Influence of landscape structure on patterns of forest fires in boreal forest landscapes in Sweden[1]

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Abstract: To analyze the effect of landscape structure (viz. amount of wetlands) on the past forest fire regime in boreal Sweden, we reconstructed detailed fire histories by cross-dating fire scars in living and dead Scots pine (*Pinus sylvestris* L.) in two different landscape types: mire-free landscapes with a low proportion (1%–2%) of mires and mire-rich landscapes with a high proportion (21%–33%) of mires. Two localities were selected and at each one, adjacent mire-free and mire-rich areas of 256–601 ha were sampled. Over the studied 650-year period, the two landscape types differed primarily in the fire intervals and sizes of fires. In the mire-rich landscapes, fires had frequently stopped against mire elements. The net effect was significantly longer fire intervals in the mire-rich than in the mire-free landscape (on average, 32 versus 56 years). The mire-rich areas also had a tail of very long fire intervals lacking in the mire-free areas (maximal interval 292 years). We conclude that mires can have a profound effect on both spatial and temporal patterns of forest fires in the boreal forest, but only when they are effective fuel breaks (i.e., they are wet enough) at the time the fires burn and if they truly dissect the nonmire portion of the forest landscape.

Résumé : Dans le but d'analyser l'effet de la structure du paysage (p. ex. la proportion de milieux humides) sur les régimes de feu passés dans la zone boréale en Suède, un historique détaillé des feux de forêt a été reconstitué par datation croisée des cicatrices de feu chez des pins sylvestres (*Pinus sylvestris* L.) vivants et morts dans deux types différents de paysage : les paysages sans bourbiers avec une faible proportion (1 % – 2 %) de bourbiers et les paysages riches en bourbiers avec une proportion élevée (21 % – 33 %) de bourbiers. Deux endroits ont été sélectionnés et des zones adjacentes sans bourbiers et riches en bourbiers de 256–601 ha ont été échantillonnées à chaque endroit. Au cours de la période de 650 ans sur laquelle a porté l'étude, les deux types de paysage se distinguaient principalement par l'intervalle et la dimension des feux. Dans les paysages riches en bourbiers, les feux s'étaient fréquemment arrêtés à cause des bourbiers. L'effet se traduisait par des intervalles significativement plus longs entre les feux dans le paysage riche en bourbiers que dans le paysage sans bourbiers (56 versus 32 ans en moyenne). Dans le cas des zones riches en bourbiers, l'écart dans les intervalles entre les feux pouvait être très long (intervalle maximum de 292 ans) contrairement aux zones sans bourbiers. Nous concluons que les bourbiers peuvent avoir beaucoup d'effet sur le comportement spatio-temporel des feux de forêt en forêt boréale mais seulement lorsqu'ils agissent effectivement comme coupe-feux, c'est-à-dire qu'ils sont suffisamment humides au moment où survient un feu, et s'ils découpent vraiment la portion du paysage forestier sans bourbiers.

[Traduit par la Rédaction]

Introduction

Spatial and temporal patterns of fires ultimately depend on fuel availability, ignition patterns, and weather (Johnson 1992). Landscape features, such as lakes, watercourses, wetlands, and rock outcrops, can form fuel breaks that may act as barriers to a spreading fire and can therefore potentially affect the display of fires on the landscape (Foster 1983; Bergeron 1991; Larsen 1997; Niklasson and Granström 2000; Heyerdahl et al. 2001). In boreal landscapes, mires are a common physiographic feature of the landscape. In northern Sweden, mires cover on average 17% of the total land area, but there are many districts, particularly those with flat terrain and fine-grained till, where mire cover is above 25% (Sjörs 1983). In comparison with, e.g., lakes and boulder fields, mires are highly dynamic fuel breaks. Hydrology varies over time scales of weeks to months, and this complicates an understanding of their potential in stopping fires. Normally, mires are wet at the surface and act as fuel breaks but may after severe droughts be dry enough to carry fires. Furthermore, there are many different types of mires with significant differences in fuel structure and fuel load. Finally, the proportion of mires in the landscape and their specific form are likely to influence their capacity to stop fires, e.g., isolated mires that a fire can circumvent will be of little or no consequence to the long-term fire regime.

Several authors have suggested that mires have an effect on spatial and temporal patterns of forest fires in both Europe (Niklasson and Granström 2000) and North America

Received 21 February 2003. Accepted 25 July 2003. Published on the NRC Research Press Web site at http://cjfr.nrc.ca on 16 February 2004.

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[1]This paper was presented at the 4th International Workshop on Disturbance Dynamics in Boreal Forests: Disturbance Processes and their Ecological Effects, held 9–14 August 2002, Prince George, B.C., and has undergone the Journal's usual peer review process.

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 doi: 10.1139/X03-175

(Foster 1983; Dansereau and Bergeron 1993), but there is little evidence of an effect at the local scale. To quantify the effect of mires on critical fire regime variables, we reconstructed fire histories with high spatial resolution in adjacent landscapes with a low versus a high proportion of mires.

Materials and methods

Study area

The study was conducted in two areas, Linsell and Grimsjön, in the province Härjedalen in the midboreal zone (Ahti et al. 1968) (Fig. 1). In each area, two types of landscapes were sampled: those with a low proportion of mire (mire-free landscapes) and those with a high proportion of mire (mire-rich landscapes) (Fig. 2). Mires were defined as areas covered with peat with a depth of >30 cm. The selected landscapes represent extreme cases with respect to the proportion of mires (high and low, respectively). The Linsell area (62°08′N, 13°52′E) is at an elevation of approximately 400 m. The topography is nearly flat. The two landscapes are approximately 4 km apart. Sampling was done within a 403-ha area in the mire-free landscape and within a 601-ha area in the mire-rich landscape. The bedrock consists of young granites (Lundegårdh 1997), and the quaternary deposits are mainly glaciofluvial sediments (Lundqvist 1958). The Grimsjön area (61°57′N, 14°02′E) is situated 25 km south-southeast of Linsell and with the two landscape types adjacent to each other. The topography is flat at an elevation of approximately 500 m, with the exception of a hill in the southeast corner that reaches 575 m. Sampling was done within a 291-ha area in the mire-free landscape and within a 256-ha area in the mire-rich landscape. The bedrock consists of sandstone (Lundegårdh 1997), and the quaternary deposit is mainly moraine (Lundqvist 1958). The relative proportions of landscape elements are presented in Table 1.

The vegetation, both in forest and on mires, is similar in both Linsell and Grimsjön. The ground vegetation is dominated by lichens (*Cladina* spp.) and some pleurocarpous mosses (mainly *Pleurozium schreberi*). The field layer is dominated by ericaceous dwarf shrubs (*Empetrum hermaphroditum*, *Calluna vulgaris*, *Vaccinium vitis-idea*, and some *Vaccinium myrtillus*). The dominant tree species is Scots pine (*Pinus sylvestris* L.). On moist ground, some Norway spruce (*Picea abies*) and hairy birch (*Betula pubescens*) are found, but Scots pine is still the dominant tree species. The mires are of four types: dry *Sphagnum* hummocks, intermediate *Sphagnum* carpet, wet *Sphagnum* lawns, and mud bottom (sensu Sjörs 1983).

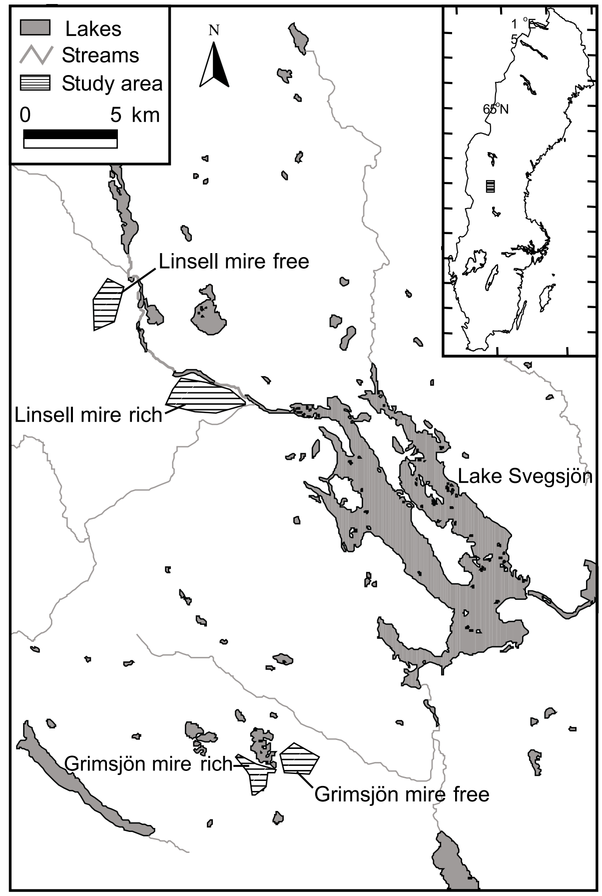
This region has the most continental climate in Sweden. The length of the vegetation period is on average 155 days (Alexandersson et al. 1991). For the reference period 1961–1990, the mean annual temperature for Sveg is 1.9 °C, with mean monthly temperatures of 14.2 °C for July and –10.5 °C for January. The annual precipitation is 585 mm/year, of which 64, 83, and 71 mm falls in June, July, and August, respectively (Alexandersson et al. 1991).

Sampling technique

Sample points for tree-ring sampling were distributed on topographical maps (scale 1 : 50 000), with the purpose of obtaining a good trade-off between spatial coverage of sample points and investment of labour. We aimed for a maximum distance of 1 km between points. The mire-free landscapes lacked enough collectable wood to build chronologies at some sites, probably because of logging operations and removal of wood for production of tar. Thus, fewer points were sampled in the mire-free landscapes than in the mire-rich landscapes. In total, 28 points were sampled: five in Linsell mire free, nine in Linsell mire rich, six in Grimsjön mire free, and eight in Grimsjön mire rich. Vegetation and edaphic conditions were similar at all sample points.

Wood samples of Scots pine were collected within approximately 30 m from the centre of the point. Samples were taken with a chainsaw from living trees, snags, down logs, and stumps. From snags and living trees, partial cross sections were cut out (sensu Arno and Sneck 1977), and from stumps and down logs, complete cross sections were taken. Fire scars were distinguished from other types of scars by their triangular shape (widest at the base) and the presence of charcoal but also through microscopic features unique to fire damage (e.g., heat-induced morphological changes in tracheids).

Fig. 1. Map of Sweden (inset) and the study areas.



Dendrochronology and cross-dating

All samples were finely sanded to clearly expose rings. Difficult sections were cut with a scalpel and zinc paste was applied to increase visibility. In total, 133 samples (5.2 samples/plot) were cross-dated, 13 from living trees and 120 from dead trees and stumps. The cross-dating was done

Fig. 2. Maps of the four studied landscapes with positions of sample points: (A) Linsell mire rich; (B) Grimsjön mire rich (left) and mire rich (right); (C) Linsell mire rich. Sample points in each landscape are numbered from north to south.

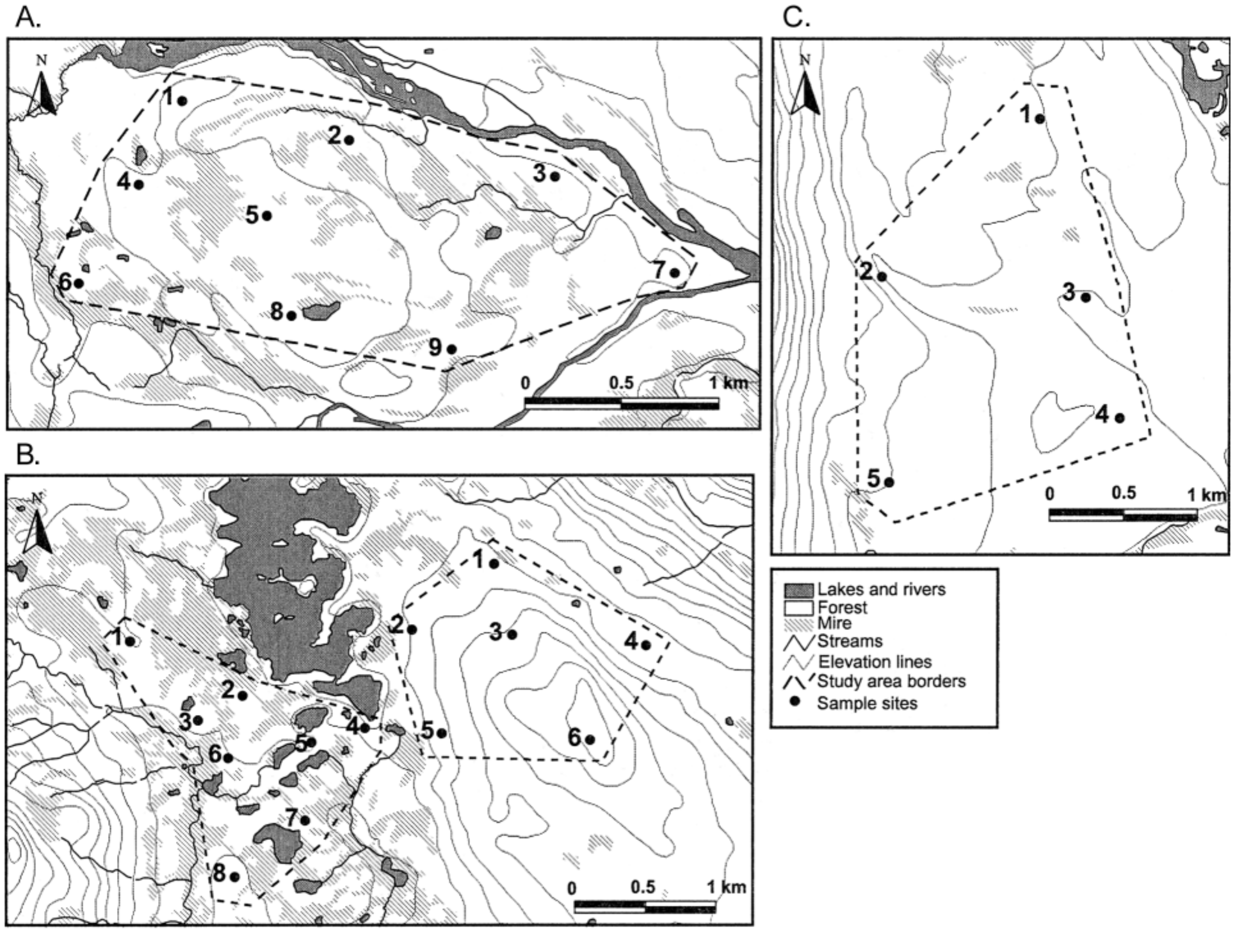


Table 1. Relative proportions of forest, mire, and water bodies within the analyzed landscapes and the surrounding region.

	Linsell			Grimsjön		
	Mire free	Mire rich	Region	Mire free	Mire rich	Region
Forest (%)	99	78	82	98	54	59
Mire (%)	1	21	14	2	40	33
Water bodies (%)	0	1	4	0	6	8

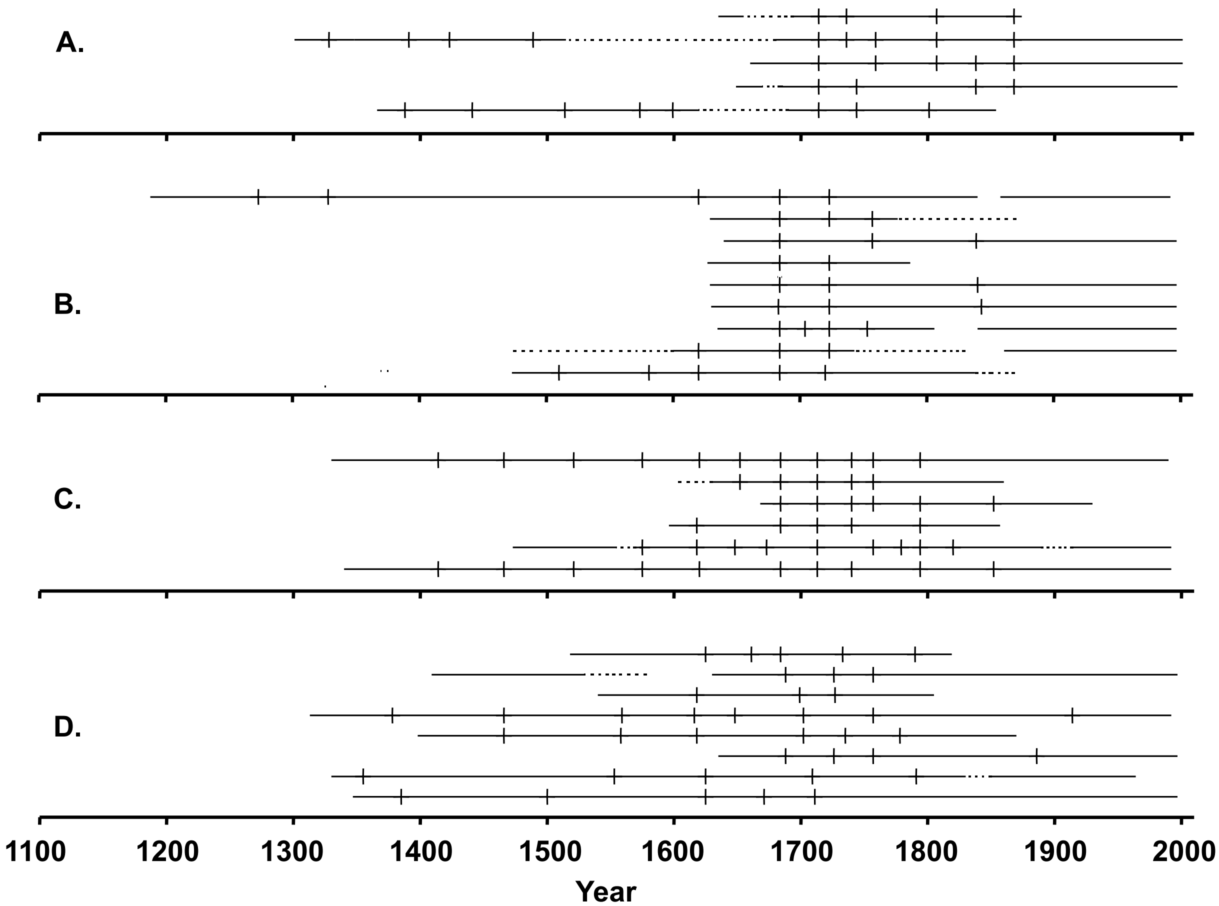
Note: The region is defined as the area that is covered by the local vegetation maps (Anonymous 1994*a*, 1994*b*) covering an area of approximately 940 km^2.

using methods described by Douglass (1941) and Stokes and Smiley (1968) with modifications for northern Swedish conditions (Niklasson et al. 1994; Niklasson and Granström 2000). In total, 296 fire scars were examined. Fire scars formed in the dormant period between two rings were assumed to be early fires, before wood formation starts in early summer (approximately mid-June), because the climate and risk of ignition result in a higher probability of fires burning before than after the growing season (Granström 1993).

Fire chronologies

The results from the dendrochronological analysis were used to create fire chronologies for each sample point. A common problem of dendrochronological reconstructions of fire history is the variation in recording of fires during different times. To minimize the effect of noncomplete fire data, we examined all chronologies in detail and only intervals formed during periods with good recording material (e.g., trees with high scaring susceptibility and a good degree of preservation) were used in the analysis. Fire interval data were analyzed using the Life Table routine of SPSS (Anonymous 1993). Only intervals formed before 1801 were used to avoid the influence of fire suppression during the 19th and 20th centuries. Intervals that did not end prior to 1801 were treated as censored cases. In total, 114 fire intervals (88 uncensored and 26 censored) were used in the analysis. The null hypothesis that there was no difference in fire

Fig. 3. Fire chronologies from the four studied landscapes: (A) Linsell mire free, (B) Linsell mire rich, (C) Grimsjön mire free, and (D) Grimsjön mire rich. Each line corresponds to an individual sample point comprising on average 5.2 sampled living or dead trees. Sample points are arranged from north to south (with the lowest point number at the top and highest at the bottom; see Fig. 2). Vertical bars indicate fires and broken lines indicate periods with poor recording ability. The parts of the two longest chronologies at Linsell mire free extending beyond the 16th century are only formed by one wood sample each and these intervals have been omitted from the Life Table analysis.



intervals between the different landscape types was tested using Wilcoxon–Gehan statistics.

Results

At all sample points, there was evidence of repeated fires (Fig. 3). Generally, the fires were nonlethal to the canopy pines and thus of relatively low intensity. The time depth varied considerably, and in some instances, synchronous age of the oldest dated pines at nearby sample points (e.g., points 2–7 at Linsell mire rich) indicates that a stand-replacing fire had occurred shortly before (Fig. 3). In total, 69 fire years were dated (Fig. 3). The earliest dated fire was in 1273 and the latest was in 1914.

In the mire-free landscapes, individual fires generally burned over a larger number of the sample points compared with fires in the mire-rich landscapes (Fig. 4). This difference is probably much greater in reality, since very few of the reconstructed fires were entirely contained within the sampled sections of the mire-free study areas. However, only 3 fire years out of 69 were registered at both Linsell and Grimsjön (which are located approximately 25 km apart), indicating that few fires in this district have been of very large size.

The survival analyses showed differences in fire interval between the two landscape types (Fig. 5). Median survival time was 32 years in mire-free landscapes and 56 years in mire-rich landscapes ($p < 0.001$); the 90th percentile was 55 and 89 years, respectively. The distribution of fire intervals in mire-free landscapes ranged between 15 and 80 years and in mire-rich landscapes between 19 and 292 years.

There was some evidence for a higher number of fire events per time and unit area in mire-rich landscapes. At Linsell, there were 10 fires in the mire-rich and eight in the mire-free landscapes over the last 400 years. At Grimsjön, this difference was larger: 22 fires in the mire-rich landscape versus 13 in the mire-free. During this time period, there were four fire years common to both landscape types in Grimsjön; at Linsell, the two landscapes had no fire years in common during the last 400 years.

Discussion

There were substantial differences in the spatial and temporal patterns of forest fires between the two landscape

Fig. 4. Distribution of fire sizes for the period 1600–1800 (pooled data for mire free and mire rich, respectively). Relative size refers to the proportion of active sample points that recorded each fire in each landscape. A fire covering all active sample points in a landscape has a relative size of 100%.

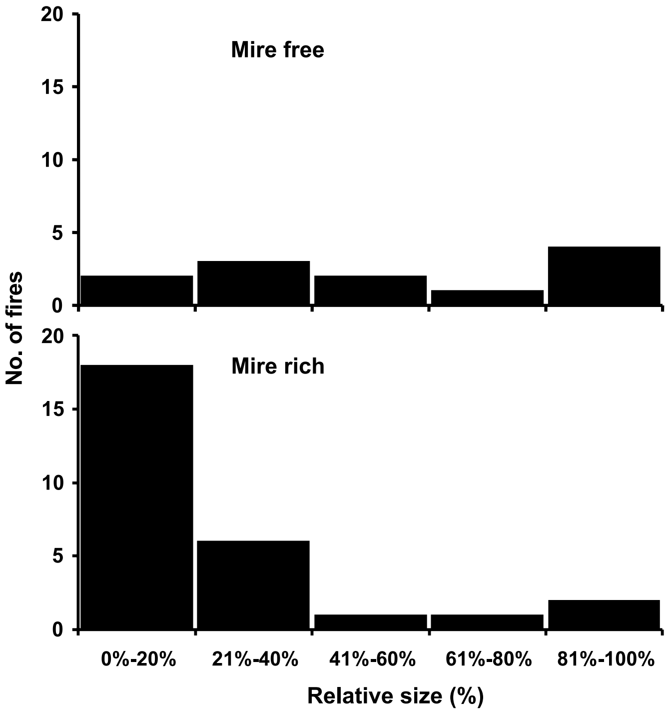
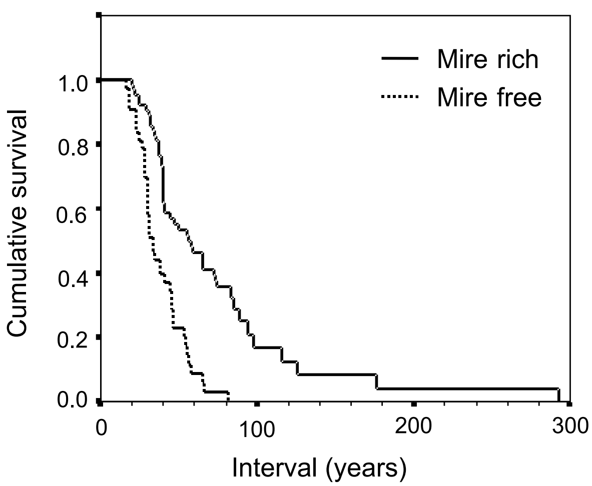


Fig. 5. Survival functions based on 66 and 48 intervals, respectively, in mire-rich and mire-free landscapes until the year 1801. Median fire intervals are 56 and 32 years in mire-rich and mire-free landscapes, respectively.



types. In mire-rich landscapes, there were higher numbers of fire events per unit area, but fires were of smaller size and the resultant fire intervals at the point scale were longer. Since the mire-rich and mire-free sample areas had similar soils and vegetation in their forested parts, and lay close to each other at both Linsell and Grimsjön, we believe that these fire regime differences are due to the presence–absence of mires.

Mires as fuel breaks

It is clear that mires frequently stopped fires, but they have not acted as absolute fuel breaks. We occasionally found evidence on the mires, in the form of scarred pine trees or charred wood, that fires had sometimes been burning on the mire surface itself. The mires within the studied areas are mainly of the intermediate *Sphagnum* carpet, wet *Sphagnum* lawn, and dry *Sphagnum* hummock type (sensu Sjörs 1983), which are characterized by a sparse field layer above a continuous mat of *Sphagnum* moss. In the first two types, *Eriophorum* spp. and *Carex* spp. dominate, and in the third type, there is a mixture of *Rubus chamaemorus*, *E. hermaphroditum*, *Vaccinium uliginosum*, *C. vulgaris*, and *Betula nana*. These types of mire have low fuel loads in the field layer and the distribution of the fuel is frequently discontinuous. Fire behaviour in northern European mire types has not been studied, but observations during prescribed fires and wildfires (A. Granström, personal observation) suggest that fire is generally not supported in these mire types as long as the underlying *Spagnum* moss is moist. However, after long periods of drought, the *Spagnum* moss will dry out and form a continuous fuel bed that can carry a fire. Fires spotting over mires is a second avenue for fires to overcome them, but we consider this less likely here because fires seem to have burned with a low intensity (inferred from the ubiquitous presence of multiple-scarred trees and snags). A third avenue is of course that fires can circumvent mires by burning over land bridges.

In the mire-rich landscape at Linsell, fires were generally larger than at Grimsjön, which could simply be an effect of differences in the proportion of mire, 21% and 33%, respectively. However, when looking at the distribution of the fires in the mire-rich landscapes, we observed that sample points that burned in the same fire events typically had connecting land bridges between them. In the mire-rich Linsell area, for example, fires in the years 1620, 1684, and 1723 covered large and interconnected land areas. The same pattern can be seen in the Grimsjön area, where fires that were registered in more than one sample point always had interconnecting land bridges. Therefore, the smaller fire sizes at Grimsjön are probably explained by the lower degree of connectivity of the forested areas here compared with Linsell (Fig. 2). Further, these patterns indicate that fires burned over the mires only during extreme drought and that this did not occur for the majority of fires.

Landscape structure and fire regime

Our results on the influence of mires on the fire regime confirm on a local scale what Foster (1983) observed on a large scale in eastern Labrador. He found an extremely long fire cycle in regions with a high proportion of mires. In our study area, differences in fire intervals between landscape types were not dramatic, but it is likely that they would increase with the size of the mire complexes and with decreases in ignition densities.

Differences in fire intensity have also been suggested to result from differences in landscape structure. In northwestern Quebec, Dansereau and Bergeron (1993) found a large, homogenous landscape, devoid of lakes, to have large fires and of greater intensity compared with a landscape containing numerous water bodies and rough topography. Bergeron (1991) also documented similar traits for mainland versus islands in a large lake. However, in our area, there does not appear to have been any major difference in fire intensity between landscape types; few fires have been stand replacing in both types. One reason may be the relatively short intervals between fires, often substantially less than the approximately 50 years required for full recovery of the surface fuels (Schimmel and Granström 1997).

It may seem contradictory that the observed number of fires per unit time and area was higher in the mire-rich landscapes. Pooling the two localities, there were 32 fires in the mire-rich versus 20 fires in the mire-free landscape after 1600. A part of this can be due to the higher number of sampling points in the mire-rich landscapes (five and six versus nine and eight), but on the other hand, additional sample points in the mire-free landscapes would not be expected to add many fires, given the fact that fires there generally covered large areas (Fig. 4). Also, the true number of fire events in the mire-rich landscape is probably higher still, since there were some forested areas that were isolated by mires and that we did not sample.

If all other factors (soils, vegetation, ignition density) are constant, a higher number of separate fire events would in fact be expected for a landscape dissected by fuel breaks, particularly if ignition density is high. The short fire intervals that we observed in both landscape types should lead to a high degree of fuel limitation. Fuel buildup in these forest types requires decades (Schimmel and Granström 1997) and ignitions during the early period after fire will not be successful. In mire-rich landscapes, where fires are kept small, there will continually be a higher proportion of areas containing sufficient fuel loads to allow successful ignition.

Changes over time and ignition sources

The most dramatic changes in the fire regime are seen over the last 100–200 years. Only a few fires were detected for the 19th and 20th centuries. This is most probably explained by fire suppression to protect timber resources and is a common pattern in fire history studies throughout Fennoscandia (Kohh 1975; Zackrisson 1977; Lehtonen 1998; Niklasson and Granström 2000; Niklasson and Drakenberg 2001) but with different dates for different regions.

There is a slight trend towards shorter fire intervals in the 17th and 18th centuries compared with earlier times. This could be an effect of increased human presence in the area (cf. Niklasson and Granström 2000), although we do not suspect that these forests were deliberately burned. Burning of forest lands for improved grazing has been commonplace (Tirén 1937), but this forest type is essentially devoid of palatable vegetation even in early succession after fire (Sarvas 1937; Kohh 1975). Whether or not fire was deliberately set, a fair share of the detected fires must have been anthropogenic. Ignition density from lightning in this part of Sweden is around 0.1 / 10 000 ha annually (Granström 1993), and the 24 fires that were observed for the mire-rich landscapes over the period 1600–1800 (fires common to both mire-free and mire-rich landscapes excluded) translate into a density of around 1.9 fires / 10 000 ha annually (assuming that all of these fires originated within the forested part of the respective landscape; 150 ha for Grimsjön and 469 ha for Linsell). This means that ignition by humans dominated over lightning ignition by a factor 19. Such a calculation cannot be done for mire-free landscapes, since fires there were far from contained within the sampled areas.

Conclusions

Our results exemplify how spatial and temporal patterns of fires can be affected by landscape structure. As a net effect, mire-rich areas had longer fire intervals, and there was also a tail of exceptionally long intervals that was completely lacking in the mire-free areas. Such stands might potentially offer habitat for late-successional species with limited dispersal. The controlling variables behind the observed patterns appear to be the degree of isolation of the forested areas within the mire complex and the ignition density. The degree of isolation depends on orientation and shape of mires but also on the type of fuel on the mires. As for the effect of ignition density, lower ignition densities (e.g., during periods without human influence) would be expected to result in still larger differences in fire interval distribution between landscape types.

Acknowledgements

This work was financially supported by The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning; SUFOR (Sustainable Forestry in southern Sweden); and Stora Enso Forest, who also provided valuable assistance during the field work.

References

Ahti, T., Hämet-Ahti, L., and Jalas, J. 1968. Vegetation zones and their sections in north-western Europe. Ann. Bot. Fenn. **5**: 169–211.

Alexandersson, H., Karlström, C., and Larsson-McCann, S. 1991. Temperaturen och nederbörden i Sverige 1961–1990. Referensnormaler. Report 81. Swedish Meteorological and Hydrological Institute.

Anonymous. 1993. SPSS for windows: advanced statistics, release 6.0. SPSS Inc., Chicago, Ill.

Anonymous. 1994*a*. Vegatationskarta [Vegetation map], 163 A. Lillhärdal. Luleå, Lantmäteriet.

Anonymous. 1994*b*. Vegatationskarta [Vegetation map], 163 C. Linsell. Luleå, Lantmäteriet.

Arno, S.F., and Sneck, K.M. 1977. A method for determining fire history in coniferous forests of the mountain west. U.S. For. Serv. Gen. Tech. Rep. INT-42.

Bergeron, Y. 1991. The influence of island and mainland lakeshore landscapes on boreal forest-fire regimes. Ecology, **72**: 1980–1992.

Dansereau, P.R., and Bergeron, Y. 1993. Fire history in the southern boreal forest of northwestern Quebec. Can. J. For. Res. **23**: 25–32.

Douglass, A.E. 1941. Cross-dating in dendrochronology. J. For. **39**: 825–831.

Foster, D.R. 1983. The history and pattern of fire in the boreal forest of southeastern Labrador. Can. J. Bot. **61**: 2459–2471.

Granström, A. 1993. Spatial and temporal variation in lightning ignitions in Sweden. J. Veg. Sci. **4**: 737–744.

Heyerdahl, E.K., Brubaker, L.B., and Agee, J.K. 2001. Spatial controls of historical fire regimes: a multiscale example from the interior west, USA. Ecology, **82**: 660–678.

Johnson, E.A. 1992. Fire and vegetation dynamics. Studies from North American boreal forest. Cambridge University Press, New York.

Kohh, E. 1975. Studier över skogsbränder och skenhälla i älvdalsskogarna. Sver. Skogsvårdsförb. Tidskr. **73**: 299–336.

Larsen, C.P.S. 1997. Spatial and temporal variations in boreal forest fire frequency in northern Alberta. J. Biogeogr. **24**: 663–673.

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.

Lundegårdh, P.H. 1997. Södra Härjedalens berggrund. *In* Beskrivning till berggrundskartan över Jämtlands län. Del 1: Urberget. *Edited by* R. Gorbatschev, K.-A. Kornfält, and P.H. Lundegårdh. Sveriges Geologiska Undersökning, Stockholm. pp. 203–248.

Lundqvist, G. 1958. Beskrivning av jordartskarta över Sverige. Sveriges Geologiska Undersökning, Stockholm.

Niklasson, M., and Drakenberg, B. 2001. A 600-year tree-ring fire history from Norra Kvills National Park, southern Sweden: implications for conservation strategies in the hemiboreal zone. Biol. Conserv. **101**: 63–71.

Niklasson, M., and Granström, A. 2000. Numbers and sizes of fires: long-term spatially explicit fire history in a Swedish boreal landscape. Ecology, **81**: 1484–1499.

Niklasson, M., Zackrisson, O., and Östlund, L. 1994. A dendroecological reconstruction of use by Saami of Scots pine (*Pinus sylvestris*) inner bark over the last 350 years at Sädvajaure, N. Sweden. Veg. Hist. Archaeobot. **3**: 183–190.

Sarvas, R. 1937. Havaintoja Kasvillisuuden kehityksestä pohjois Suomen kuloaloilla [German abstract: Beobachtungen über die Entwicklung der Vegetation auf den Waldbrandflächen Nord-Finnlandis]. Silva Fenn. **44**: 32–64.

Schimmel, J., and Granström, A. 1997. Fuel succession and fire behavior in the Swedish boreal forest. Can. J. For. Res. **27**: 1207–1216.

Sjörs, H. 1983. Mires of Sweden. *In* Ecosystems of the world 4B. Mires; swamp; bog; fen and moor. *Edited by* D.W. Goodall. Elsevier Science Publishers, Amsterdam, Netherlands. pp. 69–94.

Stokes, M.A., and Smiley, T.L. 1968. An introduction to tree-ring dating. Chicago University Press, Chicago, Ill.

Tirén, L. 1937. Skogshistoriska studier i trakten av Degerfors i Västerbotten. Medd. Statens Skogsförsöksanstalt, **30**: 67–322.

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