predominant in the field layer and *Sphagnum* sect. S*ubsecunda* dominate the bottom layer. Remains of *Typha* spp., *Scorpidium scorpioides* and *Warnstorfia* spp. were found in the sapropelled basal peat (Phase I). Succession of the lake vegetation to mire plant communities was probably rapid because macrofossil evidence consisted of approximately 15 % *Betula pubescens* remains during Phase I. During Phase II, *Equisetum fluviatile* and *Menyanthes trifoliata* dominated the field layer and *Sphagnum* sect. S*ubsecunda* the bottom layer. Remains of *S. papillosum* and *S. majus* were also found, representing oligotrophic conditions. The vegetation changed to a *Carex rostrata, C. lasiocarpa, Eriophorum vaginatum, Sphagnum papillosum* community in Phase III. The successional trend continued with *Pinus-Eriophorum-Sphagnum* communities along with ombrotrophic *Sphagnum* mosses (*S. fuscum, S. angustifolium* and *S. magellanicum*) in the basal layer (Phase IV). The areal extent of the small relict lake has varied due to water level fluctuations. The *Scheuchzeria palustris-Eriophorum vaginatum-Sphagnum compactum* community probably resulted from increased water levels (Phase V). As well, *Carex rostrata*, a minerotrophic species, appeared again in the vegetation composition. The flooded Phase V may have continued for an extended period of time, becoming a drier *Eriophorum-Sphagnum* community with *Sphagnum magellanicum* dominating the moss layer (Phase VI). The uppermost peat layers were formed through paludification and macrofossil remains indicate that the paleocommunity was dominated by *Eriophorum vaginatum-Sphagnum fuscum*. The same species represent the modern mire vegetation community.

On the western shore of the small primary pond, the thickness of the peat deposit was approximately one metre less than on the eastern shore (Figure 6, site 12; Figure 16B). Paludification began from the *Carex-Equisetum* community (Phase I), which quickly became an *Equisetum-Sphagnum-Scorpidium* community with individual *Betula pubescens* trees (Phase II). As a result of a significant lowering of lake levels, hydrophilic and minerotrophic species, such as *Equisetum fluviatile, Menyanthes trifoliata, Scorpidium scorpioides* and *Warnstorfia* spp. were eliminated. An oligotrophic community consisting of *Eriophorum-Sphagnum papillosum* was formed (Phase III). In Phase IV, the mire vegetation appears to have consisted of *Pinus-Eriophorum-Sphagnum* species with smaller amounts of *Betula pubescens* and *Carex rostrata*. At 80 cm, macrofossils of minerotrophic species disappeared and the site passed into an ombrotrophic stage of development dominated by *Pinus sylvestris, Eriophorum vaginatum, Sphagnum angustifolium* and *S. fuscum* (Phase V). The modern mire vegetation is similar to Phase V with fewer *Pinus sylvestris* trees.

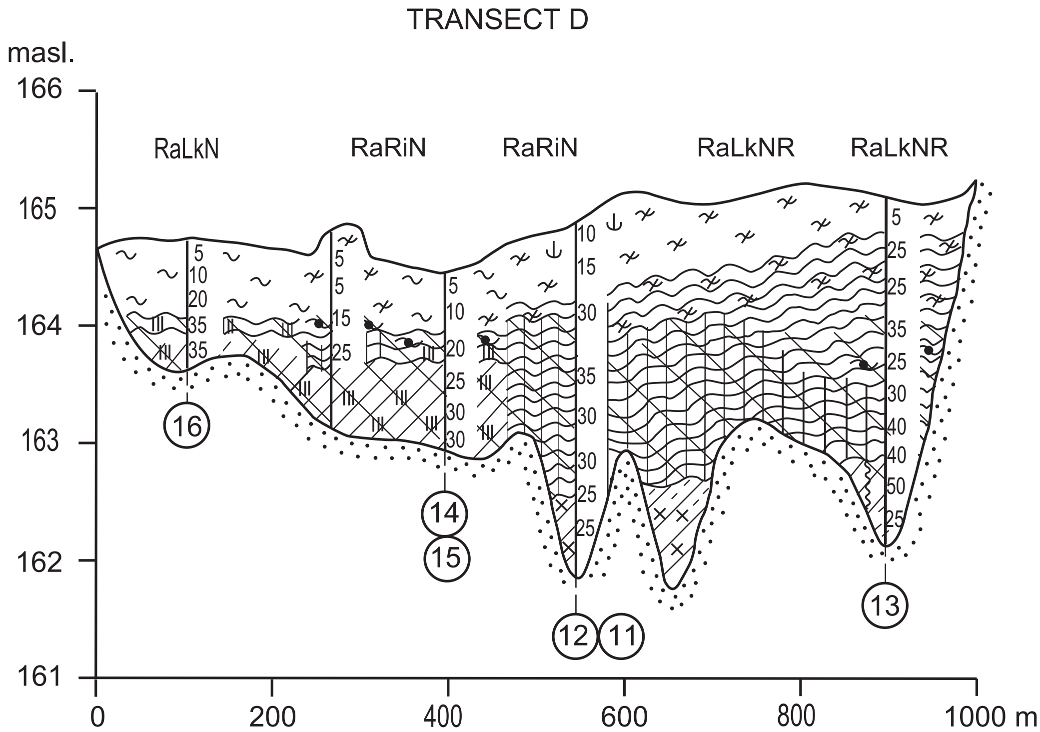
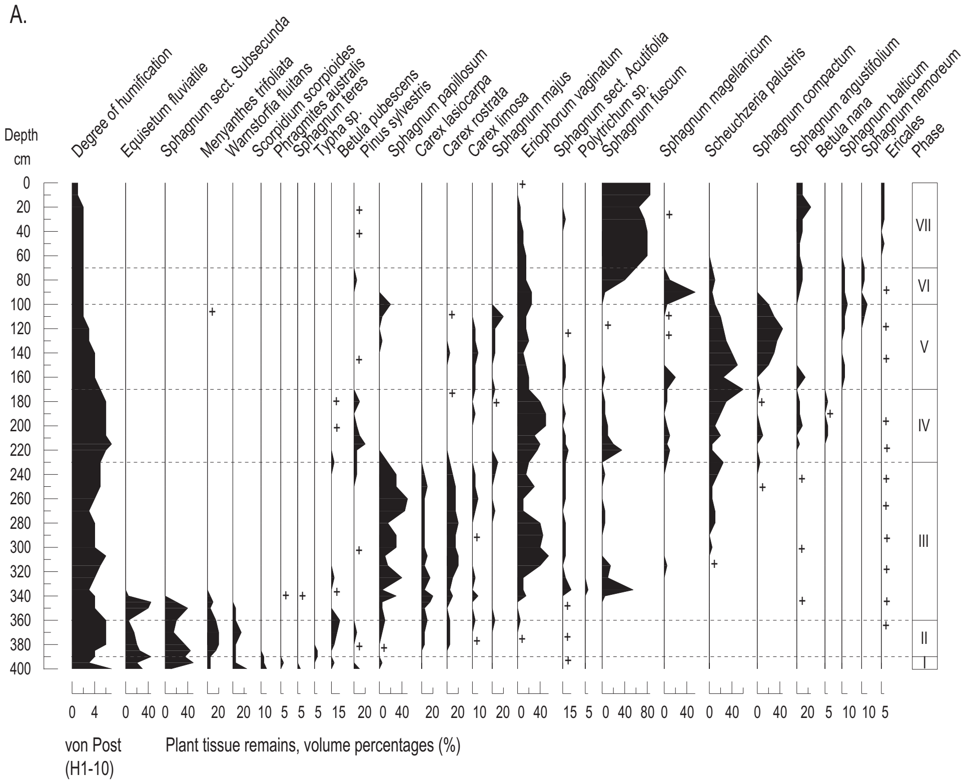


Figure 15. A cross-section of transect D, Patvinsuo. The profile shows the distribution of peat types. Explanation of symbols in Figure 7. The mire types are marked on the profiles using abbreviations. Explanation of abbreviations in Table 4.



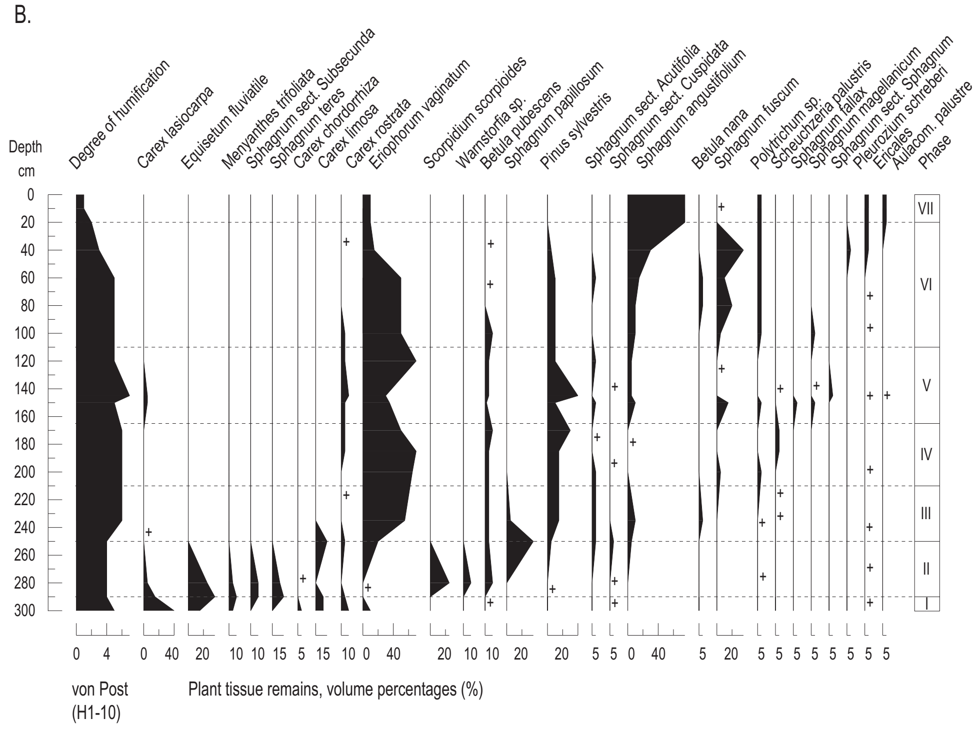
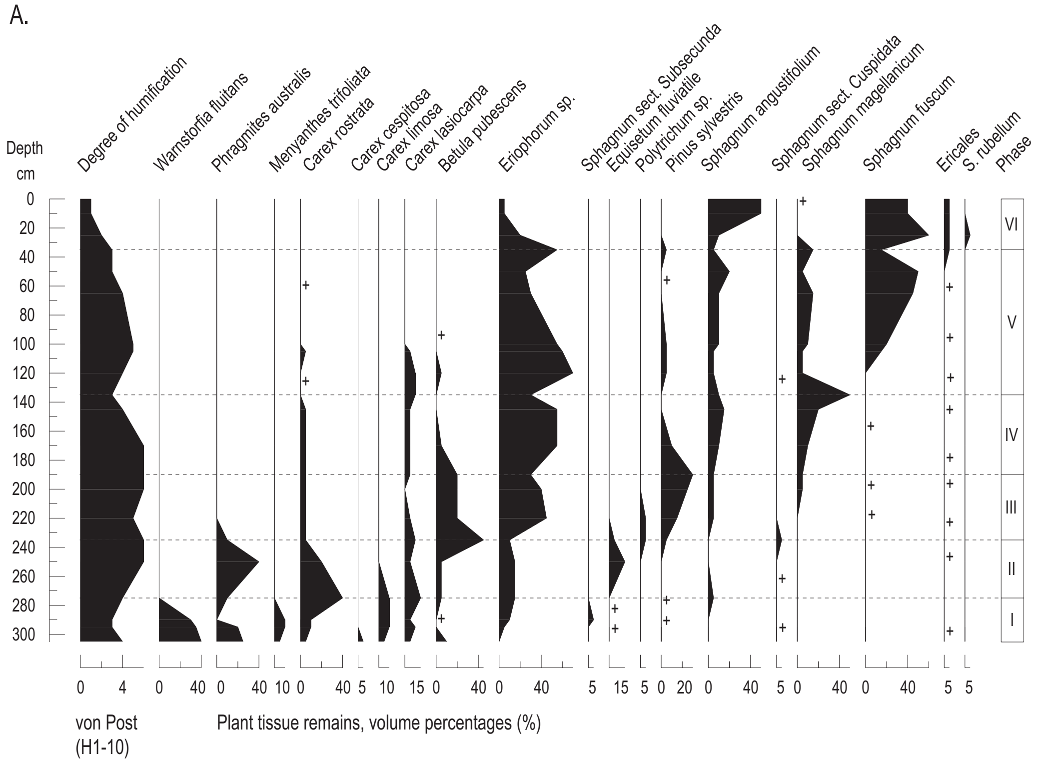


Figure 16. A) Macrofossil diagram for study site 11 and B) for study site 12, transect D in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of humification is in von Post's (1922) 10-grade scale (H1–10).

The modern plant communities at site 13 (Figure 6) is composed of *Eriophorum vaginatum, Calluna vulgaris, Rubus chamaemorus, Andromeda polifolia* in the field layer and *Sphagnum fuscum, S. angustifolium* in the moss layer (Appendix 2). This eastern part of Lahnasuo is the oldest part of the mire system. At site 13, terrestrialization may have begun about 10500 cal. years BP from a small relict shallow water body overgrown with *Phragmites australis*, *Warnstorfia fluitans, Menyanthes trifoliata* and *Carex* spp. (Figure 17A, Phase I). Cladoceran *Chydorus sphaericus* (some *C. piger* was also seen) was very frequent with *Alona* spp. and many Chiromidae remains. *Myriophyllum spicatum* pollen grains were also found along with *Ephedra distachya* at 290 cm. At 285–295 cm, the number of Bryales spores was very high (up to 28 % of the sum of AP+NAP+spores). During the initial phase of terrestrialization, over 30 cm of eutrophic peat accumulated. The percentage of *Carex rostrata* and *Eriophorum* spp. increased in Phase II (40 % and 20 %), while *Betula pubescens* and *Pinus sylvestris* increased in Phase III (40 % and 30 %). Between 220–235 cm, several charcoal layers were found in the peat. Evidence of fires was also found between 150–190 cm, at which time an oligotrophic *Pinus-Eriophorum-Sphagnum magellinicum, S. angustifolium* community was predominant (Phase IV). At 100 cm, macrofossil evidence of minerotrophic species disappeared from the paleorecord. As a result, Phase V vegetation consisted of *Sphagnum fuscum, S. magellinicum, S. angustifolium, Eriophorum* spp. with a few *Pinus* trees (<10 %).

The central area of the transect is occupied by an almost ombrotrophic ridge-hollow mire system. The *Sphagnum fuscum* hummocks are rather young. The stratigraphy of the top 100 cm of the *S. fuscum* hummocks at site 14 was studied (Figure 17B). The hummocks developed from small tussocks formed by *Carex lasiocarpa, C. rostrata* and *Eriophorum* spp. within a moist *Scheuchzeria-Carex* community (Figure 17B, Phase II). *Eriophorum vaginatum* and *Sphagnum fuscum* appeared on the higher hummock areas. From 60–80 cm, few *Sphagnum* moss remains were found; however, from 50–60 cm *Eriophorum vaginatum-Sphagnum papillosum-S. fuscum* communities became dominant. *S. fuscum* was dominant in the upper layers (0–50 cm) of the peat profile.

The present vegetation at site 15 (Figure 6) is formed by *Carex limosa, Rhynchospora alba, Trichophorum cespitosum* in the field layer and *Sphagnum papillosum, S. compactum* in the moss layer (Appendix 2). This central portion of Lahnasuo mire was initiated in the boreal chronozone about 9500 cal. years BP and was dominated (60 %) by *Carex rostrata* (Figure 18A, Phase I). The mire initiation probably resulted from primary mire formation (Huikari 1956). *Scheuchzeria palustris* and *Carex lasiocarpa* increased while *Carex rostrata* declined through Phase II. The existence of *Eriophorum vaginatum* in the early stages of mire development indicate poor water-mineral conditions. As well, the abundance of *Scheuchzeria palustris* (40 %) is indicative of a stagnant water regime. The basal 80 cm of *Scheuchzeria-Carex* peat was replaced by *Carex-Eriophorum vaginatum-Scheuchzeria palustris* peat, which accumulated during Phases II and III. During Phase III, *Sphagnum balticum* and *S. papillosum* appear in the macrofossil record for the first time. A shift in oligotrophic nutrient conditions during Phase II may have triggered the



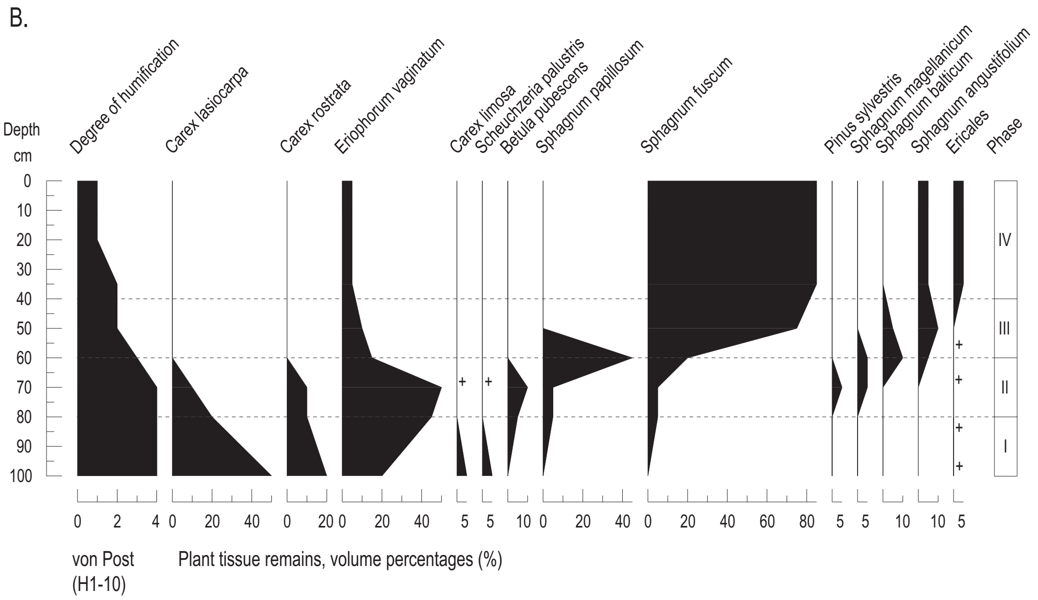


Figure 17. A) Macrofossil diagram for study site 13 and B) for study site 14 (hummock), transect D in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of humification is in von Post's (1922) 10-grade scale (H1–10).

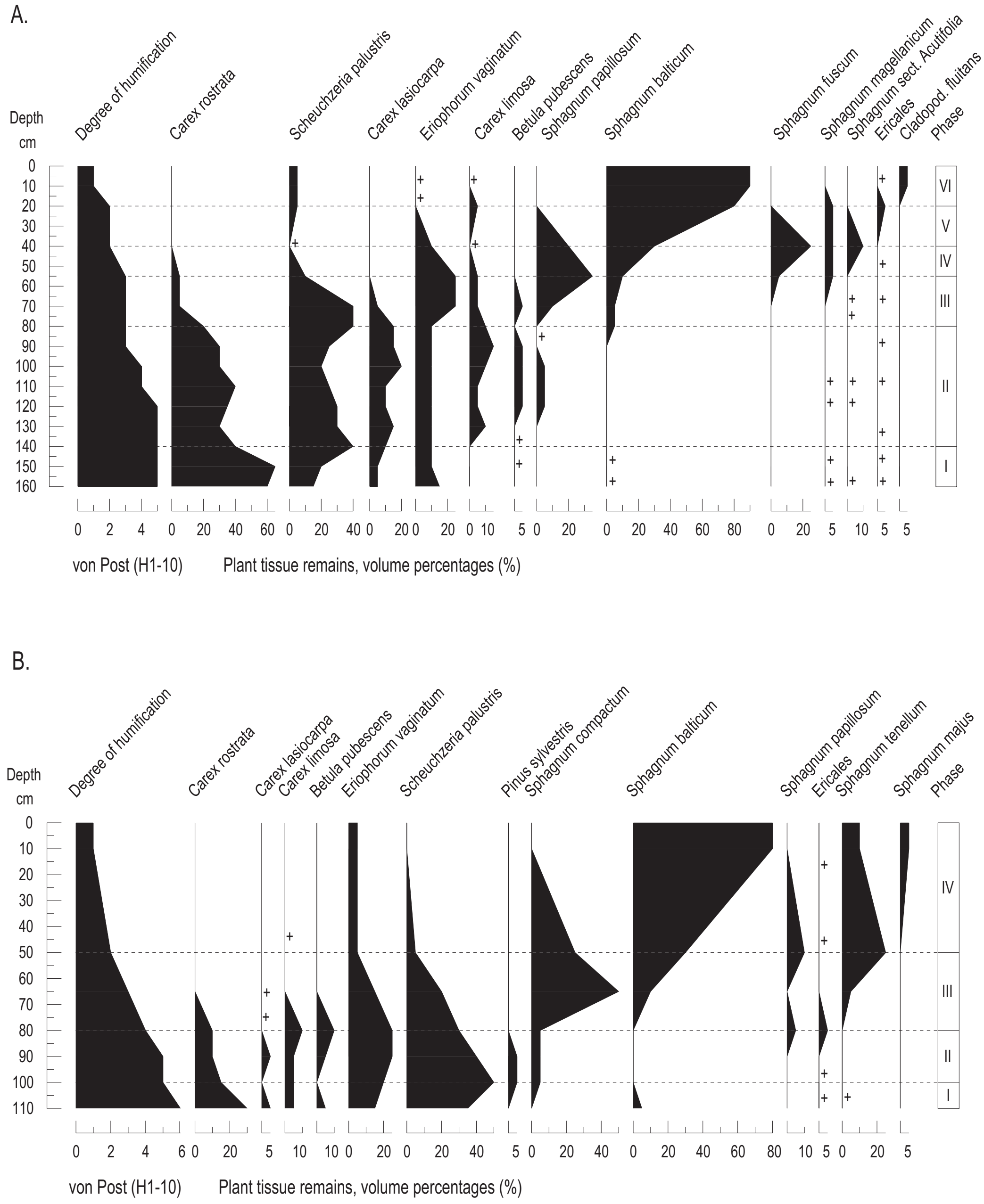


Figure 18. A) Macrofossil diagram for study site 15 (hollow) and B) for study site 16, transect D in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of humification is in von Post's (1922) 10-grade scale (H1–10).

growth of both *Sphagnum balticum* and *S. papillosum*. The gradual decline of *Carex* spp. in Phase III to about 10 % confirms the change in nutrient conditions. As well, from 100–110 cm five charcoal layers were identified in the peat profile. *Sphagnum papillosum* (30 %) and *Eriophorum vaginatum* (20 %) began to dominate the paleocommunity during Phases III and IV. The percentage of *Scheuchzeria palustris* diminished from 40 % to <10 % in Phase IV, especially after the appearance of *Sphagnum fuscum*. Gradually, *S. balticum* became dominant (60 %) with minor amount of *S. fuscum* (20 %) as the mire entered into an ombrotrophic stage (Phase V). Due to increasing humidity, *S. fuscum* was completely replaced by *S. balticum* and the modern hollows were formed. In Phase VI, *S. balticum* dominates (80 %) in the hollows with *Carex limosa* and *Scheuchzeria palustris* of secondary importance (10 %).

The modern plant communities of the study site 16 (Figure 6) are dominated by *Sphagnum balticum, S. papillosum, Eriophorum vaginatum, Carex limosa* and *Scheuchzeria palustris* (Appendix 2). Paludification of the western margin began following a fire within an oligotrophic *Carex-Scheuchzeria* community around 5500 cal. years BP (Figure 18B). During Phase I, only approximately 10 cm of peat accumulated over 1500 years. The importance of *Carex rostrata* in the paleorecord decreased (30 % to 10 %) while *Eriophorum vaginatum* began to increase in Phase II to 25 % and *Scheuchzeria palustris* (25–50 %) remained dominant. From 80–65 cm, an increase in *S. compactum* and *S. balticum* was evident in the macrofossil record. All minerotrophic species declined significantly around 65 cm and Phase IV can be described as ombrotrophic *Eriophorum vaginatum-Sphagnum compactum-S. papillosum-S. balticum* community.

5.2.5 Transect E

The Surkansuo mire is located in a depression west of Lake Suomunjärvi (Figure 6, transect E). Surkansuo mire is mainly an ombrotrophic ridge-hollow pine bog with some oligotrophic fen parts, especially around a brook in the eastern part of the mire. The initiation and developmental history of Surkansuo mire are not connected to the Patvinsuo mire system. The Surkansuo kettle stretches in a west-east direction and runoff flows into Lake Suomunjärvi. The study transect runs at a right angle to the slope, which is 1.5/1000. The mire mineral bottom is situated 165–166 m asl (Figure 19).

The modern plant communities at site 18 (Figure 6) are composed of *Sphagnum fuscum, S. balticum, Rubus chamaemorus* and *Eriophorum vaginatum* (Appendix 2). At site 18 (Figure 20A), terrestrialization started about 10000 years cal. BP (Table 1) with the development of *Carex lasiocarpa* (30 %) and *C. rostrata* (20–50 %) communities with small amounts (10 %) of Bryales mosses (*Scorpidium scorpioides, Calliergon* spp.) and *Equisetum fluviatile* in the bottom layer (Phase I). From 208–290 cm, *Alisma plantago-aquatica* was found together with leaf spines/hairs of *Utricularia* and *Hippophaë rhamnoides*. Cladoceran *Chydorus sphaericus* was frequent in this detritus material. The Bryales community was replaced by *Scheuchzeria palustris* and *Eriophorum vaginatum* in Phase II, as a result of rapid changes in water-mineral conditions, resulting in meso-oligotrophic conditions. Minerotrophic sedge species were absent about 175 cm below the peat surface. Phase III composition was dominated by *Scheuchzeria palustris* (20–50 %) and *Eriophorum vaginatum* (20–50 %), and by ombrotrophic *Sphagnum papillosum* (5–20 %) and *S. balticum* (5–10 %). Numerous fire horizons were evident throughout the peat deposits, indicating that fires had regularly occurred during the history of the area. During Phase IV, oligotrophic short *Carex-Sphagnum* vegetation was present. *Sphagnum balticum* increased from 10–65% during Phase IV, while *S. papillosum, S. majus* and *S. magellanicum* were present in minor amounts (5–30 %). Phase V is a modern ombrotrophic *Scheuchzeria-Sphagnum* community with a distinguishable 50 cm thick peat layer consisting mainly of *Sphagnum balticum* remains (60–80 %).

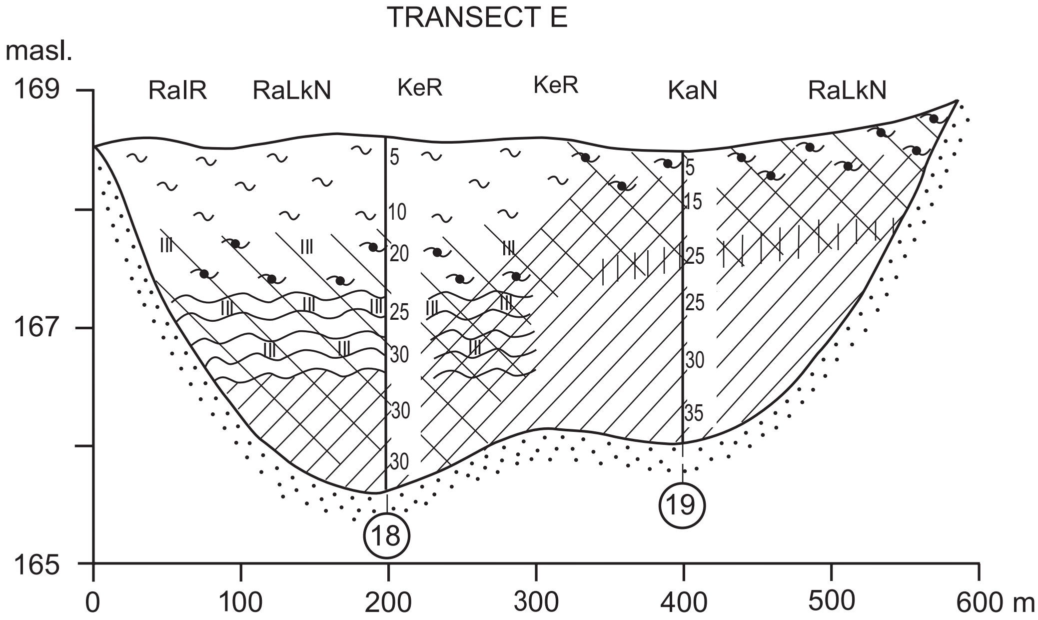


Figure 19. A cross-section of transect E, Patvinsuo. The profile shows the distribution of peat types. Explanation of symbols in Figure 7. The mire types are marked on the profiles using abbreviations. Explanation of abbreviations in Table 4.

At study site 19 (Figure 6), the present vegetation is formed by *Scheuchzeria palustris, Carex rostrata, C. limosa* in the field layer and *Sphagnum majus, S. fallax, S. balticum* in the bottom layer (Appendix 1). Paludification began through the development of *Betula-Phragmites-Carex* communities (10000 cal. years BP) at nearly the same time as site 18. The initial community at site 19 was composed of *Betula pubescens* (10 %), *Phragmites australis* (15 %) and dominated by *Carex lasiocarpa* (50 %) (Figure 20B). *Phragmites* declined and Phase II consisted mainly of *Carex rostrata* (25 %) and *C. lasiocarpa* (30–60 %) with about 10 % *Betula pubescens*. During Phase III (100–50 cm), within the tall *Carex* community, *Scheuchzeria palustris, Carex limosa* and *Sphagnum majus* increased but species such as *Betula pubescens, Carex lasiocarpa* and *C. chordorrhiza* gradually declined. The species composition indicates that the mire became an oligotrophic fen. The uppermost 50 cm was mainly composed of oligotrophic *Sphagnum majus* (75 %) remains with *Scheuchzeria palustris*, *Carex rostrata* and *Sphagnum fallax.*

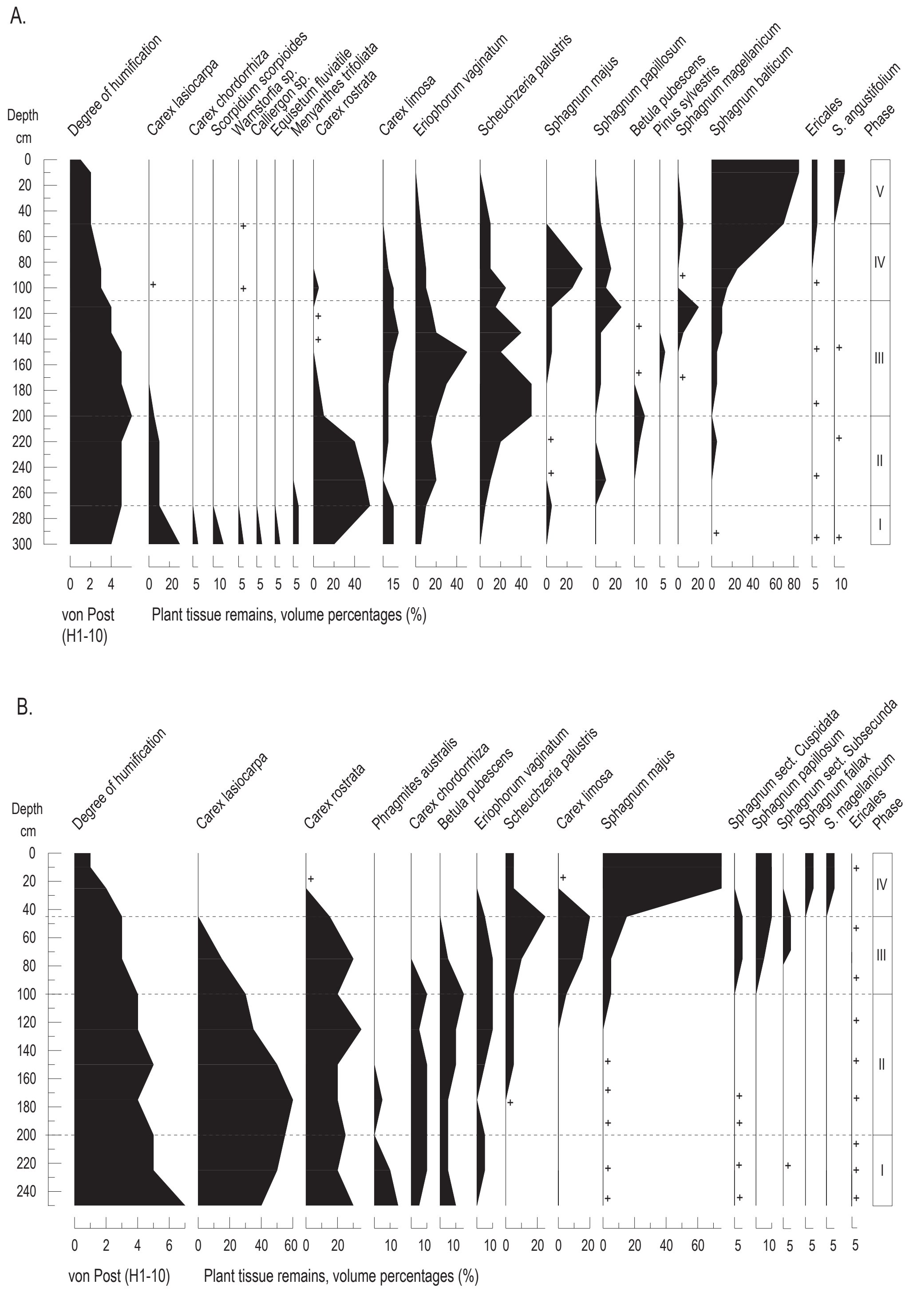


Figure 20. A) Macrofossil diagram for study site 18 and B) for study site 19, transect E in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of humification is in von Post's (1922) 10-grade scale (H1–10).

5.2.6 *Transect F*

The northwestern kettle of the Patvinsuo mire system is an eccentric ridge-hollow pine bog sloping in a north-south direction. The study transect approximately follows the general gradient of the slope, which is about 2/1000. The overall stratigraphy of this eccentric bog indicates a gradual impoverishment from rich fen peats (Bryales) to mesotrophic sedge fens with *Menyanthes* and *Scheuchzeria* to a cotton-grass dominated stage and finally to a *Sphagnum* bog (Figure 21). The height of the mire mineral bottom is about 158–160 m asl. Several original pools in the area are relicts of the post-glacial lake present during the beginning of Holocene. Stratigraphic transect F (Figure 6) indicates that paludification started at different times and from various initial plant communities.

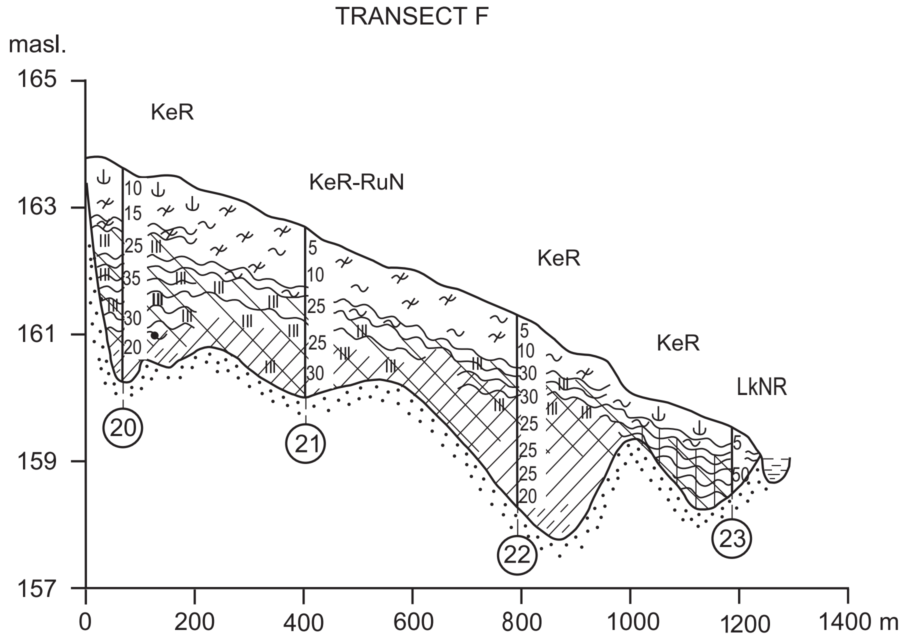


Figure 21. A cross-section of transect F, Patvinsuo. The profile shows the distribution of peat types. Explanation of symbols in Figure 7. The mire types are marked on the profiles using abbreviations. Explanation of abbreviations in Table 4.

At site 22 (Figures 6 and 22A), a Holocene lake basin is evident. The basin began to terrestrialize about 10 300 cal. years BP and was occupied by a meso-eutrophic *Equisetum fluviatile* (15 %), *Scorpidium scorpioides* (40 %) community that was replaced by mesotrophic *Carex lasiocarpa* (40–80 %) in Phase II. Phase II lasted a few thousand years and 130 cm of *Carex* peat accumulated during this phase. A change in nutrient status resulted in the replacement of the mesotrophic sedge community with an oligotrophic *Scheuchzeria palustris-Eriophorum vaginatum* (40–60 %) community with *Sphagnum majus* and *S. balticum* in Phase III. During Phase IV, 40 cm of *Scheuchzeria-Sphagnum* peat accumulated. The percentage of *Sphagnum balticum* (40 %) and *S. majus* (35 %) increased in the hollows. The beginning of ombrotrophic conditions was seen at 50 cm with remains of *S. fuscum*

(30 %) and *S. angustifolium* (20–30 %, Phase V). The modern hollow vegetation of the northwestern kettle mire is dominated by *S. balticum* (40 %) and *S. angustifolium* (35 %) in the bottom layer, with minor amounts *Eriophorum vaginatum* (>10 %) in the field layer (Appendix 2).

The present vegetation at site 21 (Figures 6 and 22 B) is composed of *Sphagnum balticum, S. fuscum, Eriophorum vaginatum, Andromeda polifolia, Scheuchzeria palustris* and *Chamaedaphne calyculata* (Appendix 2). At this site, paludification of a small depression started from a meso-oligotrophic *Carex* community dominated by *C. lasiocarpa* (60 %) and *C. rostrata* (15 %) about 8500 cal years BP (Figure 22B, Phase I). Paludification appears to have been initiated by a fire evident from a 5 cm charcoal layer. Phase I changed to a poor *Scheuchzeria* (30–70 %) community in Phases II and III, during which time all minerotrophic species gradually were eliminated. Ombrotrophic *Eriophorum-Sphagnum* vegetation (*Sphagnum majus, S. balticum* and *S. papillosum*) replaced the *Scheuchzeria* community (Phases IV and V). Drier conditions with ombrotrophic *Eriophorum-Sphagnum* species, including *Sphagnum balticum* (40 %) and *S. fuscum* (35 %) in the bottom layer, are evident in Phase V. Phase V was replaced by the modern hummock community dominated by *S. fuscum* (65 %), *S. angustifolium* (15 %) and *S. rubellum* (20 %) in the moss layer (Phase VI).

Study site 20 (Figures 6 and 23A) is located near the shore of a small primary pond and contains relicts of lacustrine origin within a 4 m thick peat deposit. The bottom layer of sapropelled peat consisted of *Phragmites* macrofossils (40 %) with small amounts (<10 %) of *Schoenoplectus lacustris, Menyanthes trifoliata* and various sedges which grew along the shallow shore of the lake. A few *Betula pubescens* trees may have been located along the shore as indicated by the *Betula* woody remains (5 %) found in the basal peat (Phase I). During peat accumulation and terrestrialization of the lake, *Phragmites australis* declined (10 %) and the percentage of *Menyanthes trifoliata* (30 %), *Carex limosa* (15 %), *C. lasiocarpa* (25 %) and *Sphagnum teres* (5 %) increased (Phase II). A substantial increase in *Equisetum fluviatile* (10–55 %) through Phase III and the replacement of Phase II with a meso-eutrophic *Carex*-Bryales community consisting of *Scorpidium scorpioides* and *Warnstorfia* spp. was evident in Phase IV. There was a clear change in the water-mineral regime 275 cm below the mire surface. Gradually, a meso-oligotrophic *Carex-Sphagnum* community was formed (Phase V). Bryales mosses and *Menyanthes trifoliata* declined and *Eriophorum vaginatum, Scheuchzeria palustris* and *Sphagnum papillosum* began to dominate the plant composition from Phase V. Phase V changed to include oligotrophic species like *Pinus sylvestris* and *Betula pubescens* with a short *Carex* community (Phase VI). Further vegetation succession included the increase of ombrotrophic *Sphagnum* species (Phase VII). In Phase VII, the percentage and significance of *Scheuchzeria palustris* increased from 20 to 40 % and the remains of *Eriophorum vaginatum* gradually reduced from 60 to 20 %. A drier, oligotrophic *Pinus-Eriophorum* community followed and the remains of minerotrophic plant species were absent at 75 cm, indicating that ombrotrophic conditions (Phase VIII) became dominant. Ombrotrophic species currently characterize the modern mire vegetation. Further, the water table of the remaining small lakes has risen as a result of peat accumulation processes.

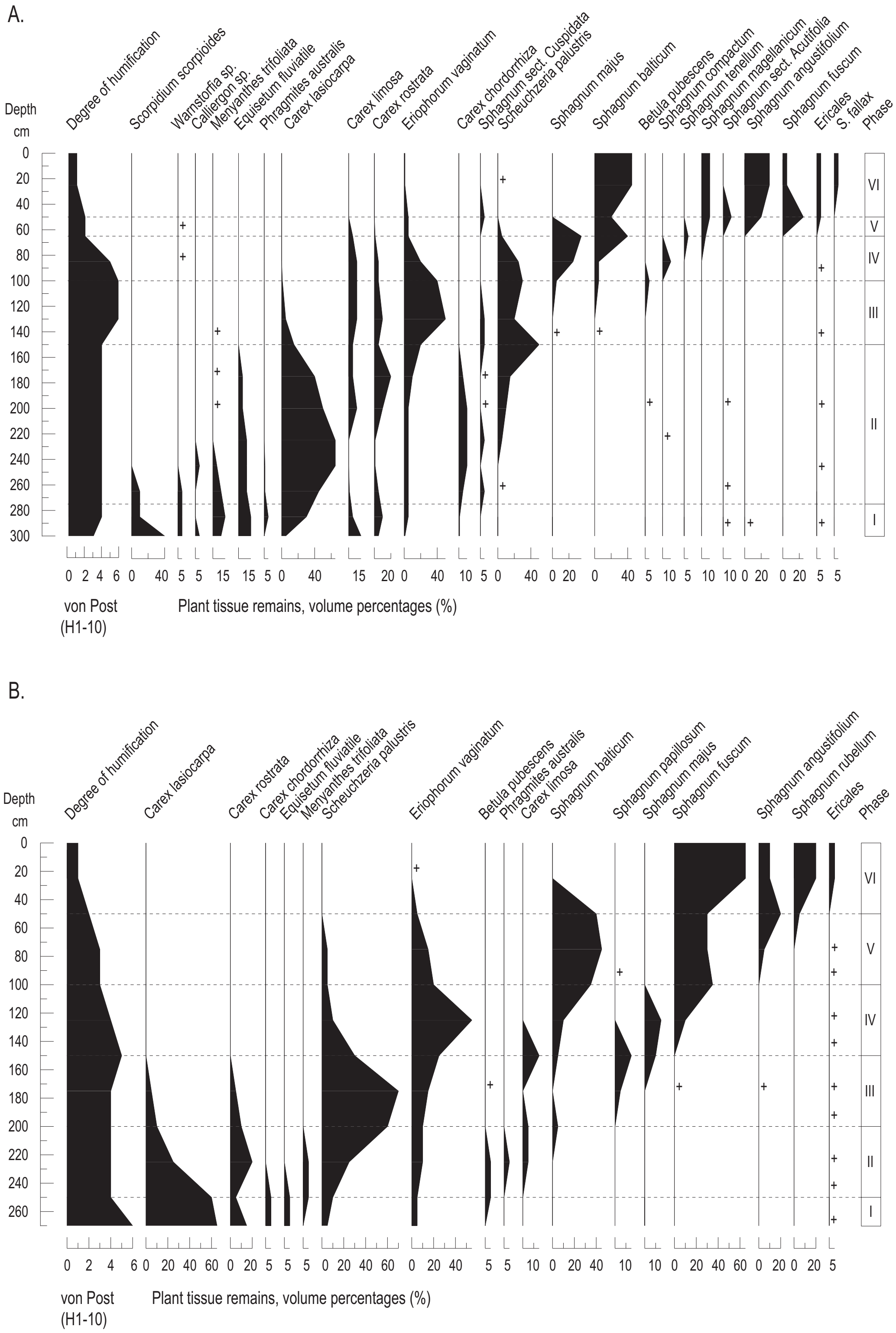


Figure 22. A) Macrofossil diagram for study site 22 and B) for study site 21, transect F in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of humification is in von Post's (1922) 10-grade scale (H1–10)

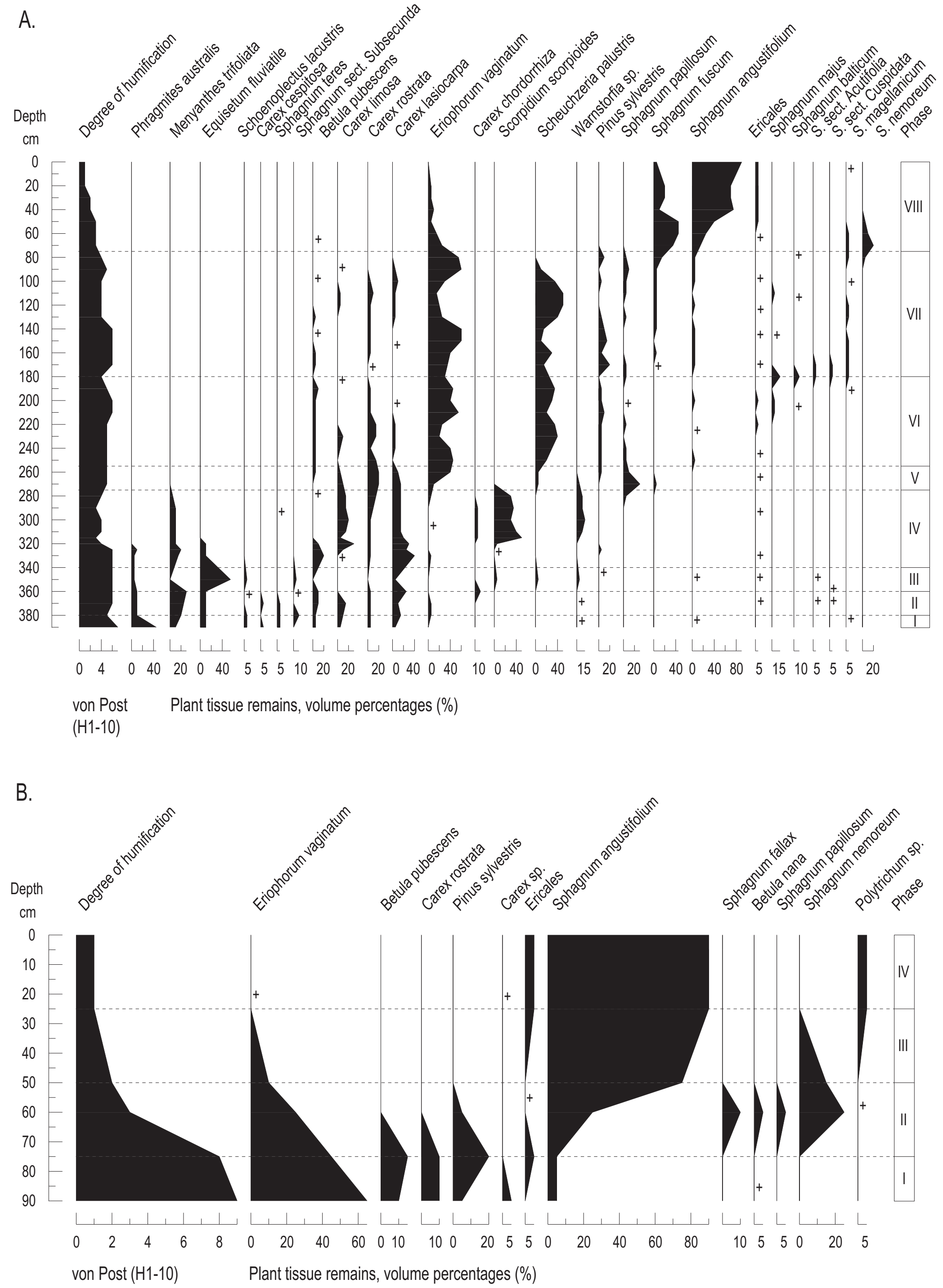


Figure 23. A) Macrofossil diagram for study site 20 and B) for study site 23, transect F in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of humification is in von Post's (1922) 10-grade scale (H1–10).

The ombrotrophic stage of the northwestern kettle (Figures 22A–23B) is rather young (perhaps from sub-atlantic period), because the layer of ombrotrophic peat begins from 125–75 cm. The permanence of the minerotrophic stage of the mire was due to a constant water source from both the adjacent mineral soil and groundwater from the mineral bottom of the mire. At the shallowest part of the mire, located along the Nälämänjoki, only the uppermost 30 cm consists of ombrotrophic *Sphagnum* and *Eriophorum-Sphagnum* peats (Figure 23B). At this site, the initial mire vegetation was rather poor despite being minerotrophic with abundant *Eriophorum vaginatum* and *Carex rostrata*.

5.2.7 Transect W

The transect runs over the upper ombrotrophic margins of an aapamire southeast of Iso Maksimansaari (a mineral soil island). The eccentrically patterned bog area has a verge slope of 2.8/1000, which is a bit steeper than the minerotrophic fens in the mire complex. On the upper margin, *Sphagnum fuscum* pine bogs prevail while the lower part is occupied by an almost treeless ridge-hollow complex. The bottom soil is humic sand originating from the ancient forest floor (Figure 24). The area paludified about 9300 cal years ago and was densely forested for the next 4000 years according to ^{14}C and pollen chronology. At all coring sites, very numerous (35–60) fire horizons were found in this peat section. Clearly, the early stages were minerotrophic (*Phragmites, Equisetum, Carex* and Bryales) but turned into a more oligotrophic *Eriophorum vaginatum*-sedge fen (*Sphagnum papillosum*) and finally to *Sphagnum fuscum-S. angustifolium* bog. The degree of decomposition gradually decreases from H7–9 in the very bottom to weakly decomposed H1–3 at the surface 0–70 cm. At site W300m (300 m SE of the starting point W0 of the transect), however, the basal Bryales-*Carex* peat is more weakly decomposed than the above peats.

The present vegetation at site 29 (Figure 6) is formed by *Eriophorum vaginatum, Andromeda polifolia* and *Scheuchzeria palustris* in the field layer and *Sphagnum balticum, S. angustifolium, S. fuscum* and *S. tenellum* in the moss layer (Appendix 2). Paludification began about 9300 cal years BP. The initial community (Figure 25) was composed of *Carex* spp. (over 90 %) with small amounts of *Phragmites* and *Equisetum* spp. (Phase I), indicating that this stage was minerotrophic. The vegetation changed to a *Scheuchzeria, Sphagnum balticum, S. compactum* and *Eriophorum vaginatum* community in Phases II and III. The plant remains composition indicates that the mire became oligotrophic and a decline in *Carex* spp. from 90 % to <10 % confirms the change in nutrient conditions. A shift in oligotrophic nutrient conditions during Phase II may have triggered the growth *Sphagnum balticum*. During Phase IV, *Scheuchzeria* and *Eriophorum vaginatum* dominated the field layer and *Sphagnum balticum* the bottom layer. Remains of *S. papillosum, S. compactum, S. annulatum* and *S.* cf. *majus* were also found. The dominance of *S. balticum* (90 %) is recorded in the upper layer (Phase V, 0–50 cm) of the peat profile. In Phase V, small amounts of *Scheuchzeria, Sphagnum annulatum, S. tenellum, S. compactum, Warnstorfia fluitans* and nanolignids were found.

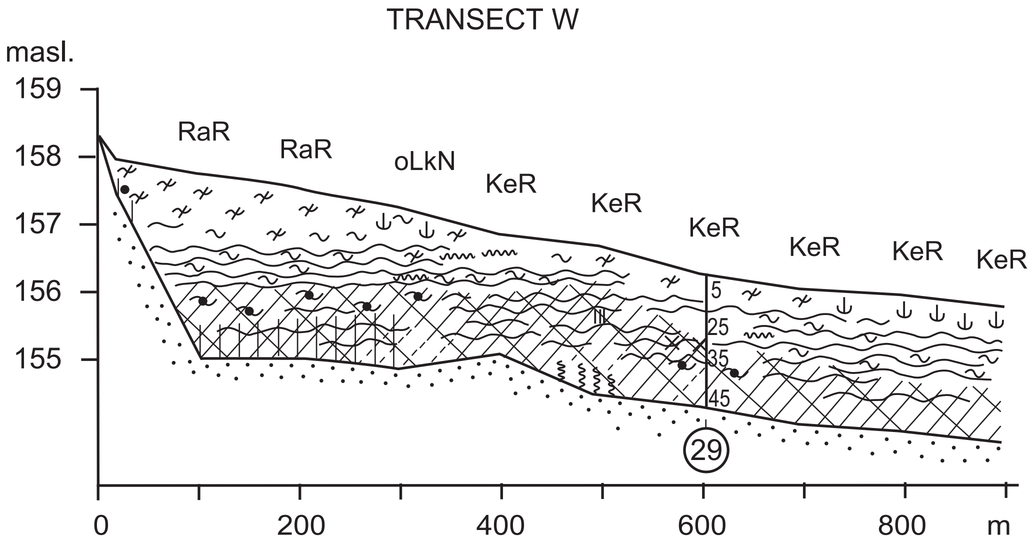


Figure 24. A cross-section of transect W, Patvinsuo. The upper profile shows the distribution of peat types. Explanation of symbols in Figure 7. The mire types are marked on the profiles using abbreviations. Explanation of abbreviations in Table 4. The lower profile shows degree of decomposition (1–10) according to von Post (1922).

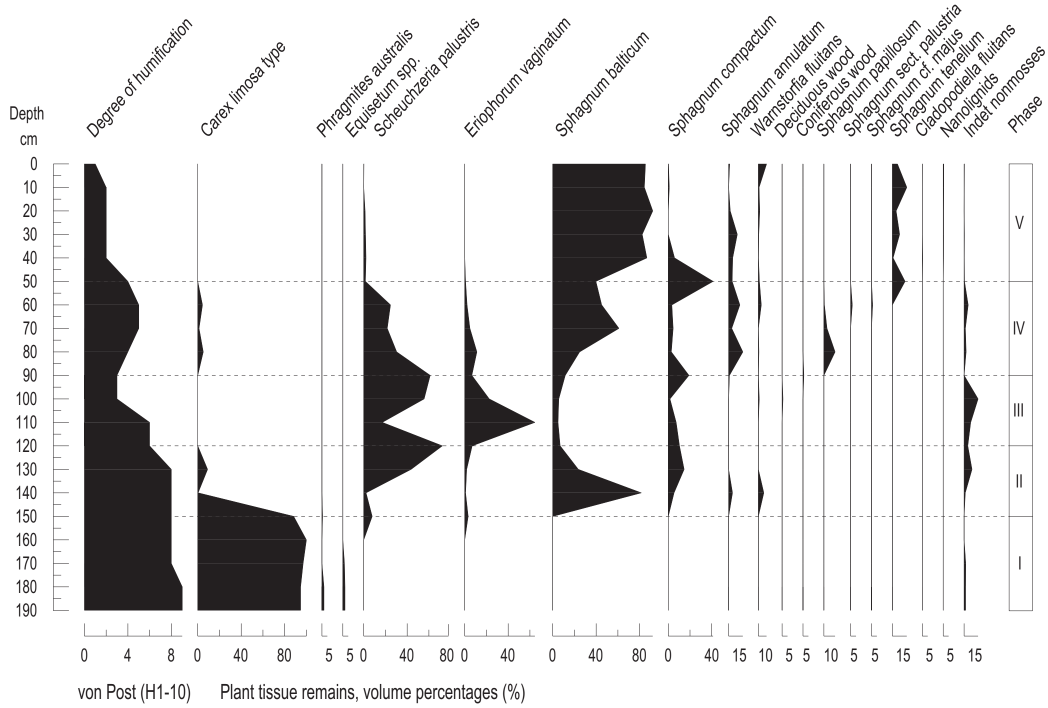


Figure 25. Macrofossil diagram for study site 29, transect W in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of decomposition is in von Post's (1922) 10-grade scale (H1–10).

5.2.8 *Transect S*

The wide aapamire complex west and southwest of Hulkkonen (a mineral soil island) was studied along transect S (Figures 6 and 26). Walking in the direction of the slope (which is about 2.6/1000) was impossible due to the wide elongated water flarks (rimpis). Flarks were comprised of *Menyanthes trifoliata, Equisetum fluviatile, Utricularia intermedia* and sedges. *Carex lasiocarpa* and *Eriophorum vaginatum* predominated the low and relatively broad strings. *Molinia caerulea* was present only on places and plenty of reed (*Phragmites australis*) was found at site S600m. *Sphagnum pulchrum* was found at S300m, and the dominate moss species were *Sphagnum papillosum, S. angustifolium* and S. *fallax*. The mire was initiated by paludification some 6000 to 8000 cal years ago (Table 1). The lowermost 50 cm of peat was burnt 10–20 times. The origins of the present water flarks postdate this period and can be estimated at 3000 cal years or less.

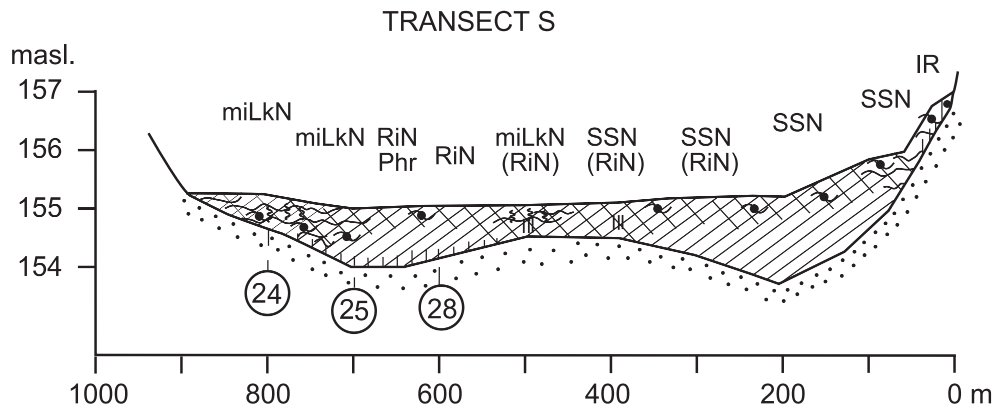


Figure 26. A cross-section of transect S, Patvinsuo. The profile shows the distribution of peat types. Explanation of symbols in Figure 7. The mire types are marked on the profiles using abbreviations. Explanation of abbreviations in Table 4.

The modern vegetation at site 24 (Figure 6) is composed of *Sphagnum balticum, S. fuscum, S. papillosum, Eriophorum vaginatum, Carex pauciflora* and *Andromeda polifolia* (Appendix 1). At this site, paludification began about 6300 cal years BP. The initial community (Figure 27A) was composed of coniferous wood, *Sphagnum* sectio *Cuspidata* cf. *balticum* and *Eriophorum vaginatum* (Phase I). The unidentified amounts of the plant remains is high because the degree of decomposition is H10 in the bottom of the mire. During Phase II, the vegetation changed to a *Sphagnum* cf. *balticum* community (from 5 % to 85 %). Coniferous wood, *Carex* spp. and deciduous wood disappeared. *Eriophorum vaginatum* declined from 35 % to 5 %. The mire became wetter than in Phase I. In Phase I and II, *Carex* spp. indicate slightly minerotrophic conditions. Due to decreasing humidity, *Sphagnum* cf. *balticum* was almost completely replaced by *Sphagnum* cf. *fuscum* during Phase III and hummocks were formed. *Sphagnum.* cf. *fuscum* dominated (over 90 %) with small amounts of *Sphagnum.* cf. *balticum* and nanolignids. In Phase III, macrofossil evidence indicates completely ombrotrophic conditions.

The present vegetation at site 25 (Figure 6) is formed by *Sphagnum balticum, S. papillosum, S. tenellum, Trichophorum cespitosum, Carex pauciflora* and *Eriophorum vaginatum* (Appendix 1). At site 25, paludification began about 8400 cal years BP from a coniferous (*Pinus*)-*Eriophorum vaginatum* community (Figure 27B, Phase I). The degree of decomposition is high (H9) in the basal layers and the amount of unidentified plant remains is high. During Phases I and II, coniferous wood declined from 55 % to 10 %. In Phase II (90–70 cm), the percentage of *Eriophorum vaginatum* macrofossils increased from 55 % in Phase I to over 80 %. In addition, small amounts of nanolignids, *Menyanthes trifoliata*, deciduous wood, *Carex* spp. and *Sphagnum compactum* remains were also present. In Phases I and II, the macrofossil evidence indicates slightly minerotrophic conditions. During Phase III, *Eriophorum vaginatum* declined to 40 % and small amounts of nanolignids, deciduous wood, *Carex* spp., *Shagnum compactum* and *Sphagnum* sectio *palustria* were also found. The coniferous-*Eriophorum vaginatum* community was replaced by *Sphagnum* cf. *balticum* in Phase IV and this change indicates that the mire was becoming more oligotrophic and possibly wetter. A *Sphagnum* cf. *balticum* community dominated Phase V with small amounts of nanolignids, *Eriophorum vaginatum, Trichophorum* spp. and *Sphagnum tenellum*.

The modern plant communities of the study site 28 is dominated by *Carex chordorrhiza, C. lasiocarpa, Andromeda polifolia, Betula nana, Eriophorum vaginatum* in the field layer and *Sphagnum angustifolium, S. fallax* in the moss layer (Appendix 1). The bottom layer of the minerotrophic peat was composed of *Carex* spp. (about 80 %), *Equisetum* spp. and *Phragmites australis* (Figure 27C, Phase I). Minor amounts of *Sphagnum teres* and coniferous wood remains were found in this phase. The bottom layer also contained alluvial sand. *Carex* spp. was dominant through Phase II. The percentage of *Carex* spp. declined while *Scheuchzeria palustris* increased due to a decrease in mineral and nutrient availability. During Phase II, *Equisetum* spp., *Phragmites australis* and *Sphagnum teres* disappeared and minor amounts of *Menyanthes trifoliata* (<10 %) were present. In Phase III, *Carex* spp. declined from 70 % to 20 %. Other species present included *Scheuchzeria palustris*, *Sphagnum* cf. *fallax*, *Menyanthes trifoliata* and *Eriophorum vaginatum*. During Phase IV, *Carex* spp., *Scheuchzeria palustris*, *Eriophorum vaginatum* and *Menyanthes trifoliata* declined while *Sphagnum* cf. *fallax* increased from 20 % to over 80 %.

The modern hummock vegetation at site 17, which is a separate coring site about 1000 m SW of point W0 (Figure 6) is composed of *Sphagnum fuscum, Cladina rangiferina, Mylia anomala* in the moss layer and *Calluna vulgaris, Eriophorum vaginatum, Ledum palustre, Vaccinium uliginosum, Empetrum nigrum* in the field layer (Appendix 2). A two meter profile was taken from the southern part of Lahnasuo on the eastern shore of Maksimanlampi. Macrofossil results (Figure 28) indicated that paludification began about 9500 cal. years BP from *Carex* spp. (*C. rostrata* and *C. lasiocarpa*) with small amounts of *Phragmites, Eriophorum* and *Betula* spp.

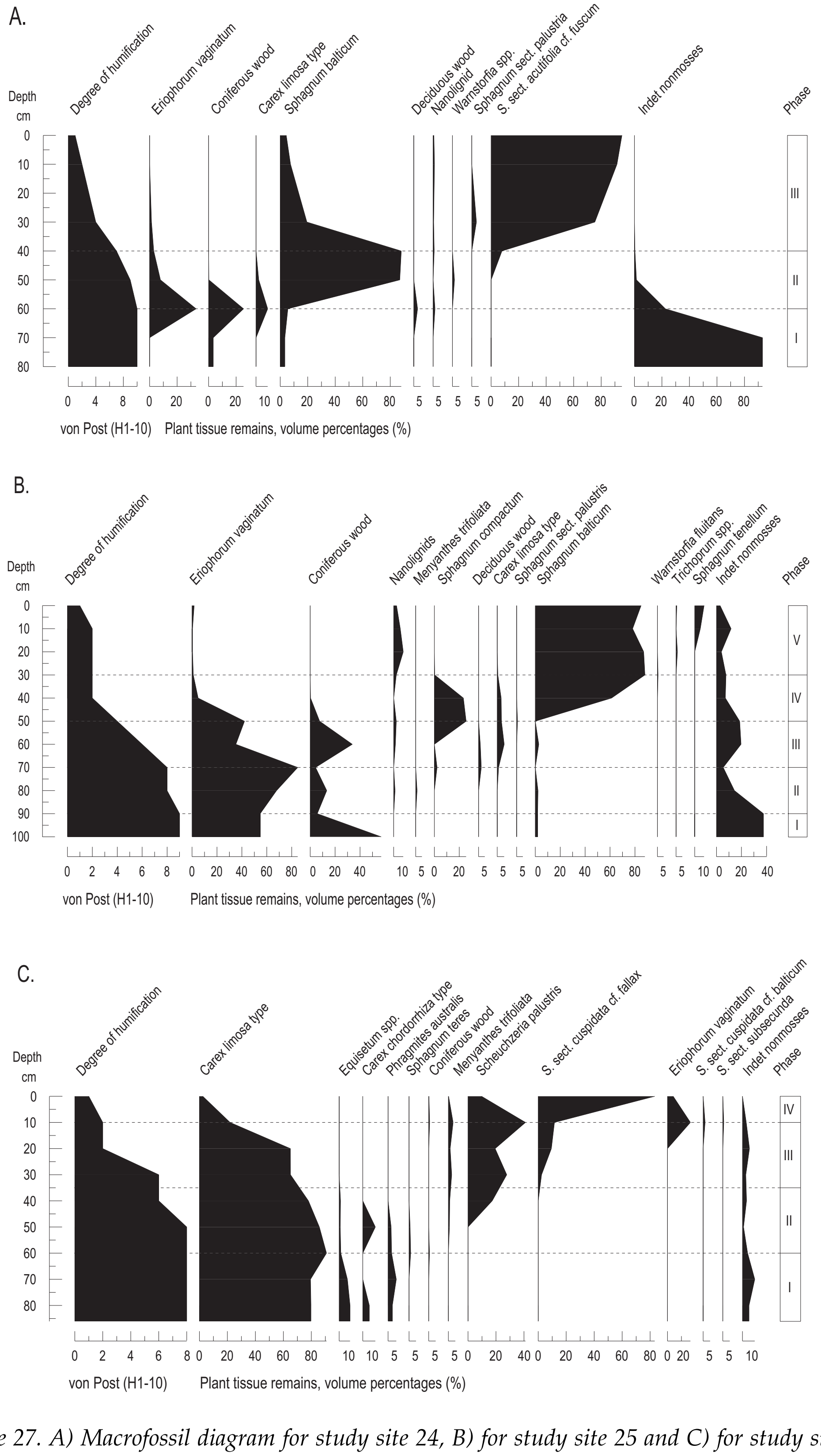


Figure 27. A) Macrofossil diagram for study site 24, B) for study site 25 and C) for study site 28, transect S in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of decompostion is in von Post's (1922) 10-grade scale (H1–10).

(10 %; Phase I). Phase I was succeeded by a drier oligotrophic community with increasing amounts of *Eriophorum vaginatum*, *Pinus sylvestris* and *Betula* spp. In contrast, *Carex rostrata* declined rapidly from 70 % to <10 % while *C. lasiocarpa* declined from 20 % to <10 %. Beginning in Phase III (120 cm) and through Phase VI, the macrofossil evidence indicated a more ombrotrophic stage with increased amounts of *Sphagnum majus*, *S. balticum*, *S. compactum*, *S. papillosum* and *S. tenellum.*

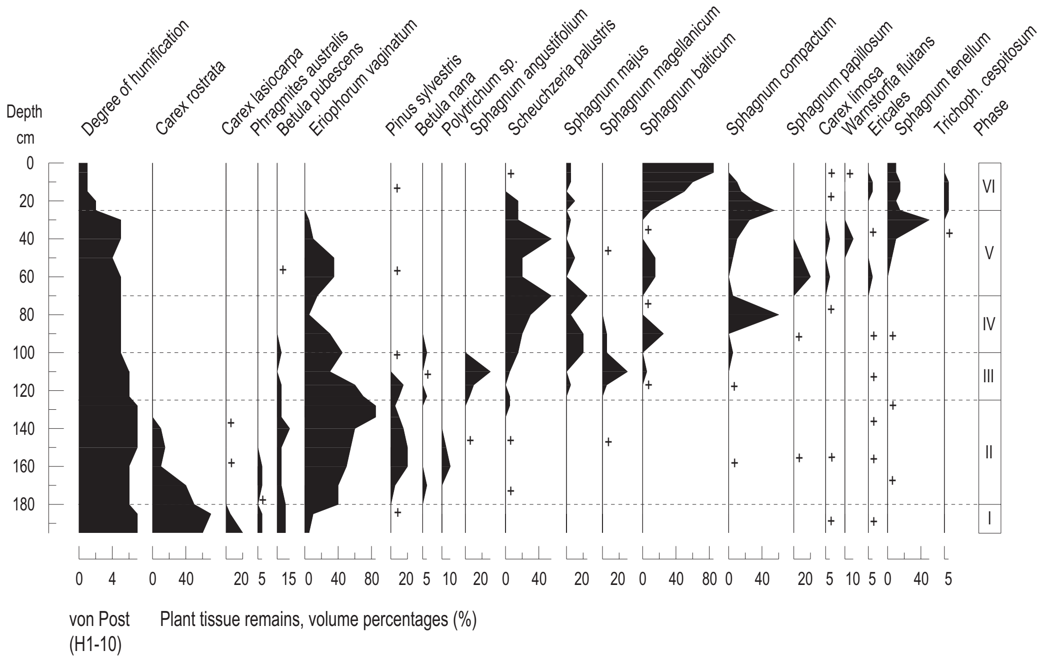


Figure 28. Macrofossil diagram for study site 17 in Patvinsuo mire, eastern Finland. The relative abundance of each macrofossil on a per unit volume basis, %. Degree of humification is in von Post's (1922) 10-grade scale (H1–10).

5.2.9 Transect L

An ombrotrophic marginal area in the southern part of Lahnasuo complex, about 500 m southeast of Lake Pirskanlampi (compartment 1169 in Leivo *et al.* 1992) was also studied. The surface patterns of this eccentric bog are fairly weakly developed. The central part is an ombrotrophic cottongrass bog with scattered pines, while the main area is an ombrotrophic cottongrass pine bog with *Sphagnum fuscum* in varied abundance. The bog slopes eastwards with a gradient of 2.5/1000, while the main transect slopes more gently south (about 1.9/1000).

The area was initiated by paludification and consequently, distinct podzol horizons were encountered in the mineral subsoil beneath the peat. Woody cottongrass peat with some sedge remains characterize the peat strata but the surface layers were mostly ombrotrophic in our 14 coring holes.

There are two to three fire scars in the living and/or dead pines in the area and the corresponding fire horizons were encountered in the surface 50 cm of the peat. Also, 25 to 30 fire horizon were found through out the basin in the near bottom peats. Mire initiation was pollen dated to about 6000–9000 cal years ago (Table 1). The present plant communities at site 27 (Figure 6) are composed of *Eriophorum vaginatum, Andromeda polifolia, Scheuchzeria palustris, Rubus chamaemorus* in the field layer and *Sphagnum balticum, S. angustifolium, S. fuscum* in the moss layer (Appendix 2).

5.3 Chemostratigraphy of peat deposits

Chemical analyses were made for sites along two transects (C and D). At study site 15 (Figures 6 and 18A), the distribution of nine macroelements and four microelements pointed to progressive diminishing of mineral elements, excluding Zn, from the basal peat up to the surface (Figure 29). The comparable regularity of the chemical elements has been recorded in many mires in southern Karelia, such as Nenazvannoe aapa mire (Maksimov *et al.* 1991, Maksimov 1996). The concentration of mineral elements in sandy mineral subsoil under peat deposits was 3–20 times higher compared to sapropelled sedge peat found in the basal layers (ash content 34.4 % of dry mass). The maximum concentration of macro- and microelements (except Zn) was found in the basal sedge peat. A significant increase in ash content, macroelement and Mn concentration was recorded between 115–125 cm. Macrofossil analysis showed a large number of *Betula pubescens* remains in this section. The high concentration of mineral elements at 115–125 cm is related to secondary changes caused by forest fires. The five clear charcoal layers were found between 100 and 115 cm.

An increase in the concentration of some elements, like Ca and Mg at 60 cm, and P and S at 70 cm, were recorded. The increase in Ca and Mg occurred in more decomposed peat layers (degree of decomposition 25 %; H4 in von Post's scale), whereas the above peat deposits were poorly decomposed (10 %, H1–2). A decreased rate of vertical water seepage in the more decomposed peat layers resulted in additional accumulations of Ca, Mg, P and S at 60–70 cm. Further, the mire site studied was located at the lowest part of the mire, which receives water surplus from the other parts of the catchment. The water runoff provides the mire with additional Ca, Mg, P and S. Only small amounts of biogenic elements (K and Mn) were found in the uppermost 20 cm of peat. Notably, Zn accumulated only in the upper peat layers and its maximum concentrations were found in ombrotrophic *Sphagnum* peat. The regularity of Zn accumulation has also been observed in earlier studies (Kreshtapova 1974, Maksimov *et al.* 1991).

At study site 9 in the centre of aapa mire (Figures 6 and 13B), the general distribution of macro- and microelements was quite similar to Lahnasuo (transect D). However, some distinctions were found. The high concentration of macro- and microelements in the bottom sedge peat may be dependant on the mineral element content of subsoil material and not on the peat type. Decreasing amounts of

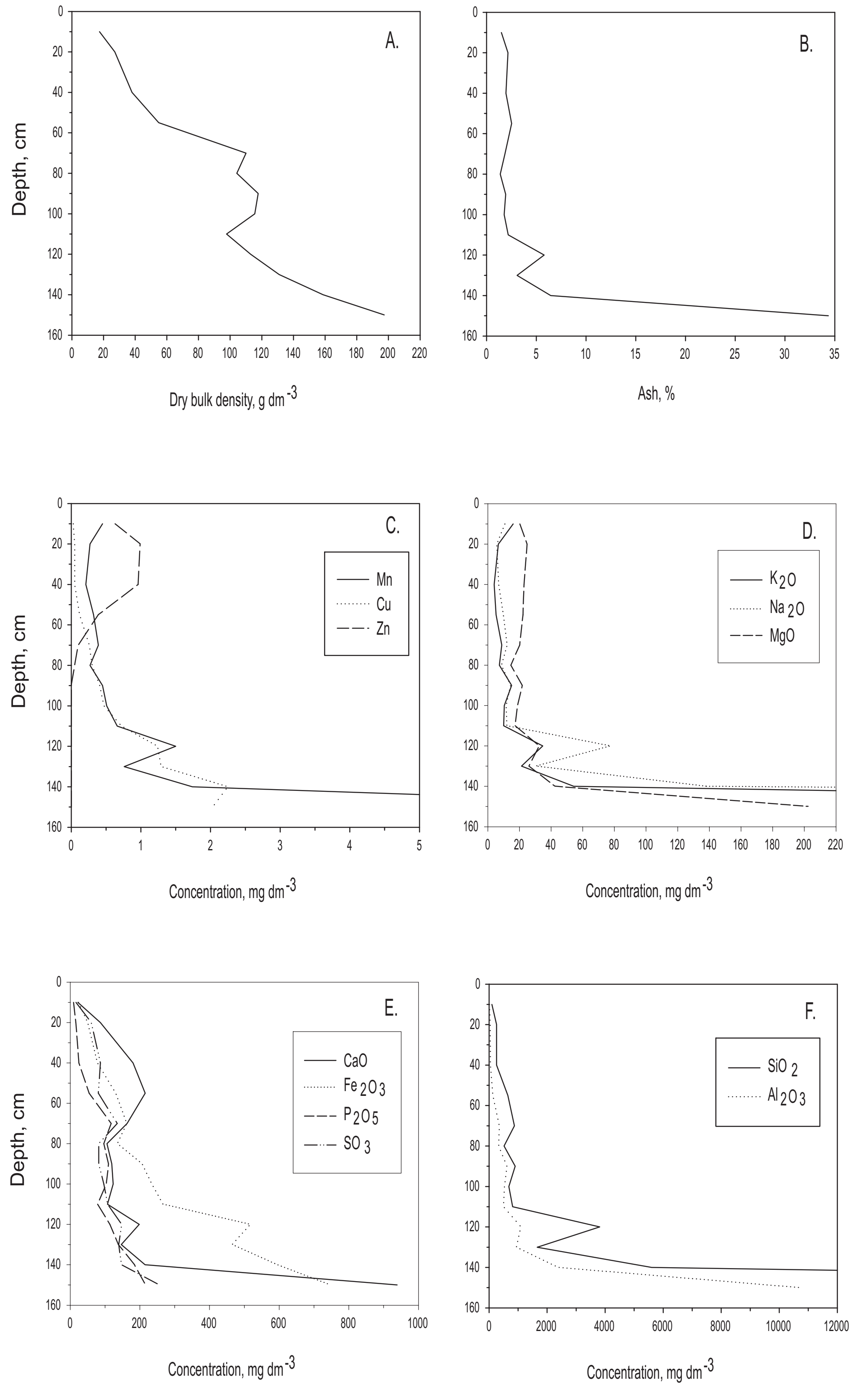


Figure 29. Results of chemical analyses at study site 15, transect D in Patvinsuo mire, eastern Finland.

macro- and microelements in upper peat layers were only recorded for peats close to the normal ash content, starting at 40 cm. The normal ash content of peat is considered to be no more than 12 % and the constituent of ash is based on peat producing plants (Lopatin 1973, Lopatin & Pyatetskii 1977, Maksimov 1988). The concentration of some mineral elements (Fe, P and Mn) at site 9 was about 3–5 times higher compared to peat at Lahnasuo (Figure 29). The higher concentration may be partly connected to the younger stage of mire formation in transect C and to the inflow of minerals from ground water sources.

5.4 Mire fires and carbon accumulation in the peat deposits

The fire history and the LORCA (long-term rate of carbon acumulation) were studied at 27 sites in the Patvinsuo mire (Figure 6, Table 1). A detailed description of the results is given by Pitkänen *et al.* (1999). A large number of charcoal layers were evident in the peat cores and basal peat ages ranged from 57 and 10500 years. The number of charcoal horizons increased with increasing age of the basal peat layer. In the basal 5–10 cm, there were several charcoal layers at short intervals in almost all sites, suggesting that the young (and thin-peat) mires have burned more often than older mires with thicker peat layers. The only exceptions were sites with basal aquatic deposits. No correlation was found between the number of charcoal layers (or mean distance between charcoal layers) and the distance to the nearest recent mineral soil forest edge.

Charcoal layers were absent in the upper sections of the peat columns, suggesting that the studied sites did not burn for a long period. If the peat accumulation rate is assumed to be constant, the timing of the last mire fires can be roughly estimated based on available datings. The pollen date for the advance of *Picea* ca. 5500 BP used as a basis for the calculation suggests that most studied sites have not burned during the last 2000 years.

High fire frequencies of about 100 years calculated for time prior to 5500 BP at a few sites in Pitkänen *et al.* (1999) must be incorrect. Tilted charcoal layers can result in overestimations of charcoal horizons, if the charcoal bands on the convex surface of peat core are simply counted (Pitkänen *et al.* in press a). The forest fire interval in the area was 400–500 years prior to 5500 BP (Pitkänen *et al.* in press b), and it is very unlikely that mires burned more frequently than forests. After the advance of *Picea* (5500 BP) the average forest fire interval shortened to about 200–260 years (Pitkänen *et al.* in press b), and most sites at Patvinsuo mire burned at an interval of 200–400 years, regardless of peat thickness at the site.

The LORCA in the sampled mire sites was 9.2 ± 1.0 (SE) g m^{-2} yr^{-1}, ranging from 2.9 to 28.2 g m^{-2} yr^{-1}. These values differed significantly compared to our reference sites in the raised bog region in Finland, which had a LORCA value of 17.7 ± 0.6 (SE) g m^{-2} yr^{-1}. Dry bulk density and loss on ignition averages of Patvinsuo mire deposits were similar to those obtained for other peat deposits in the boreal region (Kuhry *et al.* 1992, Kuhry 1994, Tolonen & Turunen 1996, Robinson & Moore

1999, Turunen *et al.* 2001). However, height increment and C accumulation were considerably lower. Considering all the sampled sites, the LORCA for the bogs differed significantly compared to the fen sites, 10.2 ± 1.2 (SE) and 5.6 ± 1.2 (SE) g m^{-2} yr^{-1}, respectively. The calculated average rate of C loss in Patvinsuo mire was 9.5 ± 1.0 (SE) g m^{-2} yr^{-1}. The difference in the average C loss between bogs and fens was not significant.

Recent (apparent) rate of carbon accumulation (RERCA) in the mire margins paludified after the most recent fires (57–182 years ago) was 69.7 ± 3.7 (SE) g m^{-2} yr^{-1}, much higher than other parts of the mire. Most of the peat in these marginal areas is weakly decomposed (H1–H3), and the mean dry bulk densities of the peats were lower (60.8 g/dm^{-3}) compared to the older parts of the mire basin (79.7 g/dm^{-3}).

A significant correlation was found between the mean interval of charcoal layers and total C and peat accumulation. The correlation suggests that fires have been a major factor in reducing both peat and C accumulation in the Patvinsuo mire. An average C loss value of 2.5 kg m^{-2} for a single fire was estimated for sites in Patvinsuo mire. The sites with highest C loss estimates represented both present fens (tall-sedge fens, flark fens, low-sedge *Sphagnum papillosum* fens, low-sedge fens), and bogs (*S. fuscum* bogs).

The mean rates of lateral expansion based on radiocarbon dates have been calculated for the transects B–F (Table 5). The range of the datings is from 3670 to 10580 cal. years BP. The mire margins and the youngest mire sites studied in Patvinsuo were paludified after the most recent fires in 1894, 1898 and 1937 (Potinkara 1993, Turunen *et al.* 1999).

5.5 Carbon accumulation in the mineral subsoil of the mire

In the Patvinsuo study area, the average C density in the mineral subsoil of mire sites was 1.6-fold higher than in adjacent forest profiles. A detailed description of results is given by Turunen *et al.* (1999). Average total C density in the sampled mire areas and upland forest areas was 5376 g m^{-2} (SE = 391 g m^{-2} and n = 34) and 3306 g m^{-2} (SE = 328 g m^{-2} and n = 14), respectively. More than two-thirds of the C density was in the E and B horizons, located above 45 cm. The distribution of C density in the soil horizons was quite homogeneous. In the paludified areas, 21 % of the C density was in the E horizon, 45 % in the B horizon, and 34 % in the parent material. These values were very similar to upland forest areas, which had C density values of 24 %, 56 %, and 20 %, respectively. Much of the variation of C between paludified sites and adjacent forest sites was in the rich illuvial horizons (B) and in the parent material (C).

Table 5. Rates of lateral expansion (cm yr^{-1}) estimated from the basal peat dates for transects B–F.

Sites	Time interval (cal. yr BP)	Distance (m)	Estimated horizontal growth rate (cm yr^{-1})
Transect B:			
mire margin–4	present–7410	500	6.7
4–2	7410–5760	500	30.3
2–mire margin	5760–present	100	1.7
Transect C:			
9–8	7050–4280	100	3.6
8–mire margin	4280–present	400	9.3
Transect D:			
mire margin–13	present–10580	050	0.5
13–15	10580–9520	500	47.2
15–16	9520–5500	300	7.5
16–mire margin	5500–present	100	1.8
Transect E:			
mire margin–19	present–9690	185	1.9
18–19	9970–9690	200	71.4
19–12*	9970–3670	125	2.0
12*–mire margin	3670–present	075	2.0
Transect F:			
mire margin–21	present–8450	400	4.7
22–21	10280–8450	400	21.9

The LORCA in the sampled mire areas was 22.1 ± 4.7 (SE) g m^{-2} yr^{-1} (n = 34), ranging from –0.2 to 99.9 g m^{-2} yr^{-1} depending on the age of paludification. The results indicate that the LORCA estimates were highest on the youngest mire areas (<500 years, n = 15), 39.3 ± 6.0 (SE) g m^{-2} yr^{-1}, while in the areas older than 500 years (n = 19) the LORCA was 0.2 ± 0.1 (SE) g m^{-2} yr^{-1}. The bog subsoils consistently had the highest LORCA. A direct comparison between the LORCAs of bogs and fens was not possible because of their different average ages (2040 and 6930 years old, respectively). In all, the relationships between the LORCA and the age of the mire were strong. The highest LORCA (0.3 g m^{-2} yr^{-1}) found in the fen sites was in a flark fen, paludified 4200 cal. years BP. The highest LORCA (99.9 g m^{-2} yr^{-1}) in bog sites was in a shallow paludified pine forest, that was paludified 58 years ago.

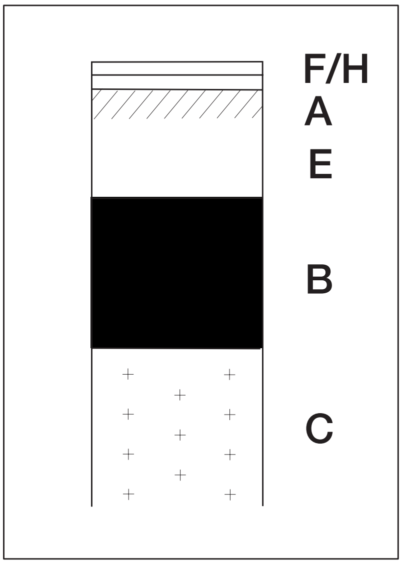


Figure 30. Scheme of podzolic soil horizons. Layer F/H consists of organic matter above mineral soil. Horizon A is greyish-coloured leaching layer, poor in soluble substances. Horizon B is illuvial horizon, coloured rust-brown by accumulated aluminium and iron oxides. Horizon C consists of the parent material.

6 DISCUSSION

Patvinsuo National Park contains a complicated mire system consisting of eccentric bogs and aapa mires. However, the mire systems can be clearly distinguished through analyses of hydrologic and botanical conditions on aerial photos. Following deglaciation, mire formation processes began in the remaining shallow water basins and on emerged waterlogged ”meadows” and alluvials.

The plant macrofossil content of the peat profiles gives information about the plant cover of the successional stages of the mires. Plant macrofossils are frequently determinable to species level. Past ecosystems cannot be observed directly from the peat because plant species have different rates of decomposition. Some mosses, especially *Sphagnum*- and Bryophyta-taxa are very well preserved. Remains of liverworts are much less frequent than those of mosses. Soft parts of vascular plant are not readily preserved. Palaeoecology is then limited to the study of past organisms whose fossils are preserved. Therefore, present species diversity compared with past species diversity is difficult and present species diversity is often bigger than past species diversity.

The lack of radiocarbon datings in different parts of Patvinsuo mire makes it impossible to extrapolate the age isochrones and calculate the rates of lateral expansion (m^{-2} yr^{-1}) over the whole mire complex. However, the dates obtained from the study transects indicate that the mire formation must have begun more or less simultaneously over the large areas of the different mire basins or deepest kettles. The oldest basal peat layers are dated from terrestrialized sites (site 13 ca. 10600 cal years, site 22 ca. 10300 cal years, sites 1 and 18 ca. 10000 cal years BP). The oldest paludified sites are comparable in age (site 17 ca. 9500 cal years and site 29 ca. 9300 cal years BP; cf. also Tolonen 1967). Primary mire formation (Huikari 1956, Tolonen 1967) was the type of mire initiation at site 15 about 9500 cal years ago and at site 28 about 6300 cal years ago. However, the youngest terrestrialized mire site found is site 9, about 7000 cal years BP, compared with a series of dated paludified sites from ca. 8000, 7000, 6000, 5000, 4000 and 3000 cal years BP. The fact that we do not have basal peat ages younger than ca. 3000 cal. years BP does not mean that paludification or the expansion of mires has halted since that time, because the very marginal areas of the basins were not dated in this study. However, Turunen *et al.* (1999) showed that paludification of dry heath forest occurred intensively after forest fires during the past two hundred years. Most likely, the peat covered area of Patvinsuo National Park had almost reached its present extent by some 3000 years ago. The calculated rates of lateral expansion of Patvinsuo mire complex showed that paludification is still a continuous process even though very slow compared to the rates of mire initiation periods (Table 5). More rapid rates of lateral expansion have been reported in southern Finland and were attributed to impermeable clay substrates underlying the mires and gentle topographic profiles (Korhola 1992, Mäkilä 1997). However, it generally looks like the lateral mire expansion during the last 3000 cal. years BP has been very slow (Korhola 1992, Mäkilä 1997). This may be simply because of the steepening of the bottom gradient in marginal mire areas and that the environments best suited for mire formation have been long since exhausted.

Regardless of the type of mire initiation (i.e. terrestrialization, paludification or primary mire formation), the first stages in the mire vegetation history within the Patvinsuo mire complex were more or less eutrophic, provided the process started some 8000–9000 cal. years BP or earlier. At younger mire sites, the initial vegetation was less dependent on mineral nutrients and pH due to the rapid impoverishment (by washing out of bases) of the runoff waters originating from or in contact with sorted fluvioglacial sands of the acidic granite parent material (cf. Crocker and Major 1955).

Typical vegetation succession in the early initiated mire parts was as follows: water vegetation with *Typha, Alisma, Phragmites* and *Equisetum* (or hardwood or mixed pine forest) → rich (flark) fen with *Scorpidium scorpiodes, Calliergon* spp., *Warnstorfia* spp., sedges, *Menyanthes* and often *Phragmites* → mesoeutrophic sedge and *Molinia* fen with *Sphagnum teres* and *Sphagnum subsecundum* group → oligominerotrophic sedge fen with *Carex lasiocarpa, C. rostrata, C. chordorrhiza* (sometimes *C. cespitosa* and/or *Eriophorum angustifolium*), *Menyanthes, Sphagnum fallax, S. annulatum* and *S. papillosum* etc. → slightly minerotrophic sedge or pine fen with *Eriophorum vaginatum, Scheuchzeria palustris, Carex pauciflora* - (on places some *Carex rostrata* and/or *C. magellanica*), *Trichophorum cespitosum, Sphagnum cuspidatum* group (on places *Sphagnum papillosum*) → ombrotrophic *Sphagnum* -communities. Most aapa mire sites have not yet reached the two latter stages.

This general ”model” of mire development prevails everywhere in circumboreal and circumantiboreal deglaciated areas and is well documented in hundreds of studies from C. A. Weber (1902) to Tolonen (1967), Frenzel (1983), Foster & Glaser (1986), Vitt & Kuhry (1992). Exceptions to this ”rule” were not found within the Patvinsuo complex and seem to be extremely rare in Nordic countries as whole (Åkhultsmyren in South Sweden and Munasuo in Pyhtää by Tolonen & Seppä (1994) are rare examples).

The age of the development history of Patvinsuo mire complex varies greatly in different parts of the complex. In the northern part of the Lahnasuo complex, the onset of the ombrotrophic stage is very recent or may even be ongoing (Kivinen & Tolonen 1972). Based on microscopic analyses of plant remains, we interpreted that the oldest ombrotrophic fossil assemblages in the Patvinsuo National Park are from the subatlantic chronozone from 2500 cal years BP (Site 2 on transect B, Table 6). In the southern part of North Karelia, the oldest ombrotrophic peats are much older, ca. 7000 cal years BP (Tolonen 1967). This area belongs to the regional raised bog zone, where the climatically controlled moisture surplus is much less than in the Patvinsuo area. Generally, the maximum age of the ombrotrophic stage within European peatlands decreases northwards (Tolonen 1967 and references there in). For example, the stage in Estonia was dated ca. 8000 cal. years BP (Ilomets 1992); in Varrassuo, Lahti over 9000 cal. years ago; and in northern Finnish bogs only 2000 cal. years BP (Ruuhijärvi 1963).

Table 6. Commonly used Holocene divisions for northern Europe divided into five chronozones. Plausible climatic characteristics and some historical forest features in the Patvinsuo area from different sources are also given. All dates are given in calendar years before present (BP).

Chronozone (abbr.)	Dating yr BP	Climatic characteristics	Forest history
Subatlantic (SA)	0–2500	more humid and/or cooler than SB	slash-and-burn cultivation ca. 100–500 BP resulting in decrease in spruce. Fewer deciduous trees than in SB
Subboreal (SB)	2500–5800	less humid than SA, cooler than AT	Strong increase and maximum of *Picea*, decrease in *Quercetum mixtum* (QM) and *Corylus*
Atlantic (AT)	5800–9000	warmer than SB, moister than late BO	(second) spread of *Picea* in the region (ca. 6300 BP, maximum of QM ind. *Tilia* since about 7000 BP. Strong rise in *Alnus* about 9000 BP. Dense forests
Boreal (BO)	9000–10000	periodic drought, warm	*Pinus* dominant, retrogression and disappearance of the first *Picea*, *Alnus* rare, no *Tilia*. Non arboreal vegetation still abundant
Preboreal	10000–11000	rapid warming of climate, probably moist	dominance of *Betula* (up to about 90%), *Picea* common and abundant in some places, *Populus* common. Forests open with rich grass, sedge, herb and/or fern vegetation in the field layer

The majority of peat forming plants in nutrient rich mires (*Phragmites australis, Menyanthes trifoliata, Equisetum fluviatile, Betula pubescens, Carex lasiocarpa* and *C. rostrata*) have a very wide ecological range and can be found dominating at mesotrophic and oligominerotrophic conditions. The occurence of these species at poor minerotrophic mire sites may indicate a recent change in ecological conditions within the mire area (Lopatin 1973). The present surface species indicate nutrient conditions at 20–30 cm depth while mosses indicate nutrient conditions 5–10 cm below the peat surface (Elina *et al.* 1984). Minerotrophic species do not occur in true ombrotrophic conditions. Contrary to the situation in western and southern Finland (see Aartolahti 1965, Tolonen 1967), all the ombrotrophic hollows studied primarily originate from the preceding minerotrophic wet surfaces. As well, the hummock ridges have developed from possible strings or more often on the lawn level of the minerotrophic stage.

The genesis of microrelief can be estimated based on peat thickness, peat types and the degree of decomposition; however, the microlandscape did not start to form before the subatlantic chronozone. Studies by Kuznetsov (1986) also dated the age of strings and flarks on the aapa mire complex in Russian Karelia to about 3000 cal years BP. In nearly concentric Kesonsuo raised bog in Ilomantsi, ca. 70 km south of Patvinsuo, the oldest secondary water pools (up to 900 m long and 40 m wide) originated from the subatlantic chronozone (Tolonen 1967), while one large secondary pond in Ilajansuo aapa mire, Ilomantsi, originates just after the general spread of spruce ca. 6000 cal. years ago (Tolonen 1967).

The mineral content of both investigated mire sites is much lower compared to results obtained from other Karelian mires (Maksimov 1988). The concentration of mineral elements in the peat in the Lahnasuo and Patvinsuo areas is close to the mineral content of mires in the vicinity of Koitajoki and Tolvajärvi (Kuznetsov & Maksimov 1995).

In general, the average long-term (apparent) rate of carbon accumulation (LORCA) in Patvinsuo, 9.2 g m^{-2} yr^{-1}, was clearly lower compared to the average value for reference bogs and fens in southern and central Finland, 17.7 g m^{-2} yr^{-1} (Tolonen & Turunen 1996, Pitkänen *et al.* 1999). LORCA showed a significant decrease with the decreasing mean interval of charcoal layers, indicating the importance of fires on C accumulation on mires (Pitkänen *et al.* 1999). The same result is found by Kuhry (1994) and Robinson & Moore (1999), obtained from *Sphagnum*-dominated peatlands in western boreal Canada. Most Finnish mires either lack charcoal layers, or contain only a few layers (Tolonen & Turunen, personal observation). Dendrochronological data indicates that during the slash-and-burn period (between early 16th and mid-19th centuries, when the majority of fires may have been of anthropogenic origin), the fire interval in forests of Patvinsuo area was 40–50 years (Figure 31). The forest fire frequency was similar also in other sites in North Karelia between 16th and mid-19th centuries (Lehtonen 1997). During this period, there is evidence of only 2–3 fires, which spread over large areas of Patvinsuo mire (Pitkänen *et al.* unpublished data). However, after the establishment of spruce (about 6300 cal. BP), prior to slash-and-burn period, the fire frequency in forests of Patvinsuo area was about 200–260 years (Pitkänen *et al.* in press b). The high number of charcoal layers at some sites suggests that during the time of ”natural” fires (ignited by lightning, especially during dry, warm periods (Kinnman 1936)), majority of the forest fires have spread into areas of the Patvinsuo mire.

Hydrological characteristics of Patvinsuo mire complex may be different than most Finnish mires, allowing the peat surface to dry relatively frequently and causing conditions favorable for mire fires. Kuhry (1994) expected that wet fens would probably be less susceptible to burning, however in Patvinsuo mire, the wet mires (including tall-sedge fen and flark fens) had the shortest intervals between charcoal bands and also the highest loss of carbon. The frequent drying may have increased the peat decay rate, contributing to recurring fires and resulting in low C accumulation values in Patvinsuo mire. Therefore, the estimated mean C loss, 2.5 kg m^{-2} for a single fire in Patvinsuo mire complex is possibly too high. Most of the mire fires are very surficial, with burning shrubs and grasses and only slight scarring of the peat surface. Possibly, most of the estimated C loss was caused by a few fires that consumed a thick layer of peat at once. Indeed, there is evidence of loss of peat deposits corresponding to 1500 years from site 10 (Pitkänen *et al.* 1999). Recent C accumulation rates in the mire margins paludified after the latest forest fires (60 to 240 years ago) were much higher compared to long-term rates of C accumulation. However, the apparent increase in the rates of C accumulation during the recent millenia can be misleading if compared directly to the LORCA because significantly more decay has occurred in older peat deposits.

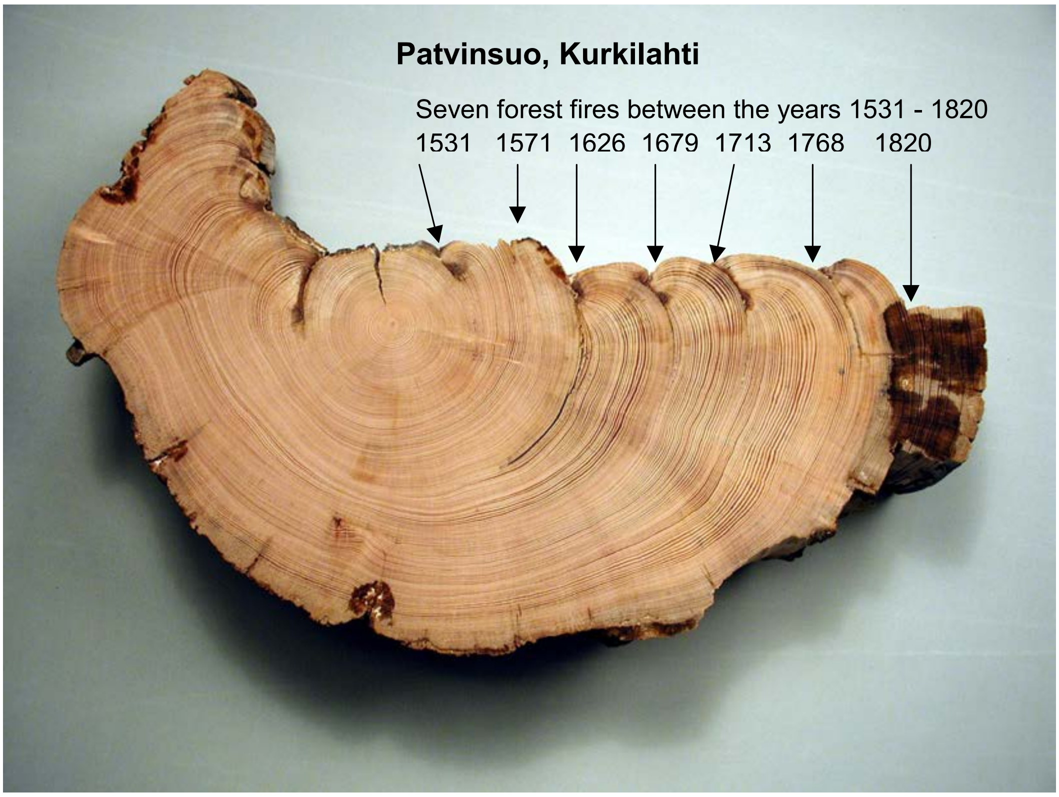


Figure 31. A cross-section of a dead pine from the mire of Patvinsuo (63°07′/30°44′). The oldest tree ring of the sample represents the year 1456 and the youngest the year 1870. Seven fire scars were determined between the years 1531 and 1820.

In the Patvinsuo study area, the average C density in the mineral subsoil of mire sites was 1.6-fold higher than in adjacent forest profiles. Bogs were found to have higher LORCA values than the fens. These results have been found in many other mire sites in Finland with similar podzolic texture and topography (Turunen *et al.* 1999). Also, a great variation was found both in the C density and the LORCA in podzolic profiles buried under peat. The LORCA in the mineral subsoil during the first stages after mire initiation was high. We believe that the roots of trees and shrubs play an important role in C input in addition to C input from the leaching of organic matter. However, C input into the mineral subsoil beneath the peat strata may be an additional C sink that usually exceeds the amount of C in the ancient forest soil prior to paludification.

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GLOSSARY OF MIRE TERMS

Aapamire: a mire complex with the middle part occupied by minerotrophic vegetation free of any marginal influence. See chapter 3

Ash: ignition residue remaining after burning at certain temperature in soil analysis

Bog: mire vegetation with only ombrotrophic water supply

BP: radiocarbon dating before present (age in years before AD 1950). In this study, all the original ^{14}C-datings are calibrated to calendar years BP.

Carbon density: amount of carbon in given soil layer on areal basis (kg m^{-2})

Cotton grass: *Eriophorum vaginatum*

Eccentric bog: (sloping bog): ombrotrophic mire complex type with surface pattern (kermis and hollows) more or less parallel. If the patterns are bent, their theoretical midpoint lies outside the mire basin

Eutrophic: mineral rich: pH usually >5.5 and calcium content >6 mg dm^{-3} in dry peat. We follow this western concept through the text. The Russian tradition (see chapter 4) is followed for peat symbols.

Fen: mire vegetation with minerotrophic water supply

Flark (=rimpi): an elongated, minerotrophic wet depression underlain by sedge or Bryales peat, which forms the basic structure of patterned northern aapa mires. The water table is within 5 cm of the surface level.

Hollow: any depression in ombrotrophic (i.e. bog) mires where the average water table lies about 5 cm below the surface.

Hummock: any elevated section of mires where the average water table during the growing season lies at 20 cm or more below the surface.

Kermi (=ridge): any elongated hummock on any ombrotrophic mire

Lagg (=laide): minerotrophic (fen) area separating an ombrotrophic portion of any bog complex from the upland (or water) vegetation

Lawn (=carpet): the basic level of mire surface, where the average mire water table varies from 5-20 cm below the surface.

LORCA: long-term apparent rate of carbon accumulation (g m^{-2} yr^{-1}) as determined for a given site by dividing the measured carbon mass of the peat column by the age of the basal age. The true (actual) rate of carbon accumulation is lower, since LORCA ignores the slow decay in deeper peat layers

Mesotrophic: mire vegetation with intermediate nutrition, pH ranges between 4.5–5.5 and Calcium content from 3–6 mg dm^{-3} in dry peat. We follow this (Finnish) concept in the text, but for peat symbols a Russian system is used, see chapter 4

Minerotrophic: vegetation receiving (extra) nutrient supply from groundwater or surface water in contact with groundwater. See chapter 3.

Mire (=peatland): wetland type occupied by 75% or more mire plants; most often a peat forming ecosystem. Either bog, fen, or swamp.

Mire complex type: Climatically controlled, similar spatial organization of mire vegetation in mires of a certain region. Examples: eccentric raised bogs, aapa mires etc.

Mixed complex: a mire system in a basin occupied by wide patterned ombrotrophic and minerotrophic sections (of aapa type). See chapter 3.

Oligotrophic: Mineral poor, pH usually below 4.5 and calcium content <3 mg dm^{-3} in dry peat. Poorest minerotrophic and all ombrotrophic mire vegetation are oligotrophic. We follow this western concept throughout in the text, but not for the peat symbols, see chapter 4.

Ombrotrophic: mire vegetation receiving water and mineral nutrient supply from rain only, see chapters 3 and 4.

Paludification: formation of mire systems via waterlogging (regressive development) of former dry land

Peat ridge (=peat bank=kermi): elongated hummocks on patterned ombrotrophic mires, i.e. raised bogs. The average mire water table is 20 cm below the surface.

Primary mire formation: Formation of mire systems on moist primary soil (usually meadow like) immediately after deglaciation or land uplift from the sea.

Primary pond (or pool): larger water-body within a mire that is a relict of a former water-course that preceded the formation of the mire

Raised bog: a mire complex with a middle portion comprised of ombrotrophic (rain fed) vegetation, see chapter 3.

Rimpi: see flark

Sapropel: joint-term for both allochtonous ("dy", "muta") and autochtonous ("gyttja", "lieju") sediments deposited in limnic (=lacustrine) environs.

Secondry pool (or pond): water bodies on mires that have *(in situ)* a peat bottom which indicates their secondary origin via regressive development.

String: an elongated, narrow and high hummock on a minerotrophic mire. Drier than its immediate surroundings.

Swamp: minerotrophic mire with strong marginal influence from limnogenic water and/or mineral soil

Terrestrialization: formation of mire systems via in-filling of water bodies (progressive hydrosere)

Descriptions of the present plant communities from minerotrophic sites in Patvinsuo, eastern Finland

The percent coverages for the field and ground layer are the averages of five one-m^2 quadrats on each site.
The standard deviations are in parentheses. The term WET indicates a shallow pool without vegetation.

	Site							
Species	1. A0	8. C400	9. C500	10. Lintu	19. E400	24. K0	25. K100	28.S650
Polytrichum strictum	–	–	–	–	–	–	–	0.1 (0.2)
Sphagnum angustifolium	–	–	–	20.0 (20.0)	–	0.2 (0.5)	–	81.2 (17.9)
S. annulatum	–	0.2 (0.5)	3.0 (6.7)	17.6 (10.2)	–	–	–	–
S. balticum	9.8 (14.0)	–	–	2.0 (2.7)	17.0 (4.5)	58.2 (17.7)	85.2 (13.3)	1.8 (4.0)
S. compactum	–	–	–	–	–	–	0.4 (0.6)	–
S. fallax	89.9 (14.1)	–	6.0 (8.2)	0.4 (0.9)	22.0 (2.7)	–	–	13.2 (15.9)
S. fuscum	–	–	–	–	–	26.4 (25.6)	–	–
S. magellanicum	–	–	–	–	–	1.0 (1.2)	–	0.1 (0.2)
S. majus	–	–	–	–	60.6 (5.6)	–	–	–
S. papillosum	0.3 (0.5)	–	–	57.0 (31.7)	0.4 (0.9)	13.5 (12.5)	9.2 (9.7)	1.0 (2.2)
S. subsecundum	–	–	–	1.6 (2.3)	–	–	–	–
S. tenellum	–	–	–	0.4 (0.6)	–	0.6 (0.4)	4.9 (4.7)	2.6 (2.0)
Cladopodiella fluitans	–	–	–	–	–	0.1 (0.2)	0.3 (0.5)	–
Wet	–	99.8 (0.5)	91.0 (13.4)	1.0 (2.2)	–	–	–	–
Andromeda polifolia	4.8 (2.4)	–	–	–	0.3 (0.2)	1.7 (1.9)	2.8 (1.3)	4.1 (6.3)
Betula nana	1.3 (1.0)	–	–	–	0.1 (0.1)	–	–	3.8 (1.5)
Carex chordorrhiza	–	–	31.0 (2.2)	5.0 (0.7)	–	–	–	36.0 (23.0)
C. lasiocarpa	–	–	–	–	–	–	–	5.1 (8.6)
C. limosa	9.2 (4.3)	17.0 (9.1)	21.0 (2.2)	34.0 (5.5)	2.0 (1.5)	–	–	–
C. pauciflora	–	–	–	–	–	7.4 (2.5)	10.6 (2.6)	–
C. rostrata	4.2 (4.0)	–	–	–	2.3 (1.1)	–	–	–
Chamaedaphne calyculata	0.7 (0.3)	–	–	–	–	–	–	0.3 (0.4)
Drosera anglica	–	–	–	0.1 (0.1)	–	–	–	–
D. rotundifolia	–	–	–	0.1 (0.1)	–	0.3 (0.4)	0.1 (0.1)	–
Empetrum nigrum	–	–	–	–	–	–	–	1.0 (2.2)
Eriophorum vaginatum	8.0 (11.0)	–	–	–	–	35.0 (15.0)	9.2 (6.4)	2.8 (1.3)
Menyanthes trifoliata	0.4 (0.4)	–	–	13.6 (4.7)	–	–	–	–
Rubus chamaemorus	–	–	–	–	–	–	–	2.0 (4.5)
Scheuchzeria palustris	–	22.0 (2.7)	6.0 (2.2)	0.8 (0.3)	3.6 (1.5)	–	–	–
Trichophorum cespitosum	–	–	–	–	–	0.3 (0.5)	33.0 (23.9)	–
Utricularia intermedia	–	–	1.0 (2.2)	1.2 (0.8)	–	–	–	–
Vaccinium microcarpum	–	–	–	–	–	1.0 (0.7)	0.3 (0.2)	0.9 (0.7)
V. oxycoccos	3.8 (1.3)	0.1 (0.1)	–	0.1 (0.1)	0.3 (0)	0.3 (0.1)	0.2 (0.2)	–
V. uliginosum	–	–	–	–	–	–	–	0.9 (1.8)
Number of species	11	5	7	16	10	14	12	17

Descriptions of the present plant communities from ombrotrobhic sites in Patvinsuo, eastern Finland

The percent coverage for the field and ground layers are the averages of five one-m^2 quadrats on each site.
The standard deviations are in parentheses. The term WET indicates a shallow pool without vegetation.

	Site										
Species	2. B100	4. B600	13. D900	15. D400	16. D100	17. PAV	18. E200	21. F400	22. F800	27. L+100	29. W600
Polytrichum strictum	–	0.2 (0.2)	–	–	–	–	0.9 (0.7)	–	2.0 (2.7)	0.2 (0.2)	–
Sphagnum angustifolium	–	10.2 (9.8)	39.3 (18.8)	0.2 (0.5)	4.8 (3.2)	0.2 (0.3)	–	–	33.4 (25.0)	22.0 (10.4)	20.0 (25.5)
S. annulatum	–	8.8 (13.0)	–	–	–	–	–	–	–	–	–
S. balticum	94.6 (8.8)	64.6 (16.8)	2.0 (4.5)	0.8 (0.3)	82.8 (6.9)	–	7.3 (2.6)	89.4 (11.5)	45.9 (34.1)	74.2 (11.7)	60.0 (31.7)
S. capillifolium	–	–	–	–	–	0.4 (0.4)	–	–	–	–	–
S. compactum	–	–	–	15.2 (18.6)	–	–	–	–	–	–	–
S. fuscum	4.0 (8.9)	14.9 (25.5)	57.7 (16.4)	0.6 (0.9)	–	94.2 (3.0)	90.0 (4.5)	6.0 (8.9)	16.8 (14.2)	1.6 (2.3)	13.0 (15.7)
S. magellanicum	0.2 (0.3)	–	–	0.1 (0.2)	–	–	–	–	0.9 (1.2)	0.5 (0.9)	1.3 (1.0)
S. papillosum	–	–	–	26.0 (25.8)	11.0 (5.5)	–	–	–	–	–	0.8 (0.8)
S. rubellum	–	–	–	–	–	–	–	0.6 (0.9)	–	0.3 (0.5)	2.2 (3.4)
S. tenellum	0.7 (0.8)	1.3 (1.2)	–	–	1.4 (0.6)	–	–	–	0.2 (0.5)	0.6 (0.4)	2.7 (1.4)
Warnstorfia fluitans	0.5 (0)	–	–	–	–	–	–	–	–	–	–
Cladopodiella fluitans	–	–	–	1.0 (0.6)	–	–	–	2.0 (1.0)	0.5 (0.9)	0.4 (0.2)	–
Mylia anomala	–	0.1 (0.1)	1.0 (0.6)	–	–	1.6 (2.3)	1.8 (1.3)	–	0.3 (0.5)	0.2 (0.3)	–
Cetraria spp.	–	–	–	–	–	0.6 (0.9)	–	–	–	–	–
Cladina rangiferina	–	–	–	–	–	3.0 (3.5)	–	–	–	–	–
Wet	–	–	–	56.1 (23.7)	–	–	–	–	–	–	–
Andromeda polifolia	1.0 (0.6)	4.9 (3.3)	4.8 (1.9)	0.9 (0.7)	1.8 (0.8)	1.8 (1.8)	3.4 (0.9)	4.8 (2.3)	2.0 (2.0)	8.4 (1.5)	3.6 (3.7)
Betula nana	–	0.1 (0.1)	–	0.3 (0.2)	–	0.2 (0.1)	–	–	0.1 (0.1)	–	0.1 (0.2)
Calluna vulgaris	–	–	14.4 (8.2)	–	–	46.0 (20.7)	–	–	–	–	–
Carex chordorrhiza	–	–	–	–	–	–	–	–	–	0.2 (0.1)	–
C. limosa	–	–	–	30.0 (10.0)	12.0 (2.7)	–	–	–	–	–	–
C. pauciflora	–	–	1.4 (0.6)	–	–	–	–	–	–	–	0.1 (0.1)
Chamaedaphne calyculata	1.6 (1.0)	2.5 (3.2)	2.6 (1.1)	–	–	1.0 (1.4)	0.2 (0.5)	3.3 (2.3)	2.4 (2.5)	0.1 (0.1)	0.1 (0.2)
Drosera anglica	–	–	–	0.6 (0.2)	–	–	–	–	–	–	–
D. rotundifolia	0.2 (0.1)	0.1 (0.1)	0.2 (0.2)	1.5 (0.8)	–	–	0.6 (0.3)	0.3 (0.2)	0.2 (0.3)	0.3 (0.2)	0.5 (0.1)
Empetrum nigrum	–	0.3 (0.4)	5.0 (4.6)	–	–	2.6 (3.3)	0.2 (0.5)	–	3.7 (4.9)	–	0.2 (0.5)
Eriophorum vaginatum	1.8 (2.5)	6.4 (6.3)	34.0 (11.4)	–	14.0 (4.2)	13.6 (4.1)	8.2 (2.5)	16.0 (8.2)	22.4 (18.7)	12.6 (7.0)	14.2 (7.1)
Ledum palustre	–	0.1 (0.1)	3.0 (2.6)	–	–	3.0 (4.5)	–	–	–	–	–
Menyanthes trifoliata	–	–	–	1.4 (0.9)	–	–	–	–	–	–	–
Pinus sylvestris	–	–	0.1 (0.2)	–	–	0.2 (0.1)	–	–	–	–	–
Rhynchospora alba	–	–	–	7.8 (8.0)	–	–	–	–	–	–	–
Rubus chamaemorus	–	0.5 (0.9)	11.6 (4.8)	–	–	0.2 (0.3)	11.4 (6.1)	0.7 (1.3)	4.5 (4.3)	0.9 (0.7)	1.7 (2.0)
Scheuchzeria palustris	4.4 (1.5)	5.9 (3.2)	–	1.1 (0.6)	1.1 (0.6)	–	–	3.2 (2.8)	1.3 (1.2)	1.2 (1.0)	1.7 (1.1)
Trichophorum cespitosum	–	–	–	2.4 (4.3)	–	0.2 (0.5)	–	–	–	–	–
Vaccinium microcarpum	–	0.2 (0.2)	0.9 (0.2)	–	–	0.2 (0.2)	0.6 (0.2)	0.4 (0.4)	0.1 (0.1)	0.3 (0.1)	–
V. oxycoccos	0.5 (0.3)	–	–	0.4 (0.1)	0.8 (0.3)	–	–	2.0 (1.0)	0.5 (0.1)	0.2 (0.3)	1.5 (0.7)
V. uliginosum	–	–	1.4 (1.1)	–	–	2.9 (3.2)	0.6 (0.4)	–	1.7 (1.2)	0.3 (0.2)	–
V. vitis-idaea	–	–	–	–	–	0.1 (0.2)	–	–	–	–	–
Number of species	11	17	16	18	9	19	12	12	19	19	17

Vuonna 2002 ilmestyneet Metsähallituksen luonnonsuojelu-julkaisut

Sarja A

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Sarja B

No 63 Metsähallitus 2002: Luonnonsuojelualueiden hoidon periaatteet. Metsähallituksen luonnonsuojelualueiden tavoitteet, tehtävät ja hoidon yleislinjat. 47 s. (10 euroa).