Fire Ecology in Swedish Forests

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INTRODUCTION

Most woodlands in Sweden have been subjected to fire in one form or another—forest fires, burning-over for cultivation, practised in former times, and the present-day prescribed burning—and almost everywhere one can find charcoal in the humus layer as evidence of fire. In determining the extent and composition of the boreal forests, fire has always been a very important factor.

In former times, when forest fires where able to spread across the country unhindered, vast areas could be devastated, but the area has now decreased, thanks to intensive fire control. During this century prescribed burning has been used to an increasing extent in reforestation until recent years. The reason for this decline is mainly the labour-demanding nature of prescribed burning, but in addition the occurrence of a fungus (*Rhizina undelata*) on burned areas.

In Scandainavia, prescribed burning is practised on inactive raw-humus sites mainly in the sparsely-populated northern areas. It is now generally accepted that on ground that is not too dry a properly conducted prescribed burn is the most efficient method of accelerating the ripening of the humus of a clearing (E. V. Komarek 1970). However, forest fires on poor, dry soils can have devastating effects, resulting, for instance, in soil degeneration. In this paper I shall only try to give a short summary of some investigations which I hope will illustrate both the unfavourable and the favourable effects of forest fires and prescribed burning.

TEMPERATURES DURING CONTROLLED BURNING

The investigation was performed in connection with burning in the province of Hälsingland, lat. 60°36′N. The felled areas had been covered chiefly by old Norway spruce (*Picea abies*) forests on an inactive raw humus cover. It is essential, in reaching an understanding of the effects of fire on clearings, to obtain some measure of temperatures in the humus cover and the air during the fire, and many investigations have been mainly on grassland and moor but also during prescribed burning in forests (Investigations by Heyward 1938, Beadle 1940, Uggla 1957 b, Beaufait 1960, Whittaker 1961, Kayll 1966, 1968, Daubenmire 1968, Smith 1968 and Gimingham 1970, offer an extensive review in the literature).

Soil Temperatures

Methods—For determining the temperature in the humus cover it is usual to employ organic salts of known melting-point, though they indicate only the maximum temperature.

In the present study the temperature fluctuations were followed by direct reading on a resistance bridge provided with a temperature pick-up. For this purpose the Philips temperature indicator Type RDM 15 was used. This resistance bridge is accurate to about 0.15°C (the temperatures are given in degrees Centigrade in all cases) and the pick-ups have a maximum error of 0.2 ohm, which corresponds to an accuracy of 0.12° at 0°C. The total error for the pick-up and the instrument is thus about 0.3°C. The 25-metre cables were matched to the instrument and the apparatus was calibrated by Svenska AB Philips before and after the measurements.

For measuring the high temperatures that occur at, and just above, the soil surface, a pick-up with a platinum element was used, while for the lower temperatures—below 150°C—a nickel one was necessary.

The nickel pick-ups were carefully placed in a horizontal position at different depths in the humus cover. The measurements were made with the platinum element horizontal on the surface, so that it was partly covered by the bottom stratum. Afer these preparations the slash was replaced and the measurements carried out as accurately as possible.

Tree Layer Temperatures

Methods—For the measurement of the temperature at the trees, maximum thermometers recording up to 300°C were used. The thermometers were hung at 3, 6, 9 and 12 metres above the ground, some on the trunks and others on the extreme ends of the branches on the windward side of the crown. Tests were carried out with pyrometers and sentinel paste, which contains salts of known fusing point, but they were discontinued because the salts did not give true readings during the short time the fire lay over the test plots. For measurements in the open flame, a radiation pyrometer having a temperature range of 600–2,200°C was used. This type of instrument is used at the Government Testing Laboratories who tested the accuracy.

Soil Temperatures

The severity of the fire is dependent on several factors, and amongst these the forest type, the moisture content of the soil and the relative humidity are not the least important (Geiger 1950). Numerous workers have commented on the efficacy of humus as an insulator. The investigations also showed a low temperature in the humus cover compared with that in the soil surface. A good example was a test with 50 cm slash, where the temperature at the soil surface during 20 seconds was as high as 540 C°, while the temperature at 3 cm depth in the humus cover (A_1) only rose from 15°C to 20°C after 30 minutes. The temperature at the soil surface on the day after the burn was about 35°C, owing to the absorption of the sun's heat by the charred layer. In another test (Fig. 1–3) the slash was about 100 cm thick, and the temperature at the soil surface was between 300–350°C during 30 minutes. In this test the temperature at

FIG. 1. Test 4. The slash was about 1 metre thick.

3 cm depth (A_1) was 60°C during about 5 minutes, and 90 minutes later it was 35°C. The temperatures immediately before burning were 15°C, and 20°C at 3 cm depth respectively.

From these examples and other tests it is evident that the humus cover is an excellent insulator. This may be explained by the condensation that always occurs in the ground during a burn. *As the fire passes over the ground the damp humus cover acts as a cold barrier, where moisture is condensed.* Immediately below the fire zone there is a "*sweating zone*", which effectively prevents the fire from penetrating humus cover. Before this can happen, the moisture must be

FIG. 2. The same area as in Figure 1 after the fire front had passed.

evaporated. As a rule the high temperature does not last long enough in prescribed burning for all the moisture to evaporate. Only if the firefront is arrested, and on dry ground in particular it is likely that the humus cover will burn partly or completely. On moist sites the fire will usually consume only slash and litter, dried-out vegetation and possibly the uppermost dry part of the humus cover to which the air has free access. The moisture content of the humus is thus a critical factor in burning. The higher the moisture content, the greater the thermal capacity and hence the less the risk of an unfavourable effect of burning. Finally, as the uppermost part of the

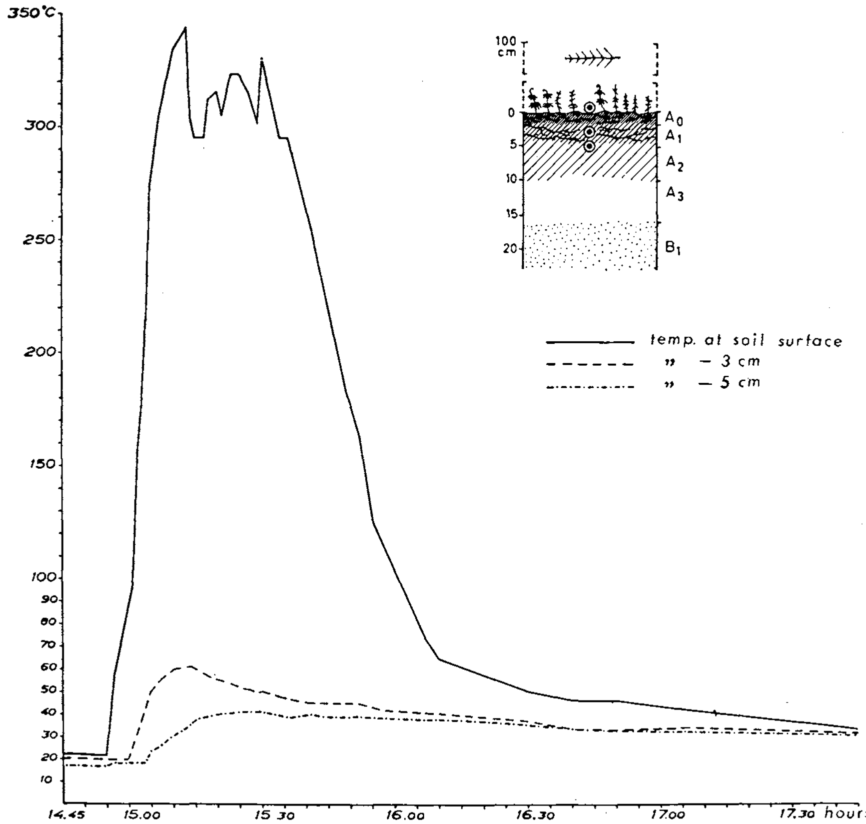


FIG. 3. The irregular curve for the temperature at the surface and the rather high soil temperatures are due to the unusually thick slash. (Fig. 1).

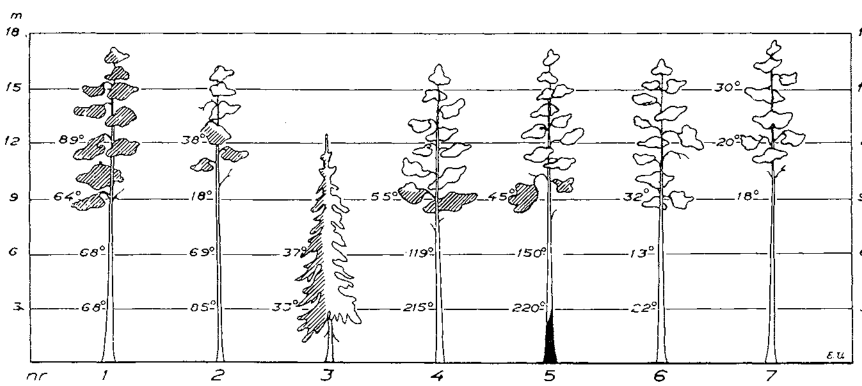
humus cover can be sterilized this will be of importance for the composition of the micro-organisms after the fire.

AIR TEMPERATURES

The study of the air temperatures was intended to provide data to serve as a basis for discussion. Repeated measurements in the open flame from burning slash—on an average 50 cm thick—gave a temperature in the hottest part of about 1150°C. The high temperatures

Fig. 4. Tree No. 4 during and immediately after the burn (on the left). At a height of 3 metres the maximum temperature was 215°C, at 6 metres 119° and at 9 metres 55°.

are similar to those obtained in similar Swedish fire prevention experiments. The temperature at the tree crowns was low—between 33°C to 89°C—and the difference between the temperatures associated with partial killing of tree crowns, and those associated with no damage, was quite small. Serious damage to the needles was observed only in the parts of the crowns exposed to the yellowish-brown to black smoke, formed during incomplete combustion. The grey to white condensation smoke in these experiments was not lethal (Figs. 4, 5). As Kayll (1968) pointed out, it is a question for further study whether the damage is attributable to the brown-black



Hygge Cutting area		Källbacken			Gluggen		Born
Vindstyrka Force of the wind		stark strong			svag weak		svag weak
Träd nr......................... Tree No.	1	2	3	4	5	6	7
Gulbrun-svart rök (min.) ... Yellowish-brown to black smoke (minutes)	15	10	7	5	5	0	0
Gråvit rök (min.) .... Grey to white smoke (minutes)	60	50	60	15	15	20	15

FIG. 5. The temperature at the trees, and the period during which the smoke was over the trees. The part of the crown that was killed is shaded.

smoke only or whether it is produced by excessive drying of the crown. The latter ought to be the case at short distances from the fire. Figure 5 may give some basis for further discussion, such as Beaufait (1960).

FOREST FIRE AREAS IN LAPLAND

Since 1945 I have, at intervals, studied forest fire areas in the largest reserve of primeval forest in Sweden, the Muddus National Park, situated about 30 km north of the arctic Circle (Uggla 1949, 1958 a, b). This National Park has an area of 50,000 hectares (123,-000 acres), and provides excellent opportunities for following the undisturbed colonisation and succession of vegetation on different forest site types within fixed sample plots (20 $\times$ 25 m). These are connected with belt transects of different sizes to examine immigration into the burnt area (Figs. 6–8) (Heikinheimo 1932, Sarvas 1937 b, Sirén 1955, Ahlgren I. F. and Ahlgren C. F. 1960, Hansen 1964, Trabaud 1970). The principal area of these studies is 3,160 hectares which was rather severely burned in 1933. On an easily reforested lichen heath, about 5,000 pine seedlings (*Pinus silvestris*) per hectare were counted 12 years after the fire. But the dryness of the strongly insolated burnt area, the attacks of snow blight (*Phacidium infestans*) and other factors led, however, to the result that 24 years after the fire, of this large initial number of seedlings, only about 300 pine plants per hectare still survived and of them, only 50 had reached a height of more than 1.3 m in the centre of the burnt area. These plants grow mainly in the shelter of stones and fallen trees, and the number of seedlings decreased very rapidly towards the centre of this heath (Figs. 9, 10).

After the passage of the fire, the soil was covered by a layer of gray ashes, and around the glowing stumps and fallen trees the humus was so badly burnt as to leave the mineral soil exposed. In cases where the fire front had not stood still, the humus cover was as a rule only slightly burnt, and in depressions the vegetation was completely undamaged. From such spots colonisation can begin, as also from surviving subterranean runners of various types, from seeds which have survived the fire in the humus cover and from the living vegetation itself.

The subsequent development of the primary succession depends upon many interacting factors. The condition of the humus prior to the fire will decide both the degree of activation of the soil, and the duration of this condition of the humus favourable to the plants. Changes can be produced in the geological, hydrological, and climatological factors which will determine the limits within the vegetation that it will be able to change. In the study of the colonisation of a burnt area by plants, the following main factors have to be taken

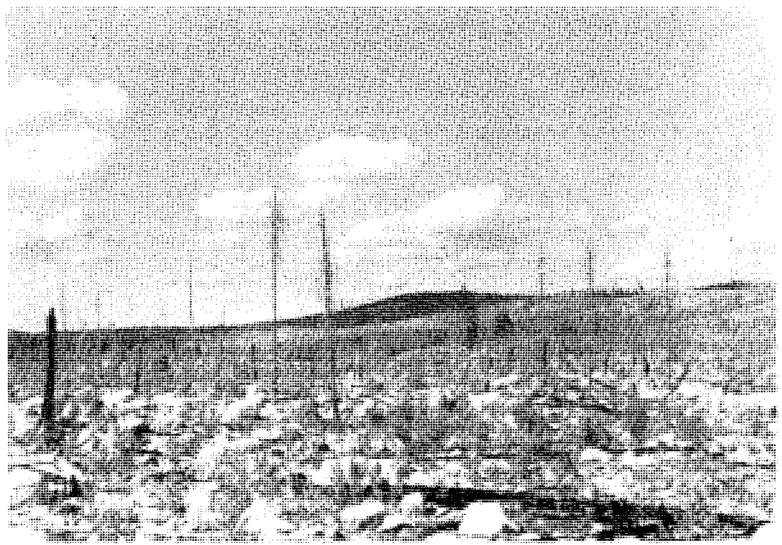


FIG. 6. Twelve years after the fire the regrowth was very feeble upon the boulder terrace in the southern part of the burnt area of 1933.

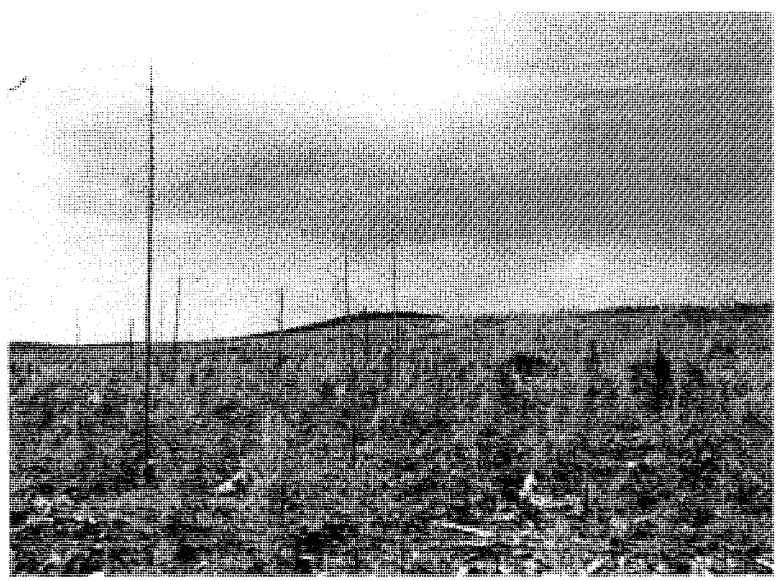


FIG. 7. The same area 12 years later from sample plot 3.

1957

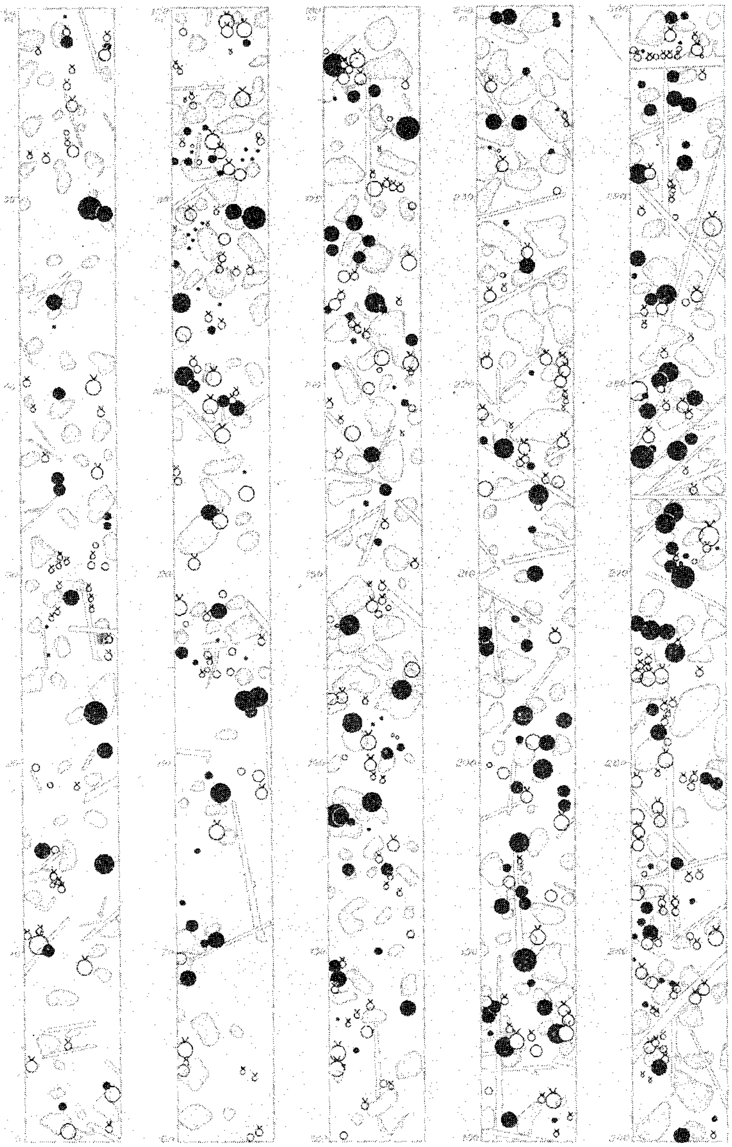


FIG. 8. Belt transect (5 × 300 m) from sample plot 3 in the center of the southern part of the burnt area to sample plot 4 next to the growing forest. Vegetation analysis every $25 m^2$. Cf. explanation in Figure 10.

FIG. 9. Heaving by frost is very common upon the pine heath. In the field stratum *Calluna vulgaris* was predominant, and 24 years after the fire the reindeer-lichens were still very scarce. Sample plot 1. Burnt area of 1933.

into consideration as is shown by many investigations; the vegetation before the fire, the intensity of the conflagration, and the possibilities for the dispersal of the species.

Species of *Cladonia* occurred sparsely on the heaths within the investigated burnt areas. All who have studied the regeneration of the reindeer lichens (Sarvas 1937 a, b, Uggla 1958 a, Ahti 1961, Scotter 1963, 1971) on burnt areas agree in stating that a very long time is required before they reach their former abundance. This agrees well with the conditions in Muddus and there is no doubt that

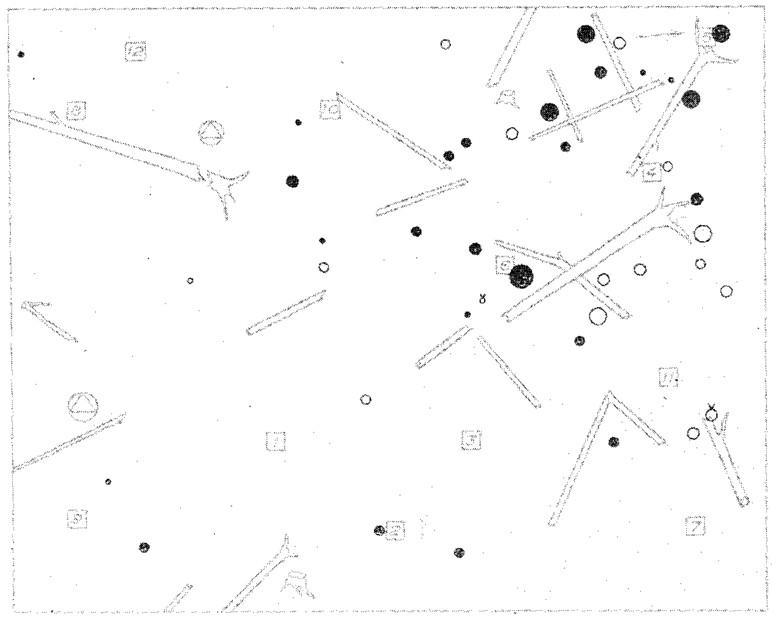


FIG. 10. Sample plot 1 (20 × 25m) 24 years after the forest fire. Black circle = pine, white circle = birch.

it will take the reindeer lichens (*Cladonia alpestris, C. rangiferina, C. silvatica*) more than 40 years to recover completely; this applies particularly to *C. alpestris* (Fig. 9).

These heaths are traversed every year in December by Lapps with 20,000–30,000 reindeer on their way down to the forest pastures. In April they return again towards the mountains. At this time the pine seedlings are frozen and brittle, and for this reason part of the damage can be attributed to the trampling of reindeer (*Arnborg* 1955).

That moose numbers increase after fire is pointed out in Alaska by *Spencer* and *Hakala* (1964). The number of plants damaged in Muddus by the European moose (*Alces alces alces*) is very large. In one sample plot it was 17 percent, 12 years later 52 percent. The investigation also indicates that an ample supply of deciduous forage plants (*Betula pubescens*, *B. verrucosa* and *Populus tremula*), as is the case on burnt areas, does not induce moose to desist from a coniferous diet, and also that moose in Muddus National Park do not avoid the extensive regeneration areas, which lack refuges.

EFFECTS OF FIRE ON A THIN LAYER OF RAW HUMUS

As the burned heath in Muddus was an example of the effect of a very severe forest fire, this study is an example of the effect of intensive prescribed burning on a thin and desiccated layer of raw humus on the top of a podzolised glacial soil. It is quite natural that some part of the clearfelled area may be too burnt, even during an otherwise properly conducted prescribed burn and this study concerns such a case.

The investigation was carried out in connection with a provenance trial at Övra in northern Sweden, situated about 375 m above sea-level, Lat. 63°50′N. The area was burnt in 1943, and seeded with spruce (*Picea abies*) in the following year. Since the soil is uniform, and since only half of the plot was burnt, the site is suitable for use in comparing plant development, vegetation and soil on the burnt and unburnt parts. Annual examination of the spruce showed that initially, the plants on the burnt part were larger and more vigorous. However, after 9 growing seasons the curves for height increment crossed; thus after 21 growing seasons, the current height increment of the plants on the unburnt part was on the average greater by 65 percent (Fig. 11).

Vegetation analyses showed that great changes had occurred, especially in the ground layer. The mosses *Hylocomium splendens* and *Pleurozium schreberi*, which often lack connection with the substratum, dominate on unburnt areas and provide protection to a thin humus layer against desiccation, had been replaced by the characteristic moss of burnt areas, *Polytrichum juniperinum*. This moss has long, abundantly branched rhizoids, which break up the soil, a process which may be detrimental to the micro-climate and water-regime.

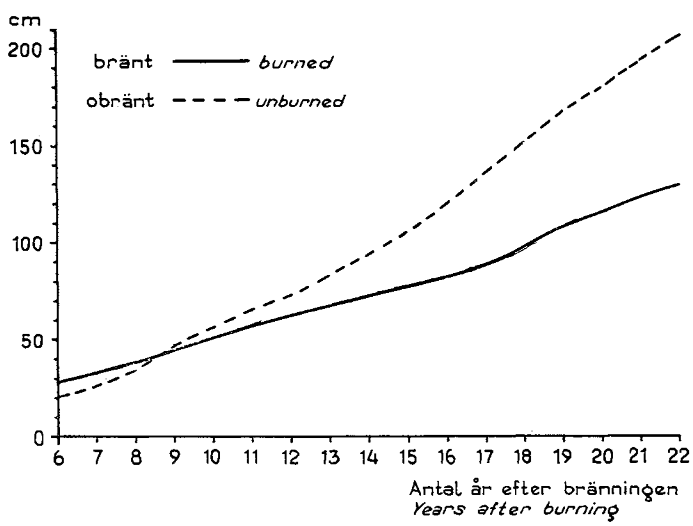


FIG. 11. Above: 18-year old plants on the burnt and unburnt part of the plot. Below: The current height-increment of Norway spruce (*Picea abides*).

Chemical analyses of the soil, and foliar analysis, showed that there was a lack of nitrogen in the soil of both burnt and unburnt areas and that pH and the calcium content were higher in the humus layer of the burnt area, even 19 years after the fire. Laboratory experiments also showed that the burnt humus layer had a decreased water-holding capacity and a greatly increased permeability.

That the burning in this instance seems to have had a deterimental effect on plant development seems primarily to depend on the fact that the dried-out humus layer was attenuated by burning an average thickness of 1.3 cm, while the humus was 2.5 cm thick in the unburnt part of the experimental plot. The composition of the bottom layer was also radically changed. The humus layer could thus no longer sufficiently protect the superficial roots of the spruce plants against desiccation and temperature changes.

COMPARATIVE STUDIES OF BURNED AND UNBURNED CLEARINGS

This study, finally began in 1962 and is intended to compare the effect of several treatments of clearings on the development of Scots pine (*Pinus silvestris*), the dynamics of the vegetation and the soil. Studies are being performed in four experimental forests from the Arctic circle to the neighbourhood of Stockholm; the experiment is divided in to four blocks (according to *Fisher*), in which one parcel was burned and one was covered with slash and one without. All plots were planted with 1,200 *Pinus silvestris* plants and were investigated annually. After 3–4 growing seasons the mean height and vitality of plants on the burnt plots were significantly better than was the case on the unburnt plots principally, in comparisons between the plants in the parcels with slash. The diagrams of the mean heights show this tendency even in 1972, i.e. after 9–11 growing seasons, depending on where and when the plots were burned and planted (Fig. 12). In 1972, in the southern experimental forest the number of dead plants was 5 percent within the burnt parcels, 10 percent within the unburnt without slash and 22 percent with a slash. The number of dead plants increased in the northern experimental forests,

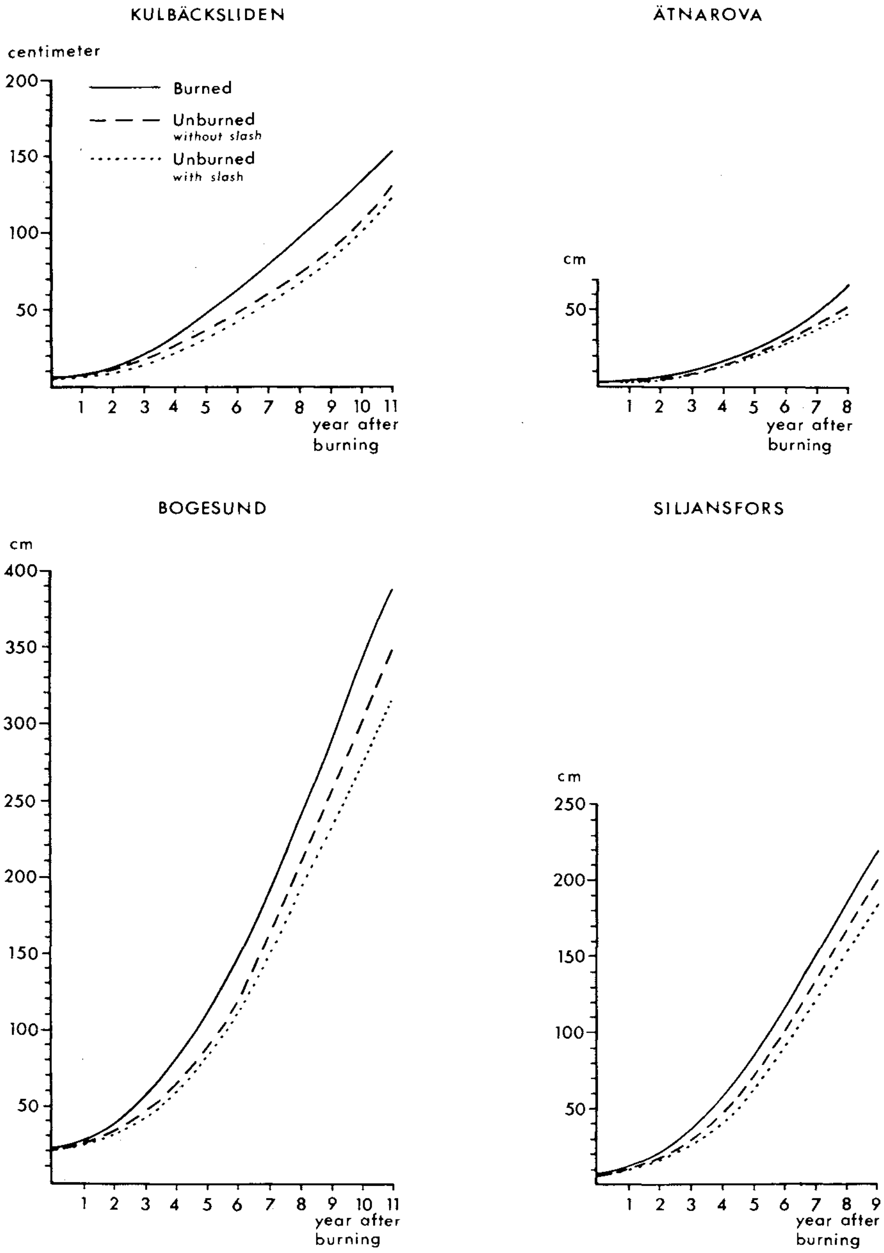


FIG. 12. The height growth of Scotch pine (*Pinus silvestris*) on comparative studies of burnt and unburnt clearings from Bogesund lat. 49°30′N, Siljansfors lat. 61°10′, Kulbacksliden lat 64°20′ to Atnarova 67°12′ (10 km north Arctic Circle).

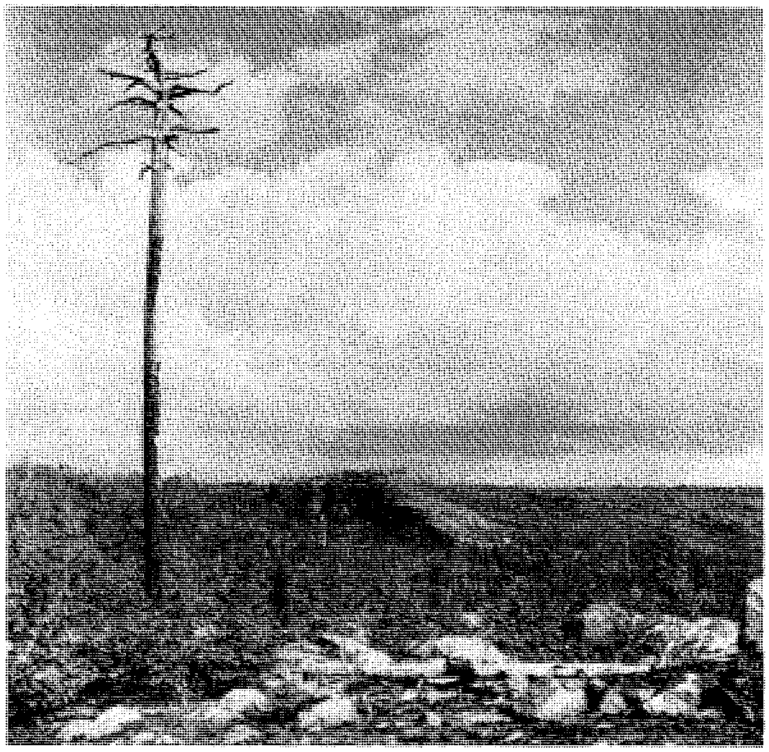


FIG. 13. Within large parts of the burnt area the 1933 fire was so intense that part of the humus cover was incinerated. The picture was taken 24 years after the fire and illustrates the slow rate of regrowth.

depending on the severe climate, but the tendency on the whole was the same. The circumstance that the slash had an unfavourable effect on height growth and vitality of the pine plants and was associated with high mortality, seems mainly to depend on shading and attack by voles. Damage by these animals was almost exclusively concentrated to the parcels with slash, which provided protection for them.

The dynamics of the vegetation were normal for the forest site type at the various latitudes. *Deschampsia flexuosa* dominated on the unburnt parcels and the slash tended to protect the vegetation, especially bilberry (*Vaccinium myrtillus*) and the mosses above all *Hylocomium splendens*, which is dependent for its nutrition on canopy, drip etc.

The analyses of the soil showed that pH, P, K and Ca increased markedly after burning and that the values 5–6 years after the burning were normal for the experimental forest.

The study thus shows that controlled burning has a favourable effect on the establishment of Scots pine (*Pinus silvestris*) seedlings, This result applies only to about 10 growing seasons after the burning, but practical experience and research have shown that fire on moist forest land with inactive raw humus has a beneficial ecological effect on boreal forest vegetation even in the long term.

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