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Influence of man on forest fire frequency in North Karelia, Finland, as evidenced by fire scars on Scots pines

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Fire scars on living Scots pines (*Pinus sylvestris* L.) and pine stumps dated by dendrochronology were used as evidence for fire history, the chronology of which was established for a period of 582 years, 1412–1994. A total of 36 different fire years were identified, the average incidence of fires in the area being once every 11.2 years. The mean fire interval was 36.7 years on the upper part of the hill and 58.6 years on the lower part. Forest fires increased in the 17th century and decreased at the end of the 19th century.

Key words: boreal forest, dendrochronology, fire history, fire interval, slash and burn cultivation

INTRODUCTION

The ecological importance of fire in boreal forests has been stressed by many authors (Sarvas 1937, Siren 1955, Uggla 1958, Heinselman 1973, Zackrisson 1977, Engelmark 1983, 1987, Johnson 1992), and fires are considered to have been a major factor in determining the composition and structure of the vegetation of these forests. The biodiversity of boreal forests is predominantly the end product of the long-term influence of natural and human-induced fires, and therefore a knowledge about forest fires is important as a basis for conserving this biodiversity.

Fire has been used for a long time to clear forests in various parts of the world, and burning of forest for agricultural purposes was once common practice in Finland (Heikinheimo 1915, Soininen 1974). Slash and burn cultivation was used for cereal production for some two thousand years in southern Finland (Huttunen 1980) and was the most widely used cultivation technique prior to the present century in the eastern parts of the country, as it was the method best suited to the stony soils of that region (Heikinheimo 1915, Soininen 1974). Slash and burn cultivation was not a uniform method as different types of forest demand different techniques (Soininen 1974). A cultivation plot cleared in a mature stand of coniferous forest, called a *huuhta*, would yield a good rye crop, but only for a few years. The most common method, however, was to cut down and burn an area of deciduous forest about 15–40 years old, which provided 2–4 harvests (Soininen 1974). In both methods, the plots were left to become reforested after the last harvest or were used as pasture. Fire could spread very easily from a slash and burn cultivation area to the adjacent forest, and therefore human-induced fires make it difficult to generalize about the role of fire in the natural dynamics of vegetation.

The dendrochronological techniques of fire scar analysis have been developed to determine the history of forest fires (Heinselman 1973, Zackrisson 1977, Dieterich & Swetnam 1984, Johnson & Fryer 1987, Bergeron & Brisson 1990, Brown & Swetnam 1994). Fire scars give good estimates of fire history, whereas tree ages are less dependable indicators (Houston 1973). Ring counting does not allow absolute temporal comparison of fire scars within or between trees because of the possibility of missing or false rings (Madany *et. al*. 1982), but cross-dating of ring series offers a means for identifying such anomalies and provides absolute dates for fires. With the use of cross-dating techniques, the remnant material can be used to reconstruct the local fire history over a maximum period of time, but naturally the chance of finding fire scars decreases as we go back in time. The only accurate way to determine the correct date of a fire is to cross-date the sample against a master chronology (Fritts 1976).

The aims of this research were to determine the forest fire history of a selected area in North Karelia during recent centuries and to determine how man has affected the frequency of fires, especially through slash and burn cultivation. There is little precise information available on the fire history of the boreal forests of Finland.

METHODS

The area studied here, Autiovaara, is part of the Patvinsuo National Park in North Karelia, eastern Finland (63°7´N, 30°40´E). It covers 300 ha and has about 80% mineral soil and 20% mires. The mean annual temperature is 2.1°C and the mean annual precipitation 562.8 mm (Heino & Hellsten 1983). The area ranges in altitude from 170 to 270 m. The granite bedrock is covered by morainic deposits. The most common forest types are the *Myrtillus* and *Vaccinium* types *sensu* Cajander (1949). The area supports mixed conifer forests of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karsten), and locally abundant hardwoods are the European white birch (*Betula pendula* Roth.), pubescent birch (*Betula pubescens* Ehrh.) and European aspen (*Populus tremula* L.). There has been anthropogenic influence in the area for hundreds of years, including extensive slash and burn cultivation (PKMMKA 1899).

The past fire history was reconstructed by the fire scar method as presented by Arno and Sneck (1977) and Zackrisson (1977), in which fire dates are determined from scars on living trees or stumps. The Scots pine is ideal for this work as it can attain an age of several hundred years and normally possesses fewer special problems for dating based on annual rings than other species.

Thirty-seven samples were collected from different parts of the area (Fig. 1), of which 36 could be accurately cross-dated. Because of repeated fires and human activities, it was impossible to find samples representing old slash and burn cultivation areas. Cross-sections were sawn from the scarred area on the stumps or dead trees, about 10–50 cm above a root collar. One increment core was taken. The samples were first sanded with a mechanical sander and then finished with a razor blade to expose the rings clearly. The ring widths were measured under a microscope to the nearest 0.01 mm. To avoid misinterpretation of the fire years, all the samples were cross-dated using the master chronology for North Karelia, which is based on living trees and historical timber (Zetterberg 1986, 1987).

Although a variety of statistical distributions might be fitted to fire interval data, the Weibull (Johnson 1979) and negative exponential (Van Wagner 1978) distributions have received the most attention. These are applicable to either area-based or fire-interval data. As the sampling area was small and human influence has been strong, it was difficult to reconstruct the area of the land affected by each fire. In this case the Weibull distribution was fitted to the fire-interval data (Clark 1989, 1990) after dividing the area into homogeneous parts. The goodness of fit and differences between distributions were tested with Kolmogorov-Smirnov two-sample tests.

The fire interval data from all samples were pooled to form a fire-interval histogram, and a non-parametric kernel estimator was used to explore and present the fire occurrence and fire-interval data. In non-parametric estimation methods the distribution is determined by the data as such instead of estimating the parameters of some known distribution (Silverman 1986). The kernel estimator with kernel K is defined by:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right), \qquad (1)$$

where n = number of observations, h = smoothing parameter, K = kernel function, x = sample from the unknown density function and X_i = random variable. The kernel function K, which determines the shape of the kernels, was chosen in this case to be the Gaussian function. The value of the smoothing parameter h, describing the width of kernels, was specified by plotting several curves with different values for this parameter and subjectively choosing the most suitable one.

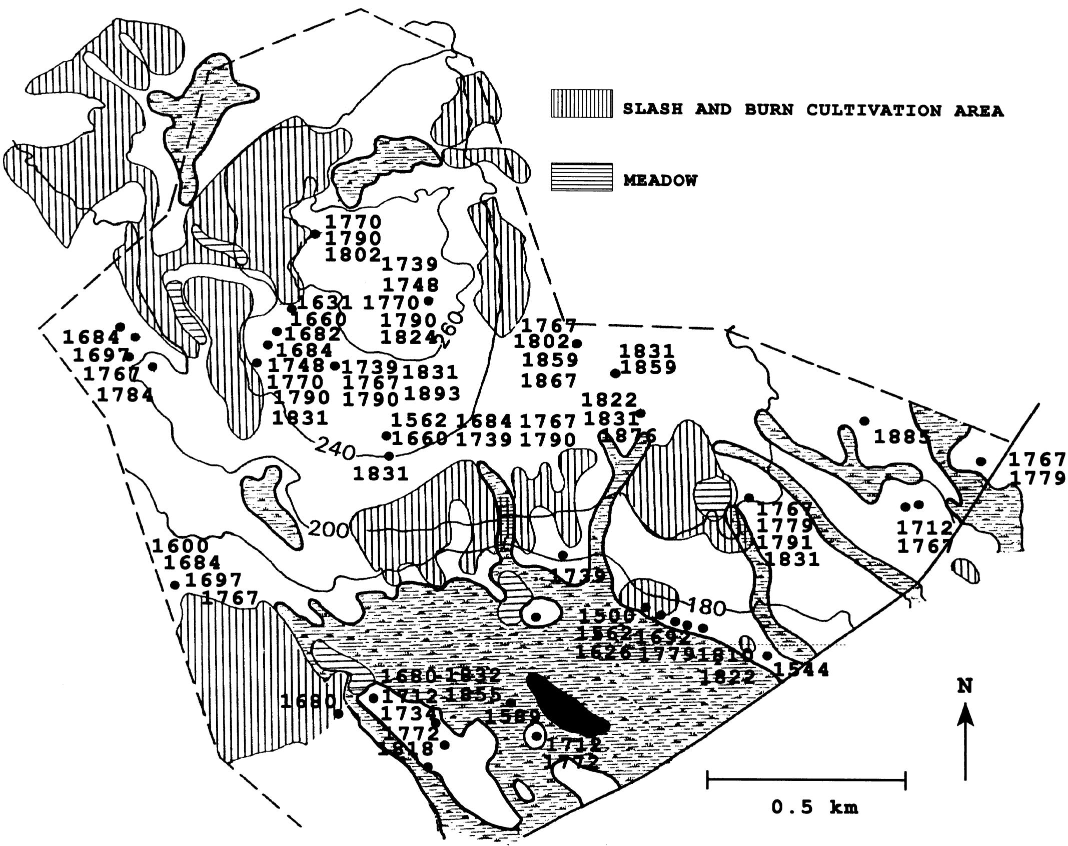

Fig. 1. Map of Autiovaara showing the location of slash and burn cultivation areas and meadows prior to 1899 (PKMMKA 1899), sites from which samples were collected, and dated fire years determined from the material.

Fire frequency is one element of a complex system that makes up the fire regime of a landscape. Fire behaviour in boreal forests has at least four characteristics that are important for understanding the dynamics of forest populations: crown fires, the size of the area burnt, fire frequency, and the amount of forest floor that is ashed (Johnson 1992). Trees generally survive only passive crown fires and ground fires, but their fire tolerance increases with increasing tree diameter (Kolström & Kellomäki 1993). Fire intensity was estimated here by measuring the diameter of each tree at the time of first scarring. The smaller the mean diameter at the time of first scarring, the less intense the fires. The tree diameters were pooled and the Weibull distribution was fitted.

RESULTS

A fire chronology covering 582 years (1412–1994) was established although it may be regarded as reliable only from around 1500 onwards as there are so few trees dating from before that time (Fig. 2). A total of 36 different "fire years" were identified during this period. Evidence was found for four forest fires in the 16th century, and 9, 10, 13 and no fires in the 17th, 18th, 19th and 20th centuries, respectively. The fire-scar evidence shows that fires occurred in the area on an average of once every 11 years. The fire dates are presented in Fig. 1. Fires increased in frequency towards the end of the 17th century and ended prior to the 20th century (Fig. 3).

The conglomerate density of all the intervals does not appear to be entirely homogeneous as would be expected of identically distributed random variables (Fig. 4). Since two peaks in the kernel density estimator were observed, the area was divided into two parts: 1) the upper part of the hill, above 200 m a.s.l., and 2) the area below 200 m a.s.l. The small island of mineral soil surrounded by mire was included in the upper part of the hill. Weibull distributions gave a significant fit with both sets of fire-interval data ($p < 0.05$;

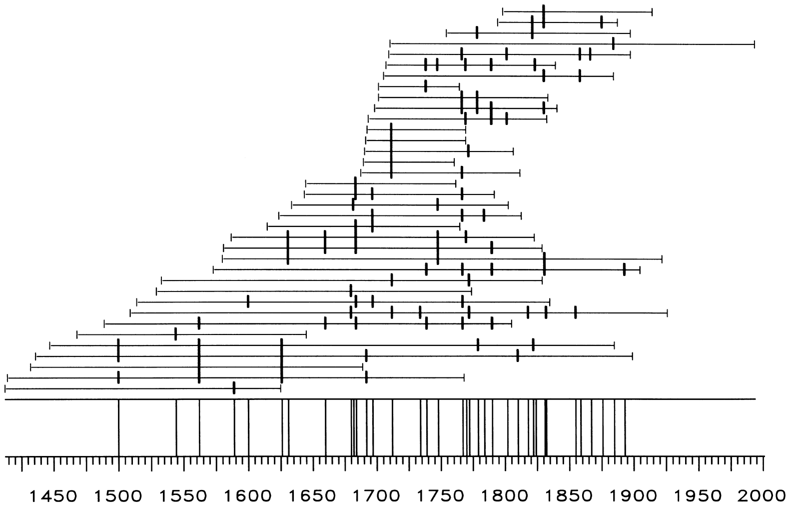

Fig. 2. Fire chronology for Autiovaara. Horizontal lines represent individual trees, on which the fire years are marked with vertical lines.

Kolmogorov-Smirnov two-sample test), the distributions of which differed at the $p < 0.05$ level (Kolmogorov-Smirnov two-sample test). The mean fire interval was 37 years on the upper part of the hill and 59 years on the lower part (Fig. 5).

The distribution of stump diameters at the time of first scarring indicates that the trees were fairly small at that time. The average diameter of the stumps upon first scarring was 15.7 cm (Fig. 6). The distributions in the upper and lower parts of the area did not differ in this respect.

DISCUSSION

It has been pointed out that different types of forests have different fire frequencies (Zackrisson 1977, Tande 1979, Zackrisson 1980, Engelmark 1983). Thus estimates of mean fire intervals in boreal forests in North America range from about 60 to 100 years or more (Heinselman 1973, Tande 1979, Johnson *et. al.* 1990). Zackrisson (1977) indicated that in northern Sweden before fire suppression started in the 19th century, forest had burned at a mean interval of 80 years. The results obtained here, mean fire intervals of 37 years on the upper part of the hill and 59 years on the lower part, can best be compared with those reported by Zackrisson (1977), Haapanen and Siitonen (1978) and Engelmark (1983). Zackrisson obtained a mean value of 55 years for a forest of the *Vaccinium* type in northern Sweden, and Engelmark 110 years, while in the northern part of North Karelia, Haapanen and Siitonen (1978) obtained a mean value of 112 years. Zackrisson (1977) obtained a mean value of 90 years for a forest of the *Myrtillus* type, and Haapanen and Siitonen (1978) 128 years.

The main reason why the fire interval in our area of North Karelia is markedly shorter than those reported elsewhere is the greater human impact. The intentional use of fire for manipulating the ecosystem has been practised in various ways within this area. The rotation of slash and burn cultivation in the same area has been estimated to be 20–40 years (Heikinheimo 1915), a range into which the fire interval for the upper part of the hill conveniently falls.

The difference in fire interval between the upper and lower parts of the hill is probably a consequence of the effects of the slope on the spread of fire. Several authors have found an increase in the rate of spread fires when advancing uphill (Van Wagner 1988). It is assumed that fire will have spread from the slash and burn cultivation areas more easily towards the upper part of the hill, and thus the hilltop forests will have burned more frequently.

The increase in the frequency of forest fires in the area at the end of the 17th century points to an expansion of slash and burn cultivation, while the fact that fires no longer occurred after the beginning of the 20th century may be explained by the discontinuation of slash and burn cultivation (Heikinheimo 1915) and efficient prevention of fires in modern times, which has totally prevented forest fires in the area.

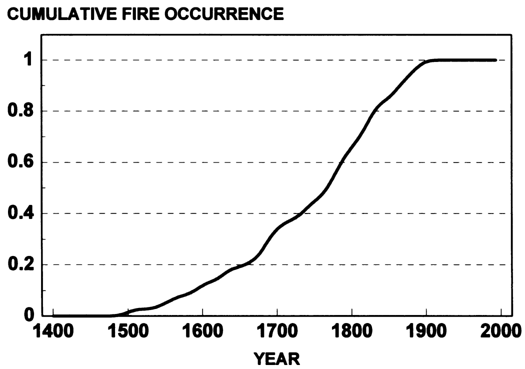

Fig. 3. Cumulative fire occurrence distribution at Autiovaara, smoothed by kernel estimation. Variations in the steepness of the line indicate changes in fire occurrence in the area.

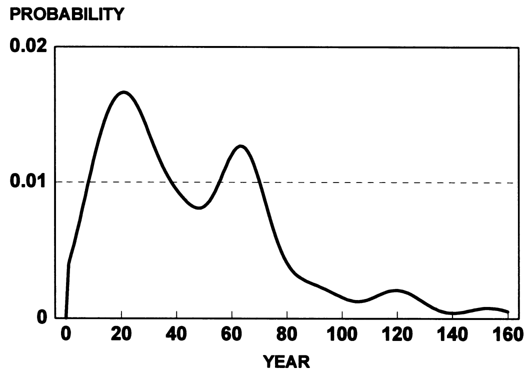

Fig. 4. Fire interval distribution at Autiovaara, smoothed by kernel estimation.

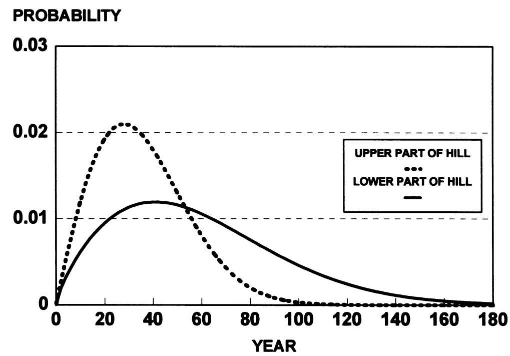

Fig. 5. Weibull distribution of fire intervals on the upper and lower parts of the hill at Autiovaara.

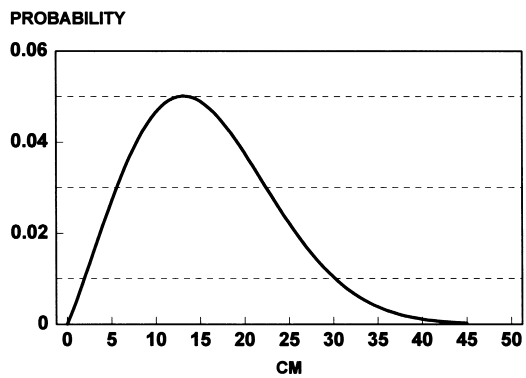

Fig. 6. Weibull distribution of tree diameters at Autiovaara at the time of first scarring.

The distribution of tree diameters at stump height at the time of first scarring, with a mean value of 15.7 cm, shows that fire intensity was low, and as a result quite small trees could survive a fire. In their examination of the effects of fire on tree mortality at two experimental sites also located in the Patvinsuo National Park in North Karelia, Kolström and Kellomäki (1993) found that although fire intensity was low, Norway spruce and birches did not survive and may be said to be utterly intolerant of fire. Large Scots pines, with a mean breast height diameter of 15.8 cm did survive, however. Their results provide strong support for the present observation that most fires were of low intensity.

High intensity natural fires are the rule in boreal forest (Johnson 1992), but Eurasian boreal forest fires are generally not of lethal mean intensity (Van Wagner 1983). In the present area, it is possible that repeated fires caused by human agency had reduced the accumulation of combustible material, so that the fire intensity remained low. The other reason could be that the short intervals between fires prevented the recruitment of Norway spruce and favoured Scots pine and especially hardwoods. The canopy moisture of a deciduous forest is higher than that of a coniferous forest (Johnson 1992), so that more heat will be required to ignite the canopy foliage and to start a high intensity crown fire.

The present results provide strong support for the hypothesis that past forest fires have had a substantial influence on vegetation succession in the boreal forests of North Karelia, and they also show that man has greatly affected the fire interval. It has been demonstrated on a number of occasions that the frequency of fires has largely determined the composition and structure of the forest vegetation (Frissell 1973, Heinselman 1973, Rowe & Scotter 1973, Viereck 1973, Tande 1979, Dieterich 1983, Bergeron 1991). It is the fire rotation that largely controls the age-class distribution of stands and the succession within stands, but the type and intensity of each forest fire will also have a decisive influence on the course of the succession, since no two fires have the same effect. This is an important factor which must be constantly kept in mind when making generalizations about fires and their effects. The repeated low intensity fires that affected this area in the past have created an uneven-aged forest dominated by uneven-aged pines and young deciduous trees. The last fire in the area was more than a hundred years ago and as a result, the area supports mixed coniferous forests of Scots pine and Norway spruce. Assuming that fire prevention will continue in the future, the forest on Autiovaara will proceed to complete spruce dominance, on account of the greater capability of this species to regenerate in such old stands.

It has been found several times previously that a decrease in the fire cycle leads to a decline in the structural heterogeneity and biodiversity of the forest (Tande 1979, Bergeron 1991). A direct effect of the drastically reduced influence of forest fires is that organisms adapted to the special environment created by repeated fires may not always be able to find other sites in which to survive and will thus decrease in both number and distribution (Rassi & Väisänen 1986). To reduce these effects, prescribed burning could be used more in silviculture.

Overrepresentation of the later stages of the forest succession and a shortage of the early stages of forest succession in nature conservation areas, on account of fire prevention measures is something of a problem from a nature conservation point of view. There is therefore some justification for the suggestion that fire should be used more in the management of nature conservation areas.

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