Potentials and limitations for human control over historic fire regimes in the boreal forest

Anders Granström^{1,*} and Mats Niklasson²

¹*Department of Forest Ecology and Management, Swedish University of Agricultural Sciences,
901 83 Umeå, Sweden*

²*Department of Southern Swedish Forest Research, Swedish University of Agricultural Sciences,
230 53 Alnarp, Sweden*

Fire, being both a natural and cultural phenomenon, presents problems in disentangling the historical effect of humans from that of climate change. Here, we investigate the potential impact of humans on boreal fire regimes from a perspective of fuels, ignitions and culture. Two ways for a low technology culture to impact the fire regime are as follows: (i) by altering the number of ignitions and their spatial distribution and timing and (ii) by hindering fire spread. Different cultures should be expected to have quite different impacts on the fire regimes. In northern Fennoscandia, there is evidence for fire regime changes associated with the following: a reindeer herding culture associated with few ignitions above the natural; an era of cattle husbandry with dramatically increased ignitions and somewhat higher fire frequency; and a timber exploitation era with decreasing fire sizes and diminishing fire frequency. In other regions of the boreal zone, such schemes can look quite different, but we suggest that a close look at the resource extraction and land use of different cultures should be part of any analysis of past fire regimes.

Keywords: anthropogenic fire; fire regimes; circumboreal; fire management; culture

1. INTRODUCTION

The boreal forest is one of the least populated biomes of the world (Sanderson *et al.* 2002), and has most likely been so throughout history, due to low productivity and unsuitability for agriculture (Woodward *et al.* 2004). Recently, there has been a surging research interest in the long-term dynamics of the boreal zone, due not in the least to its potential importance for the global carbon cycle (Kasischke *et al.* 1995). Almost by default, human impact on the boreal forest ecosystems has been considered to be small, in comparison with other biomes. Assessments of past human influence in this region are vital for two reasons: evaluating relationships between vegetation and climate as a basis for predicting future response to climate change (Flannigan *et al.* 2005), and the management of natural areas for biodiversity, where past human influence has to be addressed (Granström 2001; Bergeron *et al.* 2002).

It is clear that direct manipulations, such as field clearing and wood cutting, have been small in the boreal until the last few hundred years (Angelstam *et al.* 1995), but a major potential for human impact would have been through the use of fire. Fire is unique in that it is a natural disturbance factor, but at the same time under potential human control. What controls the fire regimes has been an ongoing discussion for many decades, particularly regarding the western USA (Pyne 1982; Allen 2002). With respect to the boreal forest, there is surprisingly little reference to the role of

people versus natural controls in the recent ecological literature. A prime reason may be the inherent methodological difficulties in attributing the cause of fires in retrospective studies. For analyses of the recent past, written sources can sometimes corroborate quantitative field observations of a changing fire regime (Weir & Johnson 1998; Weir *et al.* 2000), but for earlier periods, interpretation is often problematic. Here, we discuss the human influence over the boreal fire regimes from three perspectives. First, we look at the potential for people to impact fire on the boreal forest. Second, we discuss the potential for detecting a human signal in palaeoecological analyses of fire history. Third, we give some examples of human impact on the fire regimes in relation to culture in one region of the boreal forest, Fennoscandia in western Eurasia.

2. OPTIONS FOR HUMANS TO IMPACT BOREAL FIRE REGIMES

Regardless of intentions, there are in essence two routes for people to affect the fire regime: one is by altering the number of ignitions on the landscape, their location and their timing with respect to season, plant phenology, drought, etc., and the other is by hindering the spread of fires. Of these, manipulation of ignitions would be the simplest to achieve. Anthropogenic ignitions are adding to the lightning ignitions on the landscape, but would partly compete with these for the area burnt and can, under particular circumstances, produce distinctly different results.

Natural ignition by lightning in the boreal region is restricted in several respects, relative to anthropogenic ignitions (table 1). To begin with, the number of

* Author for correspondence (anders.granstrom@sveki.slu.se).

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Table 1. Fundamental characteristics of lightning ignitions versus anthropogenic ignitions in boreal regions.

	lightning ignitions	anthropogenic ignitions
density	low (0.05–0.2 per 100 km ² yr ⁻¹)	potentially high (open-ended)
spatial distribution	generally random ^a	directed
seasonal distribution	concentration to middle part of the summer	flexible
climatology	concentration to periods of severe drought	flexible

^a Krawchuk *et al.* (2006) found a difference between forest types. Otherwise several studies report regional differences, but no aggregation on a local scale.

lightning ignitions is low throughout the boreal region, compared with the number of ignitions people potentially can apply. Although there are few comprehensive reports, typical lightning ignition densities are of the order of 0.05–0.20 per 100 km² yr⁻¹ (Granström 1993; Sannikov & Goldammer 1996; Podur *et al.* 2003; Larjavaara *et al.* 2005; Krawchuk *et al.* 2006). Furthermore, lightning ignitions are concentrated around the peak of the summer, and more importantly, in the periods of advanced drought (Kinnman 1936; Nash & Johnson 1996), whereas humans can potentially ignite fires whenever fire spread is possible. Fires in the typical boreal fuel beds can propagate (from whatever ignition source) when surface fuels (moss/lichen/needle litter (Van Wagner 1983)) are dry enough, typically below 20–25% moisture content, which requires only a few precipitation-free days (Tanskanen *et al.* 2006). Lightning ignition is associated with longer periods of drought, most likely because ignition depends on dried out layers of duff or rotten wood (Latham & Williams 2001). These are also favourable conditions for deep burning in humus (Van Wagner 1972), and thus for great impact on the soil system.

In predominantly natural fire regimes, a small number of large fires dominate the total area burnt (Johnson 1992). These fires burn under conditions of rapid spread and high intensity (i.e. drought, wind), and hence become large. Intentional burning by informed people would have the potential to shift this pattern towards smaller fires with lower intensities and less impact on soils, creating a higher spatial variation in fire intervals, if that is the desired result.

Also, humans can target small areas that differ from the surroundings in terms of fuel characteristics. Minerotrophic mires, riparian areas and swamp forest edges in the boreal are often dominated by grass or sedge (Charman 2002). In early spring, such areas are covered with highly flammable fuel beds of sedge/grass litter that can burn after just a very short dry period (Granström *et al.* 2000), when upland forest fuels are still moist. This opens a window for localized burning that also can have positive effects on wildlife and, thus, for people (Lewis & Ferguson 1988; Natcher 2004).

While recognizing the potential for intentional anthropogenic burning, accidental or unintentional fire starts should not be overlooked. Today, there is a spatial association between people and fire in many parts of the boreal forest (Engström 2000; Kovacs *et al.* 2004) and, to an unknown extent, this was probably the case in the past as well, although for different reasons (Drobyshev *et al.* 2004). Whenever people moved in the forest, they would have made daily use of campfires

and a portion of these would have escaped, whatever the intentions may have been (Natcher 2004).

Impacting the fire regime through intentional burning is clearly achievable for any human population in a fire-prone landscape, but the potential for controlling fire propagation from unwanted ignitions, whether anthropogenic or natural, is less obvious. Nevertheless, by burning out fuels or setting backfires, even a high-intensity fire can be controlled under the right circumstances. A note from the early 1900s can illustrate the strategic thinking and tactics of such operations:

...in the afternoon the fire went onto Känne state forest, aided by wind from the south. In the night the assisting forester came to the area, and in the morning I arrived to take command. Valuable time was lost while trying to locate the fire officer of the district, but finally I had to act, collected the sparse groups of people and set back-fire north of Långsidberget. The assistant had, prior to this, set back-fire between Knätten and Storkännberget [two mountains on the east flank]. On Monday night the fire was contained on both the flanks and the head.

Härnösands Landsarkiv. Kungliga Domäverkets arkiv, FIII 2a, Känne kronopark. Letter from Forester Tell Grenander, dated 27th of June 1920

That fire burnt in late June 1920 in northern Sweden, but methods to control unwanted fire would have been identical in previous centuries and in other regions: taking advantage of the lower wind and higher relative humidity in the night, which leads to higher surface fuel moisture, a lower rate of spread and a lower fire intensity (Van Wagner 1983); also using natural breaks such as moist draws and mires to secure backfires. This 1920 fire was traced in the field through fire scars on surviving trees (Granström & Kling 2006, unpublished data), and the margins were indeed judged to be at the topographically and edaphically most favourable positions for setting backfires.

One important question that arises when discussing the potential for early fire management is the number of people required for effective fire control. If conditions are really favourable, even a few people can stop an advancing fire by burning out fuels upwind of a fuel break that the fire otherwise would have jumped, but in many cases a larger number of people would be needed to hold the backfire line during the burnout operation. Before the development of mechanized equipment, this was usually done by sweeping the flames with spruce saplings, and sometimes adding hand-carried water (Wretling 1932). It is noteworthy that throughout boreal Fennoscandia there was a dramatic drop in fire frequency in the late 1800s (Kohh 1975; Zackrisson 1977; Niklasson & Granström 2000), when the technology was still manual and population densities

were low. More people would mean better control, but even small bands of people could act effectively close to their dwellings. Another point is that the prospects for interfering with fire spread would depend on physiognomy of the landscape, particularly the abundance of wetlands, number of streams, etc. These can vary on a small scale (Hellberg *et al.* 2004), but also between different areas of the boreal region (Charman 2002). However, under extreme conditions, high-intensity crown fires would overcome any control efforts.

A more long-term strategic fire prevention is also conceivable. In many areas with a fuel bed dominated by pleurocarp mosses and lichens, fuel regeneration after fire takes a minimum of 10–20 years before fire is again possible (Schimmel & Granström 1997). This could create the opportunity for fireproofing areas where there are permanent installations such as dwellings or storage.

3. DETECTING THE HUMAN SIGNAL

As discussed above, human influence on the fire regime could manifest itself in any or all of a number of variables: fire frequency (fire interval); spatial distribution; seasonal distribution; depth of burn; and fire intensity. Most retrospective studies have focused on the change or the lack of change in fire frequency, based on fire scar data or sediment chronologies. Fire frequency (usually expressed as average interval between fires at point scale or proportion of the landscape burnt per unit time) is, however, a blunt instrument for detecting human influence. In a study in northern Sweden using a spatial network of fire scar chronologies (Niklasson & Granström 2000), there was a fivefold increase in the number of fires per unit area and time, concurrent with agricultural settlement, but only a 1.7-fold increase in total area burnt (periods 1350–1650 versus 1650–1850). This could be due to a combination of different mechanisms: human ignitions occurring under less severe weather and therefore leading to small area burnt; active suppression of large fires; and a negative feedback between ignitions and fire frequency resulting from a slow regeneration of fuels (i.e. fires stopping against young burns (Schimmel & Granström 1997)). If this nonlinearity between number of fires on the landscape and fire frequency is common, substantial change in the fire regime can go undetected in retrospective studies. In addition, long-term palaeostudies regularly depend on charcoal peaks in lake or bog sediment, which are subject to difficult calibration problems (MacDonald *et al.* 1991; Asselin & Payette 2005; Higuera *et al.* 2005).

Tree-ring records of fire scars can offer vastly better temporal and spatial resolution than charcoal peaks in sediments, but rarely cover more than the last few hundred years in the boreal regions. Still, verifying human impact is not an easy task, particularly when looking at fire frequency. Changes in fire frequency have more often been explained by a changing climate than by changing human impact, if reasonably well tied in time to known episodes of climatic change (e.g. Bergeron & Archambault 1993).

Since fire scars can give information on the season of their formation (within the growing season), this can sometimes be used as a basis for separating anthropogenic fires from natural ones. A seasonal distribution

Figure 1. Schematic sequence of cultures over time in the interior of northern Sweden. Direction of the arrow indicates the expected dependence on fire for the main livelihood from forest: 1, moose hunting; 2 and 3, fur and hunting, later reindeer husbandry, i.e. Saami culture; 4, cattle husbandry; 5, timber exploitation. The timing is tentative before the 1500s. The transition from 1 to 2, in the early period of Saami culture, probably began 1500–2000 years BP (Aronsson 1991), but reindeer husbandry (3) became a dominant feature much later, towards the early middle ages (Storli 1993).

of observed fires that depart substantially from that of lightning ignitions is a definite proof of anthropogenic burning, regardless of any changes in fire frequency (Niklasson & Drakenberg 2001). However, the lack of a difference is not the proof of a lack of human impact, because anthropogenic fires do not necessarily differ in their seasonal distribution.

Likewise, the tree-ring data can determine the spatial patterns of individual fires. If sampling is done over a large area relative to the sizes of fires, a measure of minimum number of ignitions per unit time and area can be calculated and compared with present-day ignition density by lightning (Swetnam 1993; Niklasson & Granström 2000). Since the bulk of area burnt in natural fires in the boreal occurs during particularly dry summers, departure from this pattern should also point to human ignitions. Swetnam (1996) found such a shift for sites in central Siberia, concurrent with the influx of people after construction of the Trans-Siberian railroad in the 1880s. Earlier, fire years were significantly drier (based on the tree-ring proxies of precipitation) than random, but after 1880 this was not the case.

Another line of evidence for detecting human impact could be cultural markers in the pollen/spore record. Increasing levels of light-demanding wild herb and grass species have often been taken as evidence of a cultural impact on forest ecosystems (Segerström & Emanuelsson 2002; Hörnberg *et al.* 2005), although not necessarily through fire. There are more definite markers: detection of cereal pollen in peat and raw-humus deposits has allowed spatially precise documentation of small-scale slash and burnt agriculture in the coast region of northern Fennoscandia from the late Middle Ages (Segerström *et al.* 1994), which indirectly would suggest a human impact on the fire regime at the landscape scale.

4. EXAMPLES OF LANDSCAPES WITH A HUMAN TOUCH

Owing to the dramatic shifts in vegetation and fauna that can result from fire, people with different livelihoods would be expected to try to influence the fire regime in different directions. For northern Fennoscandia, a tentative scheme comprises four to five different

dominant cultures (figure 1). For the longest period after the establishment of the boreal forest vegetation *ca* 8000 years BP, the main food resource was moose (*Alces alces*), manifested in a strong symbolic attachment, e.g. in rock paintings and various artefacts (Lundberg 1997). Moose are browsers with a strong preference for early-successional broad-leaved tree species that dominate in early succession after a fire (Baskin & Danell 2003; De Chantal & Granström 2007). Thus, it seems that this culture to a great extent would depend on fire disturbances. Possibly the natural fire regime would have been sufficient, but intentional burning seems a very attractive option, particularly to ensure good moose habitat near dwellings. Permanent winter dwellings have been identified at distances of approximately 100 km along the major rivers (Lundberg 1997). On the other hand, many moose were evidently taken using large systems of pitfall traps in the valleys during winter migration (Spång 1997), and this process would not depend on local vegetation. In an effort to identify anthropogenic burning throughout this period, Carcaillet *et al.* (2007) reconstructed fire frequencies through charcoal peaks in three small lakes in northern Sweden, two of which were very close to documented prehistoric dwellings. There was no temporal association between fire and periods when dwellings were occupied, but, on the other hand, none between fire and known climatic shifts either, leaving the question unresolved.

Beginning approximately 2000 years BP, there was a gradual cultural transition towards a reindeer herding Saami culture, possibly in interaction with agricultural communities further south (Aronsson 1991). The north-western European boreal forest also became entrained in fur trade early, perhaps beginning in the Iron Age. A staple in the fur trade during many centuries was squirrel (*Sciurus vulgaris*), which is tied to late-successional conifer forest (Wauters *et al.* 2005). The Saami people would probably have been averse to fire due to their dependence on reindeer, whose winter feed is largely *Cladonia* lichens (Nieminen & Heiskari 1989; Baskin & Danell 2003), which are eliminated for long periods by fire (Sarvas 1937). There is evidence that the reindeer economy expanded gradually from the Middle Ages and was strong during the 1600s and 1700s. Earlier, the number of reindeer per household was low and the economy relied more on fishing and hunting (Aronsson 1991).

Beginning in the late 1600s, small-scale agricultural settlements advanced into the predominantly Saami areas and, from that period onwards, there is scattered written evidence relating to fire. A ruling from Lycksele District Court (northern Sweden) from 16 January 1755 displays the basis for conflict between the two cultures, as well as an acute understanding of fire behaviour and fire effects:

It was asked how the Laplanders [Saami] and the settlers were getting along and if they in any way interfered with each other. The Laplanders answered that now that the settlers had become so many, they felt crowded and in particular the settlers were not careful with the forests, and were the cause of many forest fires, which burn away the reindeer moss [*i.e.*, lichens]... On further enquiries they said that the moss-lands and heaths which are good [for reindeer] can stand grazing

Figure 2. (a) Fires occurring over the 11-year period 1753–1763, shortly after the establishment of a small homestead close to the river Lögdeälven in northern Sweden ($63^{\circ}56' \text{ N}$, $18^{\circ}48' \text{ E}$). Fire scars were dated in living and dead *Pinus sylvestris*, and borders for individual fires were drawn using the methods detailed by Niklasson & Granström (2000). (b) The dot on the small map shows location of the study area.

for three years and then need to rest for three years, but the heaths which have been burnt do not re-grow for 50 to 60 years, depending on how deep into the soil the fire has gone, which in turn depends on the weather.

For a period of 150–200 years after the first agricultural settlements, the fire regime appears to have been under intense human control, with ample burning. This is recent enough that the tree-ring record can illustrate both the temporal and spatial patterns of fires. Anthropogenic ignitions peak in the mid-1800s at 12 times higher than the present-day density of lightning ignitions (Niklasson & Granström 2000). There was a much less dramatic increase in fire frequency, but the landscape structure changed significantly, from one dominated by a few very large burns (thousands of hectares) to one with more numerous but considerably smaller burns (Niklasson & Granström 2000). The reasons for burning would primarily have been to improve the forest grazing habitat for cattle, sheep and goats. The economy depended mainly on animal husbandry, with some fishing and hunting (Bylund 2000). The cultivated areas were minimal (less than 1%). Anecdotal information from court rulings suggests that both the altered vegetation and the improved trafficability by the removal of coarse woody debris on the forest floor were important results of fire. Both the Saami and the new settlers were thus essentially pastoralists but, whereas reindeer depended mainly on late-successional lichen mats, cattle instead depended on early-successional herb, grass and deciduous seedlings emerging after fire. These were fundamentally conflicting interests.

Spatially detailed sampling of fire scar material reveals that burning during this period took advantage of landscape structure. Fire borders typically follow small streams and mires (figure 2). Frequently, fires were

positioned adjacent to each other over short periods of time, probably to make use of recent burns to act as fuel breaks. With respect to the season of burning, there was only a relatively minor change towards early season fires (A. Granström & M. Niklasson 2005, unpublished data), indicating that burning in this region was done when the weather was suitable, regardless of the season.

A dramatic final shift in the fire regime came in the late 1800s (figure 1). Fire frequency abruptly dropped to very low levels over the period 1860–1880, concurrent with a rapid advance of large-scale timber exploitation. This shift was enforced by strict legislation and an expanding cadre of foresters, but appears to have caused little conflict. Timber exploitation greatly improved the economy of the local population (Östlund 1993), and this is the likely reason for the smooth transition.

5. CONCLUSION

When discussing past human fire use, it is important to assess both the capabilities and the intentions of people. Our conclusion is that there is a potential for early fire management in the boreal regions, although there is precious little hard evidence one way or the other, except for the last few hundred years, as exemplified by dendrochronological studies from Fennoscandia. Somewhat increasing fire frequencies are a probable effect of any human presence, but changing spatial and temporal patterns are expected to be more pronounced consequences. Through much of the past, human resource extraction would have benefited from a high proportion of early-successional vegetation, but this is also what natural fire regimes offer throughout the boreal. Although the potential for reducing fire frequency below that of the natural fire regime also exists in certain regions, as evidenced by the drop in fire frequency in the late 1800s in boreal Fennoscandia, this would hardly be expected on a larger scale in earlier times, and not in regions with less favourable conditions for fire control.

The net effect of humans on the boreal fire regimes would be expected to differ both by culture (main resource base and its relation to fire) and by region (fire weather, landscape physiognomy). When trying to disentangle cultural and climatic influence on the palaeo-record, combining information on palaeoclimate, archaeology and fire/vegetation patterns is likely to be profitable. The present focus on fire frequency is unfortunate, since it may be a particularly poor indicator of cultural versus climatic control of the fire regime. Other indicators, such as changes in spatial or seasonal distribution of fires, may provide stronger evidence of human influence.

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