Ann. Bot. Fennici 38: 63–73 ISSN 0003-455X
Helsinki 23 March 2001

A 600-year forest fire record in a varved lake sediment (Ristijärvi, Northern Karelia, Eastern Finland)

Aki Pitkänen & Elisabeth Grönlund

University of Joensuu, Karelian Institute, Department of Ecology, P.O. Box 111, FIN-80101 Joensuu, Finland

Received 18 May 2000, accepted 1 December 2000

Pitkänen, A. & Grönlund, E. 2001: A 600-year forest fire record in a varved lake sediment (Ristijärvi, Northern Karelia, Eastern Finland). — *Ann. Bot. Fennici* 38: 63–73.

Charcoal particle and pollen influx values in the annually laminated sediment of a boreal forest lake surrounded mostly by mesic soils were used to reconstruct the history of forest fires in Eastern Finland for a 600-year period between 100 BC and AD 500, prior to any significant human influence. Six to seven local fires were detected during this period, at an average interval of 90–115 years. The corresponding fire rotation time is estimated to be 180–230 years. The local fire interval and *Picea* pollen percentages at the site were of the same magnitude as those recorded at two sites with dry soils in eastern Finland, suggesting that the average fire return interval may have been similar at dry and mesic sites. The intensity of fires was estimated from the declines in influxes of spruce and pine pollen. Pine can survive surficial fires of low intensity, but spruce trees are killed by virtually all fires. The contemporary declines in spruce and pine pollen influxes suggest that about half of the fires were strong ones, causing stand replacement.

Introduction

With the present concern about the maintenance of biodiversity, interest in boreal forest dynamics has also increased. Fires have been the most important natural disturbance maintaining successional cycles in boreal forests (Zackrisson 1977) and they are a significant factor in the continuity of various forest structures (Syrjänen *et al*. 1994, Bradshaw *et al*. 1997). By creating a mosaic of forest stands at varying successional stages, repeated fires have maintained biodiversity in the boreal forests as well as being important for the nutrient dynamics of forest ecosystems (Zackrisson & Östlund 1991). In addition, climatic conditions affect fire regimes (Engelmark 1984, Clark 1988a, 1990) and aerosol and particle emissions released by fires can also

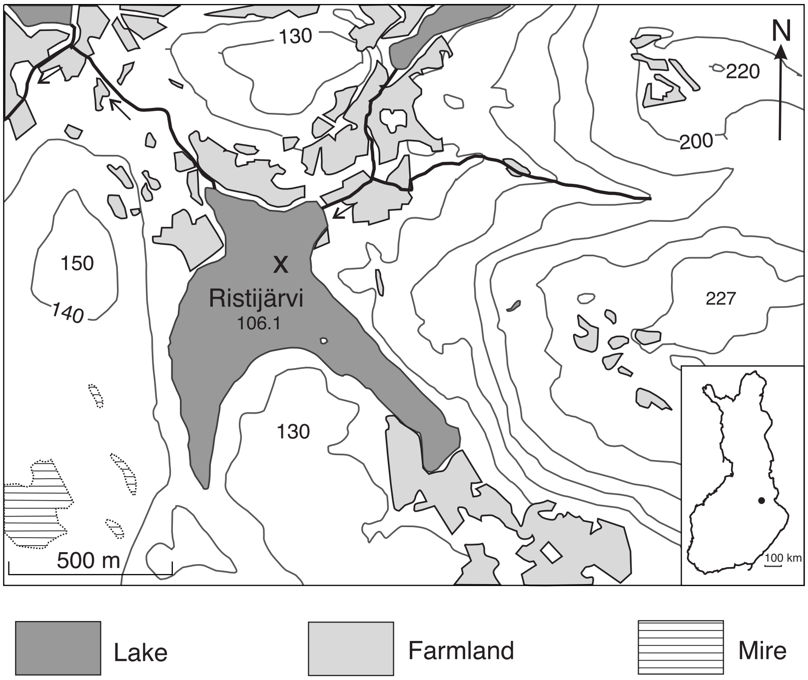

Fig. 1. Location and detailed map of Ristijärvi. The coring point is indicated by cross. The altitudes of the hills in the catchment area and of the lake surface above sea level are indicated.

have significant effects on climate (Cofer *et al.* 1997).

The long term fire dynamics of European boreal forests are poorly understood, however. Only a limited number of dendrochronological fire history studies have been performed in the Fennoscandian area (Zackrisson 1977, Haapanen & Siitonen 1978, Engelmark 1984, Engelmark *et al.* 1994, Lehtonen *et al.* 1996, Lehtonen & Huttunen 1997, Lehtonen 1998), and these usually cover only the past few hundred years, due to decaying of the wood. Also, ignition due to human activities has been a significant cause of forest fires in Fennoscandia during this period (Zackrisson 1977, Lehtonen *et al.* 1996, Lehtonen & Huttunen 1997, Lehtonen 1998), and in some areas the dominant one. To obtain information on natural fire regimes and connections between climate and the incidence of forest fires, it is necessary to be able to extend the time periods studied further back into the past.

Studies based on charcoal records in annually laminated (varved) lake sediments can provide a record of fires over periods of several millenia (Tolonen 1986), but only a few investigations based on varved sediments have been carried out in Fennoscandia so far (Tolonen 1978, Huttunen 1980, Tolonen 1983, Pitkänen & Huttunen 1999). Other authors have considered fire history on the basis of non-laminated sediments (e.g. Odgaard 1992, Sarmaja-Korjonen 1992, 1995, 1998), peat (e.g. Hyvärinen & Sepponen 1988, Tolonen 1985) or mor humus (Bradshaw & Zackrisson 1990).

The aim of the present work was to estimate the forest fire interval at a mesic forest site prior to any major human influence by means of charcoal particle and pollen analyses of a varved lake sediment. The sediment cores had originally been obtained from Ristijärvi, a lake in eastern Finland, in the winters of 1988 and 1992 for a study of palaeoecological land-use history, in which the earliest evidence of slash-and-burn cereal cultivation was dated to AD 1243, at a sediment depth of 91 cm (Poutiainen *et al.* 1994, Taavitsainen *et al.* 1998). This result is in accordance with earlier pollen and historical evidence from Northern Karelia that suggests that there were limited areas with cereal cultivation and a small population prior to AD 1300–1500 (Könönen & Kirkinen 1969, Grönlund 1995).

To reconstruct the fire frequency at this site during a period well before slash-and-burn cultivation started, a sequence of about 600 years (ca. 100 BC–AD 500), covered by earlier pollen analyses was chosen here for charcoal particle analysis.

Material and methods

The study area

The study lake, Ristijärvi (63°37´N, 28°57´E), is situated on the boundary between the south and middle boreal vegetation zones (Ahti *et al*. 1968). The average temperature in summer (June–August) is from 14 to 15 °C, and that in midwinter (December–February) from –10 to –12 °C, with a mean annual temperature around +1.5 °C and precipitation of 650 mm a^{-1}, of which an average of 220 mm falls as rain during the summer (Ilmatieteen laitos 1991).

The lake is ca. 30 ha in area and has a maximum water depth of 22 m. The drainage basin is 550 ha in area. The lake (106 m a.s.l.) is situated between morainic hill ridges, with the terrain rising about 100 m above the lake surface on the eastern side. The ridges in the other directions are lower, about 25–40 m above the lake surface. The low-elevation soils around the lake consist of fine-grained water-lain silts and clays. One brook discharges into the lake and one outlet leaves it (Fig. 1). The forests today are in commercial use and are mostly dominated by spruce (*Picea abies*) and represent the *Vaccinium myrtillus* type (*sensu* Cajander 1949), although there are also patches representing dry forest types that are dominated by Scots pine (*Pinus silvestris*). Birch (*Betula pendula* and *B. pubescens*) and alder (*Alnus incana*) are found to a lesser extent in the drainage area.

Sediment sampling, sediment characteristics and sample treatment

A sediment core of 3–109 cm was taken from the deepest part of the lake with a freezing corer (Fig. 1) (Huttunen & Meriläinen 1978) in 1988, and two longer cores, to sediment depths of 110–527 cm, with a hammer-piston corer (Huttunen & Meriläinen 1975) in 1992. The cores were photographed and correlated visually according to similarities in their varve structure. The varves in the frozen core were counted from photographs and those in the piston core from fresh sediments (Fig. 2). The sediment sequence 151–200 cm was chosen for the present charcoal analysis, as a pollen analysis had been performed on continuous 1-cm segments of it earlier (Poutiainen *et al*. 1994).

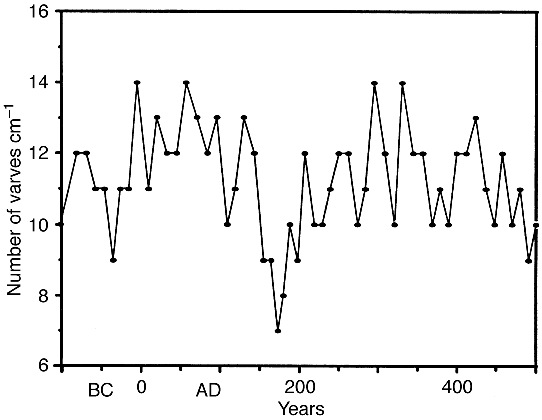

Fig. 2. Numbers of varves (years) for the sediment sequence dated to 100 BC–AD 500.

Laminations were visible in the fresh sediment in the form of yearly couplets of greyish and narrower darker bands, the latter representing accumulation of humic compounds in the winter, a common varve structure in the boreal forest zone (Renberg 1981, Simola 1990, 2000).

Samples for loss-on-ignition analysis were taken at 1 cm intervals, dried at 70 °C for 24 h and ignited for three hours at 550 °C. Subsamples of about 1 cm^3 had been taken from the sediment cores at continuous 1-cm intervals for the earlier pollen analysis and prepared according to standard procedures with a short HF treatment (Berglund & Ralska-Jaziewiczowa 1986).

Three *Lycopodium clavatum* spore tablets were added to each sample to provide marker grains for the calculation of absolute pollen frequencies (Stockmarr 1971). A wet weight of 1 g was assumed to correspond to 1 cm^3 of sediment, although about 40%–50% of the wet weight of the sediment consisted of mineral matter. Thus, the calculated absolute pollen values are smaller than the real values. The propor-

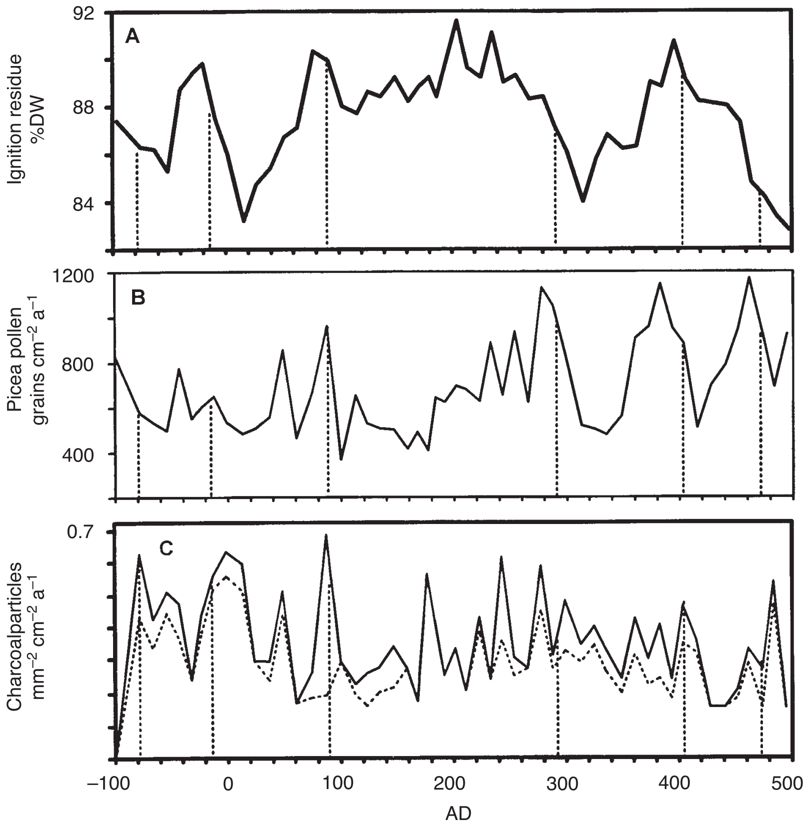

Fig. 3. Percentage stratigraphic diagram of ignition residue (**A**), *Picea* pollen influx (**B**) and charcoal particle area influx (**C**) for the sediment sequence from 100 BC to AD 500. Vertical dotted lines indicate the dates of estimated local fires. In **C**, dotted line = influx values for charcoal particles < 625 μm²; solid line = influx values for charcoal particles > 625 μm².

tions of mineral matter in the samples varied only slightly, however (Fig. 3A), so that the influx values for the samples are comparable with each other.

Pollen concentrations in the samples were calculated using the following formula:

$$C = P \times L/L_c \times W \quad (1)$$

where C is the pollen concentration (pollen grains cm^{-3}), L is the number of *Lycopodium* spores added, L_c is the number of *Lycopodium* spores counted in the samples, P is the number of pollen grains counted, and W is wet weight (g) of the sample.

Pollen influx values were calculated from the formula:

$$I = C/V \quad (2)$$

where I is the pollen influx, cm^{-2} a^{-1}, C is the pollen concentration, cm^{-3}, and V is the number of varves counted in the sample.

Charcoal particle analysis

The area of charcoal particles was measured with a graticule of mesh size 6.1 μm², the particles being divided into two size classes: 50–625 μm² and > 625 μm². Large particles in the > 625 μm² size class were measured individually. Only two size classes were used because the slides were "foggy" making it very difficult to count and measure the small charcoal particles. Particles smaller than 50 μm² were therefore ignored. This problem may have been due to too short a duration of the hydrofluoric acid treatment.

The particles were counted at 400× magnification on traverses across the microscope slides at 1 mm intervals. Counting was continued until at least 20% of *Lycopodium* spores counted in the pollen analysis were recorded. To obtain the total area of the smaller particle size class, the midpoint of the size class (337 μm²) was multiplied by the number of particles counted. For the total particle area, the sum of the areas of the individually measured particles was added for the value of the smaller size class. Area influx values for charcoal particles were then calculated in the same way as in the pollen analyses.

Estimation of local charcoal peaks

The interpretation of peaks in charcoal influx diagrams, in terms of the location and size of the area burned, is a problematic question in fire history studies based on lake sediments, because charcoal particles are transported into lakes via the air, and transport by surface flow is significant only in exceptional cases (*see* Clark 1988b). Thus the microscopic charcoal particles found in lake sediments may originate from sources located long distances away (*see* Patterson *et al.* 1978, Clark 1988b), or else they may have been produced in fires taking place adjacent to the lake (Pitkänen *et al.* 1999). On the other hand, macroscopic charcoal particles are transported only very short distances and their presence indicates fires close to the basin (Clark 1988b). The latter are almost absent from the sediments of Ristijärvi, however, and thus cannot be used as indicators of local fires. A scarcity of macroscopic charcoal particles is also found in some other lakes in Eastern Finland (Pitkänen *et al.* 1999, Pitkänen 2000).

For the above reasons, declines in spruce pollen influx values coinciding with charcoal peaks were taken as indicators of local fires. It has been shown that even weak fires destroy all the spruce trees in the affected area (Heikinheimo 1915, Kujala 1926, Sarvas 1937), and as *Picea* pollen grains are fairly large and heavy, the majority of the pollen grains are transported only short distances. In addition, according to the pollen dispersal model of Sugita *et al.* (1997), the *Picea* pollen influx will decline sharply after a fire on a lake shore or 100 metres of the shore. Fires at greater distances, up to a few hundred metres, may also be reflected in a decline in *Picea* and other arboreal pollen if the area burned is large enough, about eight times larger than the area of the lake (Sugita *et al.* 1997).

According to Jackson (1990), most of the pollen of poorly dispersed species (*Picea, Tsuga*) originates within 500 m of the lake, and Schmidt-Vogt (1986) similarly notes that about 50% of *Picea* pollen is deposited within 500 m of its source at a wind speed of 4 ms^{-1}, and only 25% spreads further than 2 km. In view of the poor dispersal of spruce pollen, it is reasonable to assume that declines in spruce stands due to fires are reflected in its pollen influx if the burned areas are restricted to the lake shore or are situated less than 500 m from the shore. In this study only charcoal peaks followed by a decline in *Picea* pollen lasting for at least 40–50 years, were regarded as evidence of local fires. The term local fire is used here to refer to a fire occurring within a distance of 500 m from the lake shore.

Other fire history studies connecting declines in *Picea* pollen with charcoal records in lake sediments or peat include those of Tolonen (1978, 1985, 1987a, 1987b), Huttunen (1980), Sarmaja-Korjonen (1992), Pitkänen and Huttunen (1999), and Pitkänen (2000).

The *Betula*/*Picea* pollen ratio was used as an additional clue to the local character of charcoal peaks, as it may respond sensitively to local fires by virtue of the fact that *Picea* cannot survive fires and much of its pollen originates from very close distances, whereas a high proportion of *Betula* pollen originates from a large area (Jackson 1990). Also, *Betula* is a fast-growing pioneer species on burned sites, so that an increase in its pollen can be expected following a local fire.

Results

Charcoal influx

The mean estimated charcoal influx area was 0.4 $mm^2\ cm^{-2}\ a^{-1}$, with a range of 0.15–0.7 $mm^2\ cm^{-2}\ a^{-1}$ (Fig 3). The actual charcoal influx must be higher, however, because small particles ($< 50\ \mu m^2$), which were excluded from the present counts, were abundant in all samples. The number of large charcoal particles ($> 625\ \mu m^2$) was low in all the samples, and the maximum size was

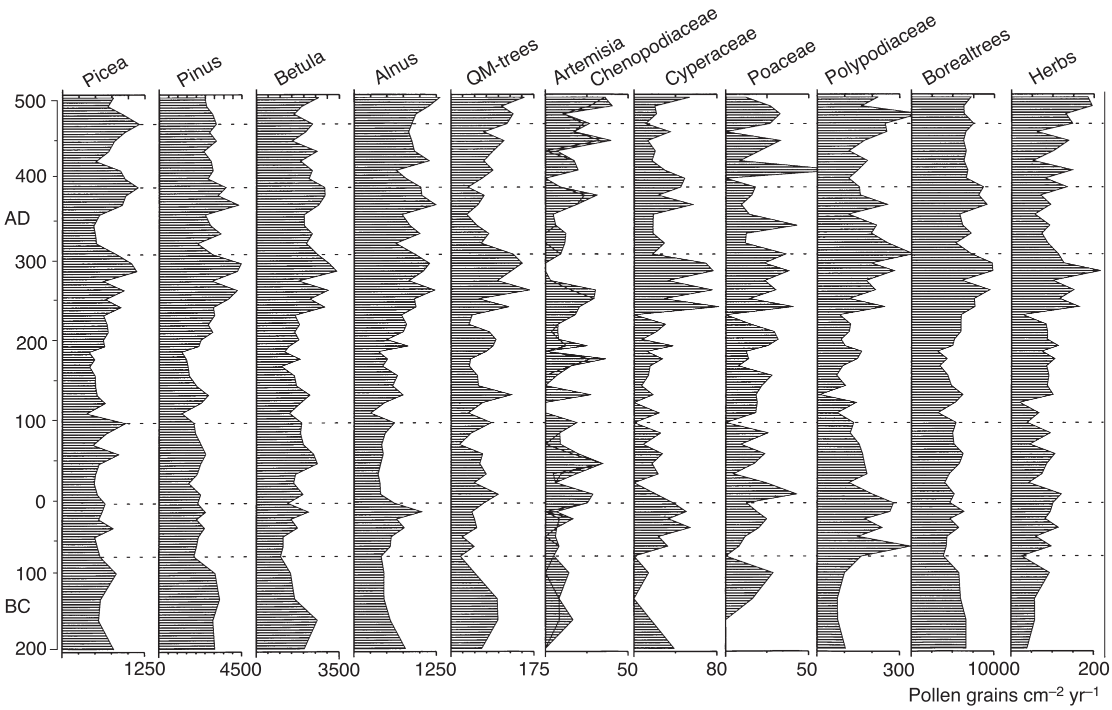

Fig. 4. Pollen influx diagram for selected taxa from 100 BC to AD 500. Horizontal dotted lines indicate the dates of estimated local fires.

5000 μm². The influx of large charcoal particles varied in the range 0–910 particles cm^{-2} a^{-1}, with an average of 120 particles cm^{-2} a^{-1}.

Pollen influx

The declines in *Picea* pollen influx which match the charcoal peaks suggest that six local fires (Figs. 3 and 4) occurred during the period studied here. The declines lasted from 50 to 100 years, and the average interval between deduced local fires is about 115 years (range about 60–200 years). There are also ten other charcoal peaks with an areal influx of more than 0.4 mm^2 cm^{-2} a^{-1}, indicating fires at longer distances than about 500 m from the lake. The arboreal pollen influx values and selected pollen taxa are shown in Fig. 4. The average influx of boreal tree pollen was 6180 grains cm^{-2} a^{-1}, with a range of 3190–10 600 grains cm^{-2} a^{-1}. The pollen records indicate a mixed coniferous forest structure in the area.

The total arboreal pollen (AP) influx values showed fluctuations connected with the inferred fires. This is reflected in an increase in AP influx during the longest interval between fires (ca. AD 90–300). There were also significant phases of decreasing AP influx lasting several decades after the fires that occurred around 80 BC, AD 300 and AD 390. The *Pinus* influx also showed distinct declines following these fires (Fig. 4). Around 80 BC *Pinus* pollen influx values declined to 30% of their previous level, after which they remained at a low level for more than 250 years.

In comparison, these decreases in total arboreal pollen influx were of much smaller magnitude than the decline in AP influx at the beginning of intensive forest clearing at the end of 17th century (Fig. 5), which suggests that prior to slash-and-burn cultivation only a part of the lake catchment may have burned during a single fire. An abrupt decline in tree pollen influx between AD 1680 and 1690 indicates deforestation of a large area, possibly the whole catch-

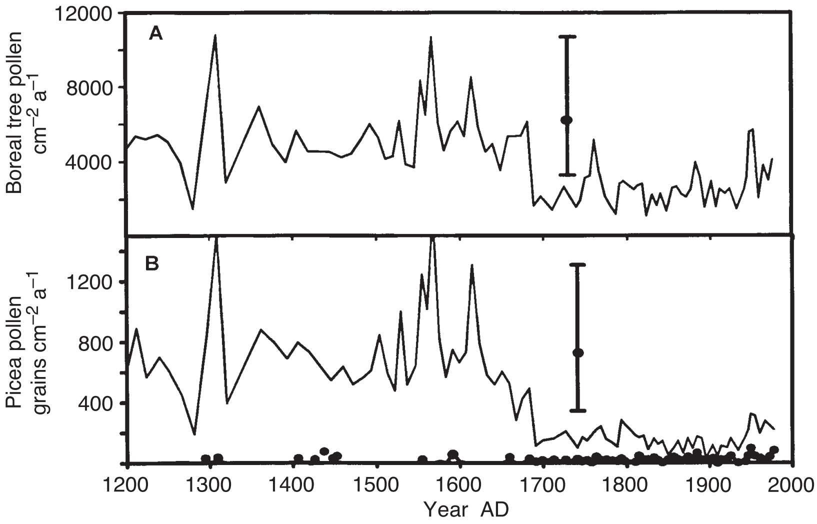

Fig. 5. Influx diagram for the arboreal pollen taxa; *Picea, Pinus, Betula* and *Alnus* (**A**) and (**B**) influx of *Picea* (solid line) and *Cerealia* pollen (black dots) during the last 800 years (AD 1200–1990). The vertical columns in **A** and **B** show the range and mean of *Picea* pollen influx for the period from 100 BC to AD 500.

ment of the lake, due to slash-and-burn cultivation (Fig. 5).

The increases in *Betula* pollen influx after the inferred fire years probably reflect an increase in birch at the burned sites, as is evident in the *Betula*/*Picea* pollen ratio. The ratio reaches its maximum about 40–50 years after each inferred fire indicating post-fire increases in *Betula* in burned areas. The halting of the increase in the *Betula*/*Picea* pollen ratio suggests that the new generation of spruce had started effective pollen production (Fig. 6). *Alnus* pollen fluctuated quite randomly and increased only after two fire dates (80 BC and AD 460). The fluctuations in the sparse non-arboreal pollen taxa followed a random pattern not associated with the inferred fire dates, but the ignition residue values suggest a slight increase in organic matter in the sediment after some of the estimated fires notably in 10 BC, AD 300 and AD 460. The changes in the values were not significant in the other cases (Fig. 3).

Discussion

Fire interval

The average local fire interval of 115 years obtained here is consistent with the findings of earlier fire history studies in Finland, where estimates of local mean fire intervals before slash-and-burn cultivation based on annually varved lake sediments vary between 70 and 124 years (Tolonen 1978, Huttunen 1980, Tolonen 1983, Pitkänen & Huttunen 1999). A slight decline in *Picea* percentages and an abrupt increase in the *Betula*/*Picea* ratio (Fig. 6) suggest one additional fire in the vicinity of the lake about AD 220, although this is not reflected in the *Picea* pollen influx. Inclusion of this possible local fire in the calculations would reduce the mean local fire interval estimate to about 90 years.

In view of dendrochronological observations that some sites burn more often than others depending on the soil type, topography and aspect of the slope (Zackrisson 1977, Engelmark 1984), it has been assumed that the advance of successive fires in the landscape may follow the same pattern, and that mesic sites burn less often than dry ones (Angelstam & Rosenberg 1993). Mesic forests may have burned as often as dry forests, however, if the fires occurred during a dry period which had lasted long enough to dry them out (Granström *et al.* 1995). The average local fire interval of 90 years obtained here differs only slightly from the corresponding estimates of 70–80 years and 85 years recorded at two dry forest sites (*Vaccinium* type) in Eastern Finland at a time prior to any significant human influence (Pitkänen & Huttunen 1999, Pitkänen 2000).

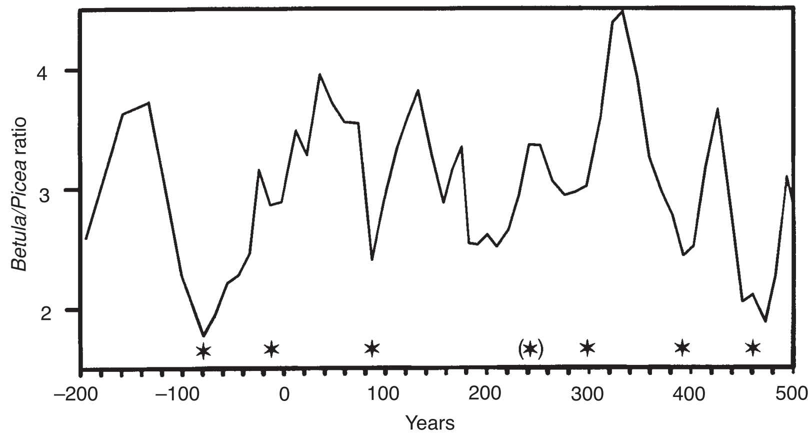

Fig. 6. *Betula/Picea* pollen ratios over the period 200 BC to AD 500 (two-sample moving averages). The estimated local fires are indicated with asterisks, of which the one in parentheses is a possible fire event not reflected in a decline in spruce pollen influx. Increases in the ratio suggest decline in spruce and simultaneous increases in birch after fires.

Fire rotation time

Heinselman (1973) used the term "fire rotation time" to refer to the average period during which the whole ecosystem would have burned over, while Zackrisson (1977) used it to refer to the time required for an area of defined size to be completely affected by fire. In that sense, a coarse estimate of the fire rotation time for the forests surrounding Ristijärvi may be obtained by considering the area over which "local fires" can be detected from spruce pollen fluctuations. This area can be assumed to exceed a distance of 500 m from the lake shore. Theoretical calculations by Sugita *et al.* (1997) predict that a burned area should be about eight times the area of the lake in order to be reflected significantly in a decline in pollen influx, i.e. at least 200 ha in the present case. Two fires of 200 ha in size may have been enough to burn over the surroundings of Ristijärvi entirely within a few hundred metres. Consequently, if the mean interval between local fires was 90–115 years, the fire rotation time may have been about 180–230 years. The shorter estimate is more probable, because the longer mean local fire estimate (115 years) was due to one possibly exceptional fire interval of 200 years.

This estimate for fire rotation time in the catchment of the lake may also broadly represent the burning rate in the landscape on a larger scale. The relatively small fluctuations in arboreal pollen influx prior to intensive human influence compared with the sudden decrease in tree pollen influx during the late 17th century (Fig. 5) indicate that the forests around the lake were only partially burned during each fire. Reconstruction of past burned areas in a one square kilometre tract of Itasca National Park, Minnesota, USA (Clark 1990) indicates that the catchments of small lakes do not usually burn entirely on one occasion. Often about half or more than half will remain intact.

Fire intensity

The declines in the influx of *Pinus* pollen after three fires (ca. 80 BC, AD 300 and AD 390) suggest that they were intensive enough to kill the pine trees. Pine survives well in the case of surficial fires of low or moderate intensity (Heikinheimo 1915, Sarvas 1937), and thus the reduction suggests strong, stand-replacing fires. In the other three cases the fires may have been surficial and of relatively low intensity, since the *Pinus* pollen influx did not decline (Fig. 4). Also, pollen and charcoal data from two other sites in Northern Karelia suggest that about half of the fires were strong enough to kill pines

(Pitkänen & Huttunen 1999, Pitkänen 2000). This result is contrary to the view that strong surface fires or crown fires are much less common in the Fennoscandian forests than low-intensity surface fires (Saari 1923, Granström 1996, Lehtonen & Huttunen 1997). One possible explanation may be that the dendrochronological and historical material available for fire history studies in Fennoscandia covers only the last few centuries, during which time fire conditions may have changed due to the greater human influence on the forests. The increase in fire frequency due to human activities resulted in the disappearance of spruce from drier sites and altered the forest structure in Northern Karelia to a pine-dominated type. Also, the proportion of deciduous trees in the forests increased due to slash-and-burn cultivation (Lehtonen 1998, Pitkänen & Huttunen 1999). The absence or scarcity of spruce reduces the probability of a fire rising to the crown layer. According to observations from Russian forests, fires are usually of low intensity as long as there are only a few spruce trees in the forest and are stronger in forests with abundant spruce (Syrjänen *et al*. 1994). Pollen studies in Finland also indicate a change to a pine-dominated forest structure after the appearance of cultivation indicators (Tolonen 1978, Sarmaja-Korjonen 1992, Grönlund *et al*. 1990, Pitkänen & Huttunen 1999).

Acknowledgements

We sincerely thank Mrs. Kirsti Kyyrönen for preparing the graphics, the skilful technical staff of the Dept. of Ecology for the fieldwork and Leena Kivinen, M.Sc., for some of the pollen analyses. Doc. Heikki Simola made valuable comments. This research has recieved financial support from the Finnish Cultural Foundation, the Northern Karelian Cultural Foundation, the Foundation of Foresters and the Academy of Finland, grant no. 1003-6.

References

Ahti, T., Hämet-Ahti, L. & Jalas, J. 1968: Vegetation zones and their sections in northwestern Europe. — *Ann. Bot. Fennici* 5: 169–221.

Angelstam, P. & Rosenberg, P. 1993: Aldrig sällan ibland ofta. — *Skog & Forskning* 1/93: 34–41.

Berglund, B. E. & Ralska-Jaziewiczowa, M. 1986: Pollen analysis and pollen diagrams. — In: Berglund, B. E. (ed.), *Handbook of Holocene palaeoecology and palaeohydrology*: 455–485. John Wiley & Sons, New York.

Bradshaw, R. H. W., Tolonen, K. & Tolonen, M. 1997: Holocene records of fire from the boreal and temperate zones of Europe. — In: Clark, J. S., Cachier, H., Goldammer, J. G. & Stocks, B. (eds.), *Sediment records of biomass burning and global change*. NATO ASI Series I 51: 347–365.

Bradshaw, R. H. W. & Zackrisson, O. 1990: A two thousand year history of a northern Swedish boreal forest stand. — *J. Veg. Sci.* 1: 519–528.

Cajander, A. K. 1949: Forest types and their significance. — *Acta For. Fennica* 56: 1–71.

Clark, J. S. 1988a: Effect of climate change on fire regimes in northwestern Minnesota. — *Nature* 334: 233–235.

Clark, J. S. 1988b: Particle motion and the theory of charcoal analysis: source area, transport, deposition, and sampling. — *Quarternary Research* 30: 67–80.

Clark, J. S. 1990: Fire and climatic change during the last 750 yr in Northwestern Minnesota. — *Ecol. Monogr.* 60: 135–159.

Cofer, W. R., Koutzenougii, K. P., Kokorin, A. & Ezcurra, A. 1997: Biomass burning emissions and the atmosphere. — In: Clark, J. S., Cachier, H., Goldammer, J. G. & Stocks, B. (eds.), *Sediment records of biomass burning and global change*. Nato ASI Series I 51: 189–206.

Engelmark, O. l984: Forest fires in Muddus National Park (northern Sweden) during past 600 years. — *Can. J. Bot.* 62: 893–898.

Engelmark, O., Kullman, L. & Bergeron, Y. 1994: Fire and age structure of Scots pine and Norway spruce in northern Sweden during the past 700 years. — *New Phytologist* 126: 163–168.

Granström, A. 1996: Fire ecology in Sweden and future use of fire for maintaining biodiversity. — In: Goldammer, J. G. & Furyaev. V. V. (eds.), *Fire in ecosystems in boreal Eurasia*: 445–452. Kluwer, Dordrecht.

Granström, A., Niklasson, M. & Schimmel, J. 1995: Brandregimer — finns dom? — *Skog & Forskning* 1: 9–14.

Grönlund, E. 1995: A palaeoecological study of land-use history in East Finland. — *Ph. D. thesis. Univ. Joensuu Publ. Sci.* 31: 1–74.

Grönlund, E., Simola, H. & Uimonen-Simola, P. 1990: Early agriculture in the eastern Finnish Lake District. — *Norw. Archaeol. Rev.* 23: 79–85.

Haapanen, A. & Siitonen, P. 1978: Kulojen esiintyminen Ulvinsalon luonnonpuistossa [Forest fires in Ulvinsalo strict nature reserve]. — *Silva Fennica* 12: 187–200. [In Finnish with English summary].

Heikinheimo, O. 1915: Kaskiviljelyn vaikutus Suomen metsiin. — *Acta For. Fennica* 4: 1–264 + App. 1–149 & 1–59.

Heinselman, M. L. 1973: Fire in the virgin forest of the Boundary Waters Canoe Area, Minnesota. — *Quat. Res.* 3: 329–382.
Huttunen, P. 1980: Early land use, especially the slash-and-burn cultivation in the commune of Lammi, southern Finland, interpreted mainly using pollen and charcoal analyses. — *Acta Bot. Fennica* 113: 1–45.
Huttunen, P. & Meriläinen, J. 1975: Modifications of a rodless core sampler for investigation lake sediments. — *Publ. Univ. Joensuu BII* 4: 1–4.
Huttunen, P. & Meriläinen, J. 1978: New freezing device providing large unmixed sediment samples from lakes. — *Ann. Bot. Fennici* 15: 128–130.
Hyvärinen, V. & Sepponen, P. 1988: Kivalon alueen paksusammalkuusikoiden puulaji ja metsäpalohistoriaa [Tree species history and local forest fires in the Kivalo area of Northern Finland]. — *Folia Forestalia* 720: 1–26. [In Finnish with English summary].
Ilmatieteen laitos 1991: *Tilastoja Suomen ilmastosta 1961–1990*. — Ilmatieteen laitos, Helsinki.
Jackson, S. T. 1990: Pollen source area and representation in small lakes of the northeastern United States. — *Rev. Palaeobot. Palynol.* 63: 53–76.
Kujala, V. 1926: Untersuchungen über den Einfluss von Waldbränden auf die Waldvegetation in Nord-Finnland. — *Comm. Inst. For. Fennica* 10: 1–41.
Könönen, A. V. A. & Kirkinen, H. 1969: *Pohjois-Karjalan historia I*. — Karjalaisen Kulttuurin Edistämissäätiö, Joensuu. 183 pp.
Lehtonen, H. 1998: Fire history recorded on pine trunks and stumps: Influence of land use and fires on forest structure in North Karelia. — *Scand. J. For. Res.* 13: 462–468.
Lehtonen, H. & Huttunen, P. 1997: History of forest fires in eastern finland from the 15th century AD — the possible effects of slash and burn cultivation. — *Holocene* 7: 223–228.
Lehtonen, H., Huttunen, P. & Zetterberg, P. 1996: Influence of man on forest fire frequency in Northern Karelia, Finland, as evidenced by fire scars on Scots pines. — *Ann. Bot. Fennici* 33: 257–263.
Odgaard, B. V. 1992: The fire history of Danish heathland areas as reflected by pollen and charred particles in lake sediments. — *Holocene* 2: 218–226.
Patterson., W. A., Edwards, K. J. & Maguire, D. J. l978: Microscopic charcoal as a fossil indicator of fire. — *Quat. Sci. Rev.* 6: 3–23.
Pitkänen, A. 2000: Fire frequency and forest structure at a dry site between AD 440 and 1110 based on charcoal and pollen records from a laminated sediment in Eastern Finland. — *Holocene* 10: 221–228.
Pitkänen, A. & Huttunen, P. 1999: A 1300-year forest fire history at a site in Eastern Finland based on charcoal and pollen records in laminated lake sediment. — *Holocene* 9: 311–320.
Pitkänen, A., Huttunen, P. & Lehtonen, H. 1999: Comparison of sedimentary microscopic charcoal particle records in a small lake with dendrochronological data: evidence for the local origin of microscopic charcoal produced by forest fires of low intensity in Eastern Finland. — *The Holocene* 9: 559–567.
Poutiainen, H., Grönlund, E., Koponen, M. & Kupiainen, R. 1994: Havaintoja Pohjois-Karjalan asutus- ja viljelyhistoriasta [Settlement and cultivation history of North Karelia]. — *Kentältä poimittua* 2: 70–75. [In Finnish with English summary].
Renberg, I. 1981: Formation, structure and visual appearance of iron-rich, varved lake sediments. — *Verh. Internat. Verein. Limnol.* 21: 94–101.
Saari, E. 1923: Kuloista etupäässä Suomen valtionmetsiä silmällä pitäen [Forest fires in Finland with special reference to state forests].— *Acta For. Fennica* 26: 1–155. [In Finnish with English summary].
Sarmaja-Korjonen, K. 1992: Fine-interval pollen and charcoal analyses as tracers of early clearance periods in S Finland. — *Acta Bot. Fennica* 146: 1–75.
Sarmaja-Korjonen, K. 1995: Pollen and charcoal analyses from the Etu-Mustajärvi, S Finland, with special reference to an early Holocene *Urtica* pollen maximum. — *Bull. Geol. Soc. Finland* 67: 37–46.
Sarmaja-Korjonen, K. 1998: Latidunal differences in the influx of microscopic charcoal particles to lake sediments in Finland. — *Holocene* 8: 589–597.
Sarvas, R. 1937: Eri kasvilajien uudistuminen ja leviäminen kulon jälkeen. — *Acta For. Fennica* 46: 1–147.
Schmidt-Vogt, H. 1986: *Die Fichte, Band 11*. Paul Parey, Hamburg. 563 pp.
Simola, H. 1990: Structural elements in varved lake sediments. — *Geol. Survey Finland, Special Paper* 14: 5–9.
Simola, H. 2000: Lake sediments in historical monitoring of the environment. — In: Heinonen, P. (ed.), *Hydrological and limnological aspects of lake monitoring*: 160–181. John Wiley & Sons, New York.
Stockmarr, J. 1971: Tablets with spores used in absolute pollen analysis. — *Pollen Spores* 13: 615–621.
Sugita, S., MacDonald, G. M. & Larsen, C.P.S. 1997: Reconstruction of fire disturbance and forest succession from fossil pollen in lake sediments: potential and limitations. — In: Clark, J. S., Cachier, H., Goldammer, J. G. & Stocks B. (eds.), *Sediment records of biomass burning and global change*. NATO ASI Series I 51: 387–412.
Syrjänen, K., Kalliola, R., Puolasmaa, A., & Mattson, J., 1994: Landscape structure and forest dynamics in subcontinental Russian European taiga. — *Ann. Zool. Fennici* 31: 19–34.
Taavitsainen, J.-P., Simola, H. & Grönlund, E. 1998: Cultivation history beyond the periphery — early agriculture in the north European boreal forest. — *J. World Prehist.* 12: 199–253.
Tolonen, K. 1983: The post-glacial fire record. — In: Ross, W., Wein, W. & MacLean, D. A. (eds.), *The*

role of fire in northern circumpolar ecosystems: 21–44. John Wiley & Sons, New York.

Tolonen, K. 1986: Charred particle analysis. — In: Berglund, B. E. (ed.), *Handbook of Holocene palaeoecology and palaeohydrology*: 485–496. John Wiley & Sons, New York.

Tolonen, M. 1978: Palaeoecology of annually laminated sediments in lake Ahvenainen, S. Finland. I. Pollen and charcoal analyses and their relation to human impact. — *Ann. Bot. Fennici* 15: 177–208.

Tolonen, M. 1985: Palaeoecological record of local fire history from a peat deposit in SW Finland. — *Ann. Bot. Fennici* 22: 15–29.

Tolonen, M. 1987a: Primary and secondary forest successions reflected in a late Holocene pollen sequence from an upland mire near the SW coast of Finland. — *Ann. Bot. Fennici* 24: 97–109.

Tolonen, M. 1987b: Vegetational history in coastal SW Finland studied on a lake and a peat bog by pollen and charcoal analyses. — *Ann. Bot. Fennici* 24: 353–370.

Zackrisson, O. 1977: Influence of forest fires on the north Swedish boreal forest. — *Oikos* 29: 22–32.

Zackrisson, O. & Östlund, L. 1991: Branden formade skogslandskapets dynamic. — *Skog & Forskning* 4: 13–21.