Some Remarks on Fire Ecology in Finnish Forestry

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INTRODUCTION

As is the case throughout the whole coniferous region of the world, fire has played an important role in shaping the dynamics of forest ecosystems in Finland. Up to the beginning of this century, wildfires ran over tens of thousands of hectares annually, renewing in this spectacular way the vegetation and the species and age class distribution of the present day forest stands. Fire was widely used in primitive agriculture too—in the form of shifting cultivation—for both crop and pasture improvement purposes. It is generally accepted that all the forest land in Finland has been overrun by fire at least once during the last half millenium.

Due to its timber destroying effects, shifting cultivation was prohibited. Thus the impact of fire was reduced for some decades until the early 1920's. After becoming independent, Finland energetically developed its economic life. The importance of forestry and forest industries grew rapidly and goal-oriented steps toward intensified silviculture were taken. Successful natural regeneration following wildfires guided the silviculturist into applying large scale prescribed burning of slash in clear cut areas. The vital burning tradition has in addition been kept alive since 1875 by the pioneers of forestry research and education.

The total area annually overrun by wildfires during the period 1894–1972 is shown in Figure 1. The corresponding figures for pre-

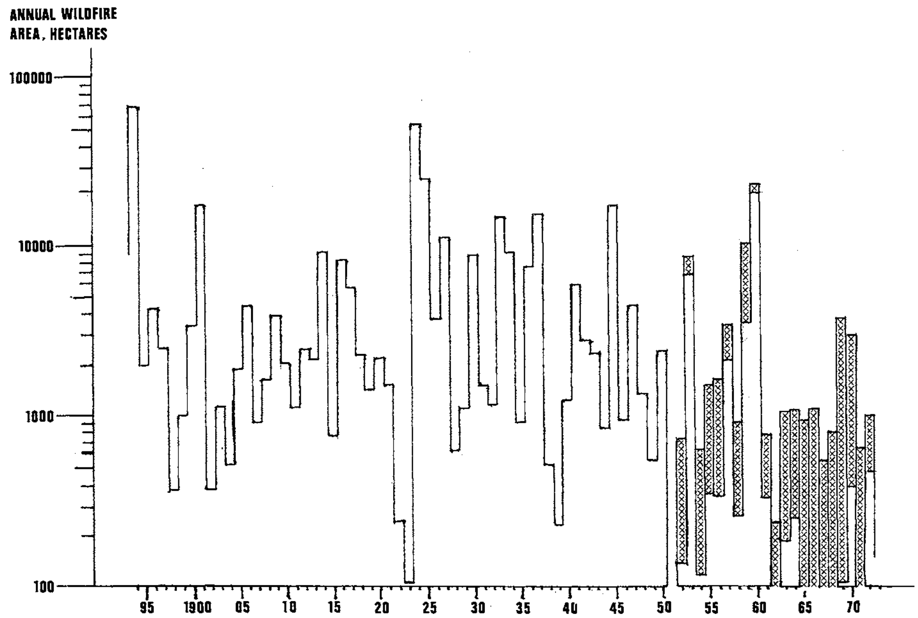


FIG. 1. Annual wildfire area in hectares during 1894–1972. Since 1950 wildfires on private land have been separately reported.

scribed burning since 1923 are presented in Figure 2. Today, fire plays almost no role at all in Finnish forestry practice. Wildfires are efficiently combatted and since 1965 the mechanization of soil preparation for forest regeneration has rapidly reduced the area of controlled fire application. Preventive slash burning for fire-hazard-reduction has never been practiced in Finland in large scale.

Concern about the unforeseen consequences of the undisciplined and rough soil treatment caused by caterpillar-hauled heavy ploughs which destroy the earlier uninterrupted natural development of the soil is, however, gaining ground. As a result of a growing understanding of the delicate balance of the abiotics, space and time dependent forest ecosystem, attention is apparently turning toward something less controversial.

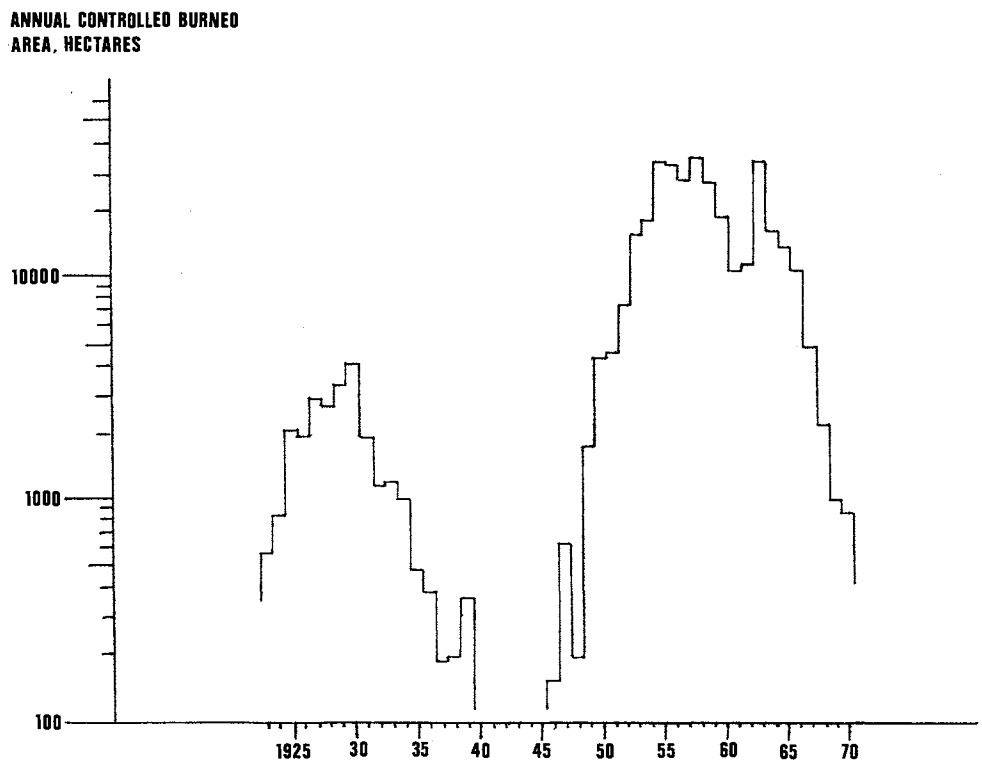


FIG. 2. Annual controlled burned area in hectares during 1923–1970.

SOME EFFECTS ON THE FOREST ECOSYSTEM

The knowledge of forest ecosystems and their function is undergoing the same pattern of change in our country as in other countries in the coniferous region. Descriptive studies on the dynamics of forests are followed by highly instrumentalized causal-oriented field and laboratory work.

The pioneers, however, concentrated their main attention upon the impact of fire on the regeneration pattern of the tree community and tree species (Blomqvist 1888), although Cajander (1909) demonstrated some interest in the natural successions following fire. Heikinheimo (1915) described the dynamics of forests invading abandoned swaling soils. Aaltonen (1919) and Sarvas (1937) concentrated on on the natural regeneration of dry sites after wildfires, whilst Kalela (1954) formulated the underlying synecological credo.

The present author studied the dynamics of spruce forests on raw humus sites situated in the cold and humid climate of northern Finland. It was found that the primary succession which follows after a fire is superior to the secondary succession replacing the overmature climax spruce stand as regards standing stock and production of the tree stand and composition and vitality of the entire vegetation (Sirén 1955). It seemed that fire re-established the original ecological conditions partly lost as a result of the accumulation of a nutrient-immobilizing raw humus layer. After a not too severe fire, the dynamics of vegetation display an exuberance similar to the invasion stage of primary successions found in the spruce forests of North America and Siberia. After a century long dominance period of broad-leaved species (mainly birch), the climax species (spruce) takes over in the tree layer. The fauna follows the pattern of the successions of the plant community—the richest stage seems to occur after stand closure in the invasion stage after fire. In the stabilized climax stage, completely dominated by spruce, a multitude of ecological niches, which exist in earlier dynamic stages, are lost. The number of different species is low. Diversity is replaced by monotony.

In the humid climate of Finland, fire has very seldom an erosive effect on the forest soil. Site quality may, however, deteriorate when fire is used on too dry thin-humus-layered sites, which has been the case in Sweden, and which also explains the negative results obtained by Swedish forest researchers (Huss & Sinko, 1969). Reforestation with spruce on burned poor sites have never been considered meaningful (Uggla 1967).

CLIMATIC AND SOIL-EROSION EFFECTS

The ecological effects of wildfires and prescribed burnings are in many respects rather similar.

As regards macroenvironmental effects, it is nowadays realized that large fires have a slightly modifying effect on the local climate. During the winter, the snow cover is thinner and denser than in slash covered areas or under tree stands. During the summer, extreme variations occur in the microclimate; exemplified e.g. by high surface temperatures in day-time and frequent spells of frost at night, caused by the strongly changed insolation and irradiation conditions. In addition to the temperature regime of soil surface, soil moisture and wind velocity are influenced in areas recently overrun by fire.

The micrometeorological extremes are, on the other hand, usually weakened after vegetation has invaded the area—with exceptions for grass and lichen vegetation. Regarding grass vegetation, it should be noticed that the extremes refer to the years during which the new crop grows through the fallen dry grass of the previous year.

The severity of the extremes depends mainly upon the soil structure and topography. Irrespective of soil type, frosthollows may remain treeless for a long time as well as coarse-structured top-soil-patches often plagued by drought in certain type of sediment areas. Except on these last mentioned locals, a comparison with other types of soil preparation reveals that fire brings about some soil ecological advantages, especially on fresh site types (Fig. 3).

Soil aeration is a factor which is usually overlooked on dense morainic soil. In old spruce stands, the trend of increasing compactness sometimes close to hard pan formation of the soil is indirectly interrupted by fire. After a fire, the previously cold soil penetrated by shallow roots suddenly receives more energy due to the greater degree of exposure and improved humus conditions. Roots of broadleaf species belonging to the primary succession penetrate deeper into the soil. After their death and decomposition the resulting air channels promote gas exchange conditions of the deep soil-layers better than before. The changed pH after fire may have a positive influence on the discompaction of the soil too (cf Sirén, 1955).

In former days, prescribed burning was opposed by some forest researchers due to supposed nitrogen-losses. According to present day knowledge (Viro, 1969), the fear of irreparable losses seems exaggerated. Some of the N of the humus layer is of course oxidized

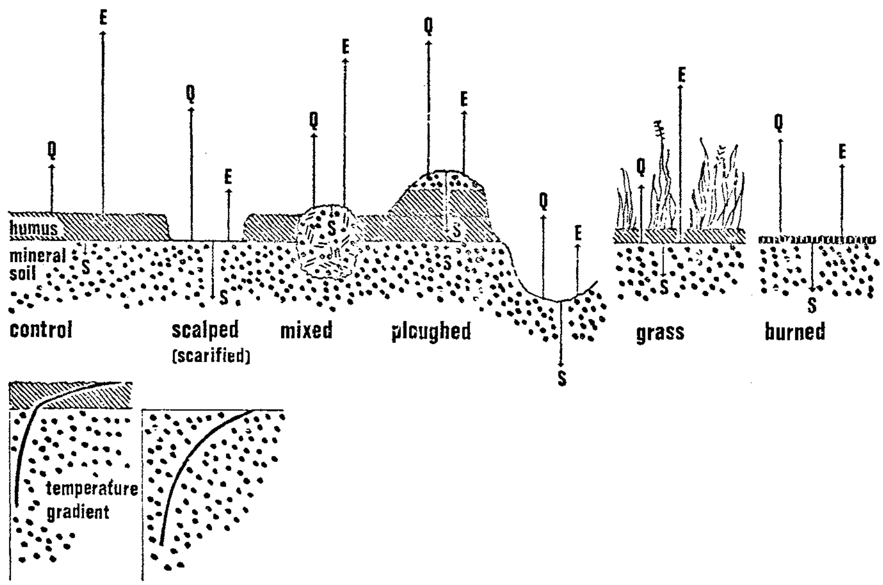


FIG. 3. Heat balance patterns after selected types of soil treatment.

and lost but a considerable part is converted by moderate heating into ammonia and partly retained by the remaining unburnt lower layer of the humus. This explains the controversy on the seemingly increased N-level after burning. Due to the heavy CaO release caused by fire, the acidity of soil is decreased, thus promoting nitrification during the first decades of the primary succession.

The amount of nutrients released by fire depends mainly upon four factors: the original site quality, the fuel loading of the slash, the amount of accumulated raw humus and the burning conditions. On the first order prescribed burning site of the thickmoss type (HMT)[1], the fertility improving effect may in principle come about in the way indicated in Table 1. The fertilizing effect would be still more pronounced if the humus layer burns down to a thickness of

[1] HMT = Hylocomium-Myrtillus-type

some 2–3 cm. The raw humus cover is completely mineralized usually in small patches only, where there is a surplus of slash of optimum size. In case of correct timing some 10–20 percent of the area is burned down to the mineral soil. More would be disastrous in the conditions of Finland according to the author's experience.

Results obtained indicate that the positive fertilizing effect is retained in Northern Finland for a longer time than the 50 years suggested by Viro (1969) for the conditions in Southern Finland. Careful comparison between parallel stands on comparable soil indicates

TABLE 1. POTENTIAL FERTILIZATION EFFECT OF BURNING SLASH AND 6 CM THICK RAW HUMUS COVER OF HMT IN NORTHERN FINLAND.

Type of fire loading	Amount ton/ha	Nutrient content kg/ha CaO	K_2O	P_2O_5	N_{tot}	Energy output, Kcal/ha (100% dry)
Slash	20–40	25	20	10	40	1.2×10^8
Vegetation Raw humus	2–8 30–70	300	80	60	> 800	2.0×10^8
Total	∽ 50–120	> 300	~ 100	~ 70	> 800	3.2×10^8 (~ 200 m^3 fuel ≈ wood)

that young stands have a considerably better nutritional situation than old stands, in which large amounts of nutrients are immobilized in the accumulating raw humus layer. This thick humus layer promotes the continuous impoverishment of the ecological conditions of the soil by lowering soil temperature, retarding decomposition, raising acidity, etc (Siren, 1955).

Burning interrupts this unfavorable trend. The N-loss is of minor importance and does not affect the fertility of the site due to the improved general conditions for microbiological activities which favour N-fixation (Hanioja, 1961). On the other hand, after clear cutting a raw humus cover, which lies inactive for a long time, seems to contribute to a severe decrease in site fertility (Huss & Sinko, 1969). Leaching goes on, but now without the compensatory supply from the production processes of the complete ecosystem—now momentarily cut down to a severely damaged ground. The complicated problems of inbalanced microbiological activities are under study of Huhta (1971) and Havas et al. (1974).

Distribution, composition and frequency of the fauna follows the dynamic pattern of the vegetation. A few years after a fire on fresh morainic soils an exuberant development begins (Karppinen, 1958a,b). The old climax stands are in this respect stable but poor in species as regards insects, mites, spiders etc. The higher fauna does not deviate from the general pattern of dynamics of the ecosystem.

SILVICULTURAL APPLICATIONS

During the burning boom in the 1950's, the main purpose of controlled fire application in Finland was to facilitate forest regeneration. The main alternatives were:

a) clear-cutting, followed by soil preparation and artificial stand establishment, and
b) selective cutting leaving seed trees, followed by soil preparation and natural seeding.

The first mentioned case was common in the thickmoss spruce forests (HMT) of the far North, which were often converted into pine stands after prescribed burning and sowing in spite of repeated recommendations of accepting the natural succession—or in forestry terms—the birch-spruce stand to a certain degree (20–25 percent) of the cases. Finally birch has been righted—it is now considered both useful and valuable from the industrial point of view.

Care needing soil preparation by fire under pine seed-trees was undertaken by skilled burners only, irrespective of the spectacular regeneration following light wildfires on e.g. dry and medium dry sites (cf. Aaltonen, 1919 and Sarvas, 1937).

After the introduction of fire-hazard warnings on the radio at end of 1950's the burning results surprisingly deteriorated rapidly—excellent premises were no longer exploited. Unfavourable weather conditions and terror-smitten public opinion caused by hostile propaganda helped the forest people to turn to the caterpillar-hauled tractor. In some cases the insufficient burning combined with immature planting material and cold summers in 1960's caused a heavy invasion of the disastrous fungus *Rhizina undulata* and other diseases. Instead of learning fire ecology and developing the burning technique to meet the new requirements of the time, forestry dropped the prescribed burning from the arsenal of silvicultural methods for site preparation—at least for a while.

The list of arguments against prescribed burning includes:
—the dependence upon weather conditions seldom fitting well enough in modern forestry planning,
—ignorance of the ecological advantages gainable by using fire in a proper way,
—the long lapse in burning technique development in the northern countries,
—the small size regeneration areas used especially in private forestry, and lack of a suitable burning technique for 'mini-areas' of a few hectares only,
—the misleading economic yield calculations; e.g. the fertilization effect of the fire application was seldom (or never) considered,
—the amount of heat energy lost in the burning activity and the air pollution caused by smoke,
—the high costs involved in the use of man power,
—the high costs of forest fire insurance premiums,
—the fear of fire getting out of control.

In the present situation, some of the vital questions are:

Has prescribed burning played out its role for good, or is a renaissance possible?

Can its return be promoted e.g. by a new awareness of ecological forestry?

May the introduction of an improved and safer burning technique and the necessity of economizing with the fossil fuels—now wasted by the caterpillar tractors in a rather unqualified soil preparation task give rise to reconsideration?

Is flexible planning including a skillful use of fire an acceptable alternative to rigid planning based partly on fixed annual reforestation areas?

I will not try to discuss the answers to all of the objections in this connection, although the energy supply of the caterpillar tractors could be of very local origin—in the best cases consisting of a fraction of the local slash.

The question of developing a modern competitive burning technique seems, however, important enough to deserve attention at this meeting. Especially in our time when the re-establishment of the original ecosystem is brought into the focus of ecologists all over the world.

PRESCRIBED BURNING PREMISES

Successful prescribed burning of clear cut areas seems—if possible at all—utterly simple judging from the administrators' viewpoint. In this field, realities are even in Finland a little bit more complicated. The fullfilment of the burning goals depends as elsewhere on;

1) previous and present weather conditions,
2) properties of fuel loading (dryness, looseness, size, amount etc),
3) topography, size and configuration of the area in question,
4) species and structure of remaining noncommercial stand,
5) burning technique and time to be chosen.

As a result of improved weather prediction, there is nowadays often a fair chance of correct choice regarding ignition time, technique and other burning conditions. Knowledge of changes in the regions' average daily temperature and windprofile helps in choosing a suitable ignition time with regard to the size of the area and fuel loading properties. Possible negative limitations caused by topography and surrounding stands can be eliminated or weakened by giving the area a rational configuration. If not done in connection with the planning before harvesting, it can in the worst cases be done e.g. by double encircling the area using a heavy plough the day before burning, if natural borders do not exist. The size of the area, fuel loading and the applied technique can be under the burners' complete control.

From the biological point of view, the most frequently overlooked burning pre-requisite deals with the discrepancy between burning goals and the moisture content of the humus layer which in some cases is to be merely overrun or in other cases considerably reduced by fire.

There are functions based on time, soil moisture, air temperature and wind velocity indicating when burning is possible. It is easy to find that a loose moss cover dries down to 20 percent moisture content in one single windy and hot day in early summer. The top layer of a 6–8 cm thick humus layer will correspondingly dry up in 6–8 days in normal Finnish summer conditions. Very seldom, however, do the fire hazard warners consider that a high fire hazard e.g. in the dry-site-pine forest still means insufficient conditions for prescribed burning in slash-covered clear cut areas on HMT-sites with a thick humus layer. The slash retards evapotranspiration from the ground and the thick raw humus need some 4–6 days more to dry out compared with slashfree areas. With a normal fuel loading (50–100 ton/ha), a moisture content of $\sim$ 40 percent in the bottom layer of the humus guarantees an average residual layer of some 2–3 cm thickness after burning, e.g. in the northern Finnish spruce forest areas.

Felling of non-commercial trees and brush a day before burning is a perfect way of spoiling the predicted result—especially if fuel-loading is scarce.

Centre-, zone- or periphery ignition is a matter of windprofile, daytime, humus moisture and wanted thickness of the reduced humus, and before all the burners' experience. Late evening burning seems often to result in unsufficient consumption causing embarassing new ignitions at noon the next day—when weather is windy and warm. Back-fires generally result in thinner humus remainder than head-fires.

SOME SPECIAL EXPERIENCES

Due to the fact that labor is expensive and that harvesting with heavy processors often spoil existing regeneration, the attention of silviculturists is in many cases once again turning to natural regeneration. An important measure for promoting the establishment of the new seedling stand is proper site preparation. On clear cut areas larger than 5–10 hectares, prescribed burning is still an economical alternative depending upon the configuration and bordering forest types of the area. In the case of natural regeneration of pine stands. some 80–200 trees/ha are enough for seeding the area. Usually the total fuel loading is < 50 ton/ha in the forest type in question.

Knowing that new shoots and needles of Scots pine survive undamaged for only about a half minute's exposure to radiation heat of $\geq +50°$ (Table 2), the opportunity of following the disastrous consequences of heat convection and heat mass transport in connection with a fire close to an ecological field station was exploited. An

TABLE 2. DAMAGE OF FULLY DEVELOPED NEEDLES EXPOSED TO RADIATION HEAT. DEGREE OF DAMAGE MEASURED TWO WEEKS AFTER EXPOSURE

Temperature of air °C	Time of exposure, minutes 1/4	1/2	1	2	4	8	16	32
	Percentage of damage							
40	0	0	20	25	45	30	55	100
50	0	0	10	35	40	55	100	
60	15	30	35	50	65	80	100	
70	20	30	55	50	70	100		
80	50	70	85	100	100			

inventory carried out after an afternoon fire in an exceptionally homogenous pine stand revealed that needle damage depended mainly on climatic conditions and fuel loadings, and in addition on the height of the trees and living undergrowth stand (Table 3). Regression analysis revealed that between 1–2 pm under the prevailing circumstances needle damage had been nil only in trees higher than 30 m (Fig. 4). After 3 pm the normal diurnal pattern of weather conditions reduced the needle damage to an almost negligible magnitude in tall seed trees. However, the damage did not end there.

As is well known, the cambium damage at the lower part of the stem is as destructive as needle damage in the crown. An inventory revealed the importance of bark thickness; a 16 mm thick bark layer reduced the cambium damage to about 5 percent in a slash-rich area burned between 2–3 pm whilst thinner bark caused irreversible damages (Fig. 5a). The heavier the fuel loading the more severe the damages. In the stems exposed to fire after 5 pm the cambium dam-

TABLE 3. REGRESSION FUNCTIONS FOR NEEDLE DAMAGE PERCENTAGE PENDING UPON x_1 = TREE HEIGHT, x_2 = SLASH AMOUNT AND x_3 = STANDING BRUSH UNDER DIFFERENT CONDITIONS AND AT DIFFERENT HOURS OF THE DAY.

Time	T°C	R%	W m/sek	Functions
17–20	16	29	0–2	$\overline{x}_0 = 18{,}48 - 1{,}50^{**} x_1 + 2{,}94^{**} x_2 - 0{,}50^{**} x_3$
15–17	18	27	2–6	$\overline{x}_0 = 49{,}40 - 2{,}88^{***} x_1 + 2{,}80^{**} x_2 - 2{,}93^{***} x_3$
14–15	21.5	27	5–8	$\overline{x}_0 = 75{,}70 - 3{,}30^{***} x_1 + 6{,}38^{***} x_2 - 1{,}38^{**} x_3$
13–14	21.0	29	3–5	$\overline{x}_0 = 99{,}22 - 3{,}36^{***} x_1 + 4{,}76^{***} x_2 - 0{,}92^{*} x_3$

Time	Functions	Lower limit of crown, m (damage = 0%)
17-20	$x_0 = 22{,}1 - 2{,}09^{**} x_1$	10,6 m
15-17	$x_0 = 43{,}2 - 4{,}14^{***} x_1$	10,4
14-15	$x_0 = 94{,}3 - 7{,}03^{***} x_1$	13,5
13-14	$x_0 = 99{,}0 - 3{,}28^{**} x_1$	30,4

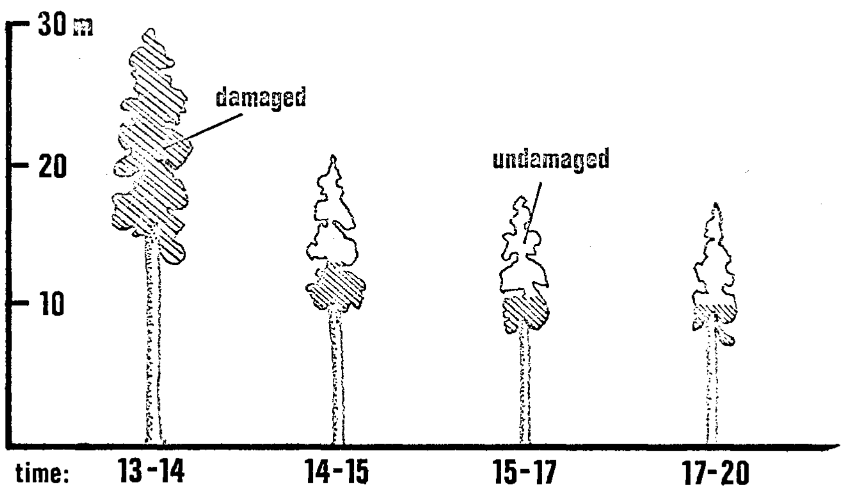
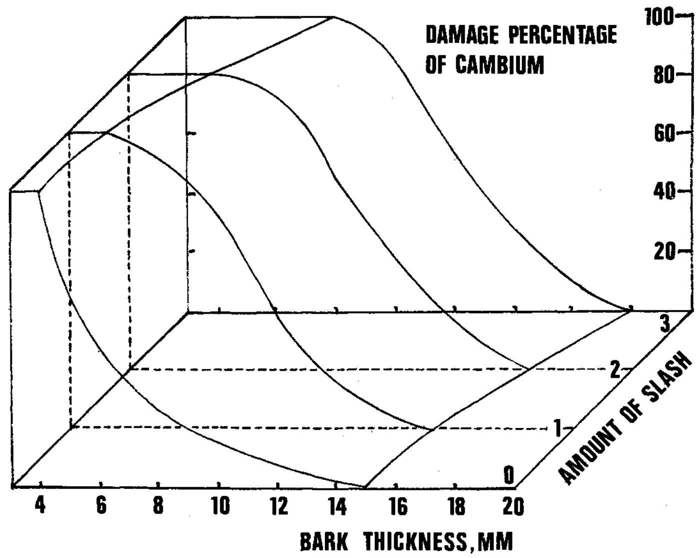


FIG. 4. Regression functions for lower limit of undamaged seed tree crown.



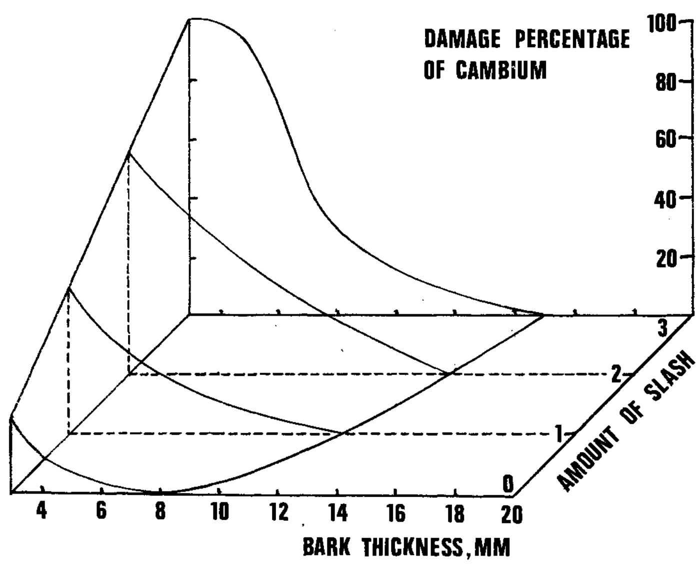


FIG. 5. Cambium damage percentage as graphical function of slash amount, bark thickness and hour of burning; the upper figure represents burning effects between 1–2 pm and the lower after 5 pm, respectively.

ages were modest even in trees with thin bark—except in case of heavy fuel loadings (Fig. 5b).

In order to obtain more distinct information about the heating process, a special experiment was carried out. Fuel beds were arranged along a row of trees parallel to the prevailing wind at a distance of 2–5 m from the trees. In this experimental situation only radiation heat was transferred to the cambium layer by conduction only. The structure of the fuel loading modified of course the heat of the flames and the distance and the burning time to some degree. The bark thickness varied in the sample trees. Some representative results were obtained, however, (Fig. 6). Although the bark thickness exceeded 12 mm in tree no. 2, the cambium was severely damaged by the 18 minutes exposure. The thin-barked (partly $<$ 6 mm) tree no. 1 was killed in 2 minutes.

The conductivity of pine bark was further studied in laboratory conditions (Fig. 7). The results obtained explained well the empirical findings from the field experiments (Fig. 8).

Besides the optimization of fuel loading a modest clearing of heavy fuel from around the seed trees combined with wetting and a proper choice of burning time regarding both season and time of the day has proved being a way of preventing disastrous cambial damages.

A SUMMARY OF REFORESTATION RESULTS

Results from long-term field experiments comparing the ecological and biological consequences of different, both old and modern soil preparation methods are not yet available. An inventory of in total 51 sample stands (usually $>$ 5 hectares) completed with the author's findings from some special small-sized experiment areas has revealed the following:

—the percentage of survival of pine seedlings and plants is generally higher on well burned than on unburned areas. When reforestation activities fail on burned areas—especially on areas unsufficiently burned—the survival of pine is often extremely low ,Yli-Vakkuri, 1961),

—survival of plants on mechanically prepared reforestation areas is generally superior to untreated areas,

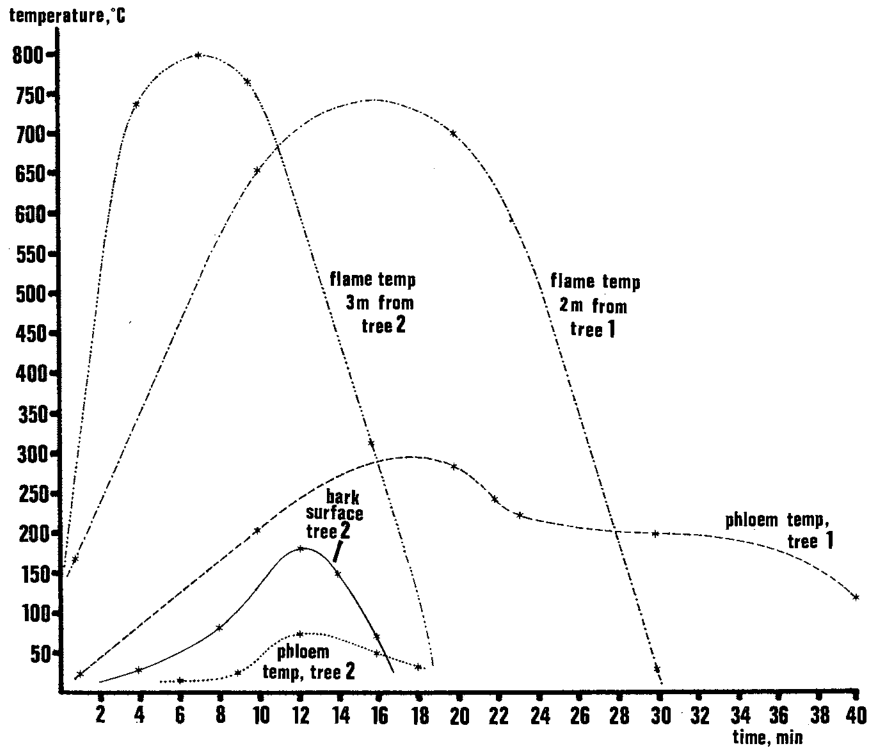


Fig. 6. Temperature development under bark and under phloem in two sample trees subjected to radiation heat during 19 respectively 30 minutes in field conditions.

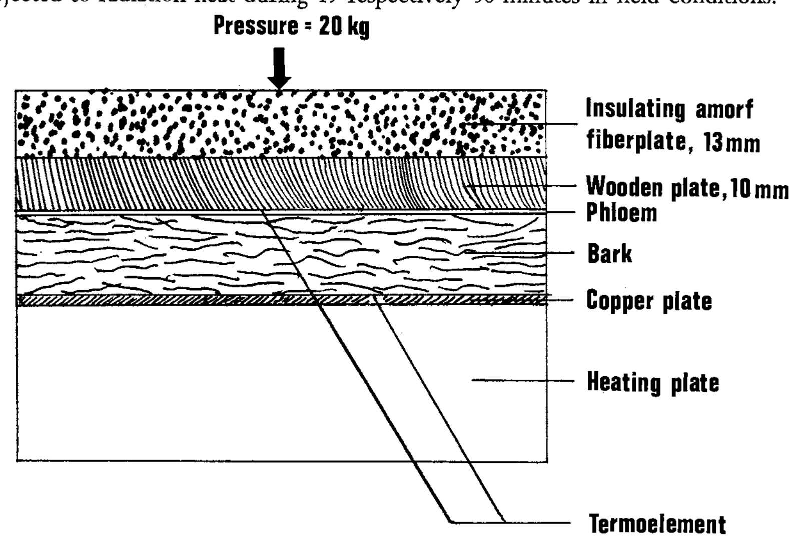


Fig. 7. The laboratory device for measuring thermal conductivity of bark.

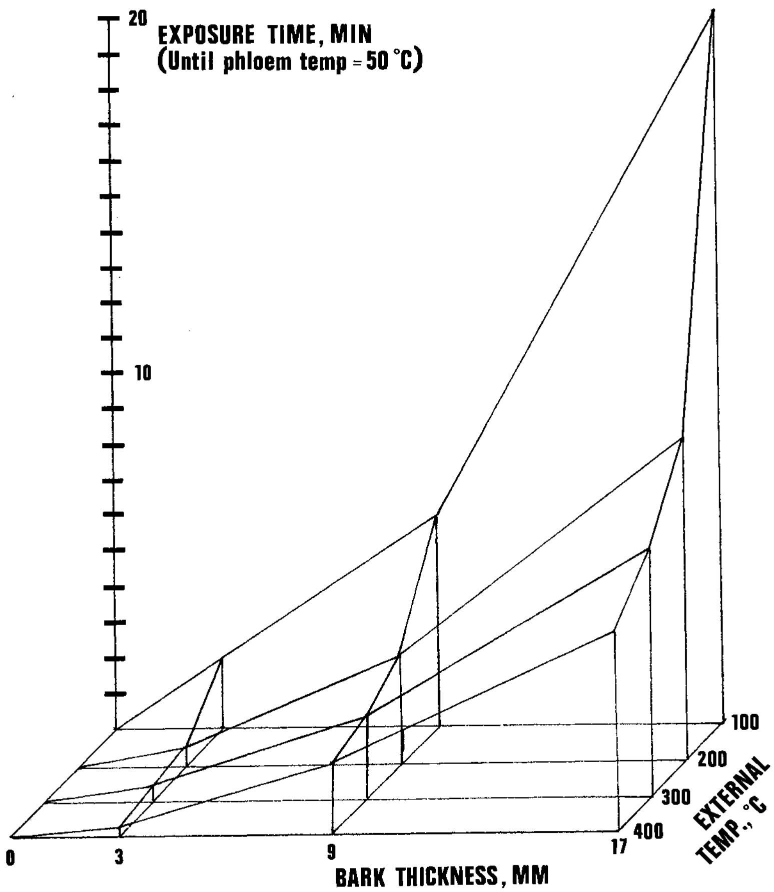


FIG. 8. Exposure time needed for a phloem temperature of +50°C as function of external temperature and bark thickness.

—time elapse between clear cut and burning has a negative effect on plant growth,
—burning has a lasting positive effect on fresh site types only (Fig. 9),
—some special experiments indicate that spruce—especially mixed with birch—is a more resistent stand alternative after fire than monocultures of pine which in many cases are severely plagued by diseases in the northernmost part of Finland,
—the final choice of species for reforestation purposes on burned

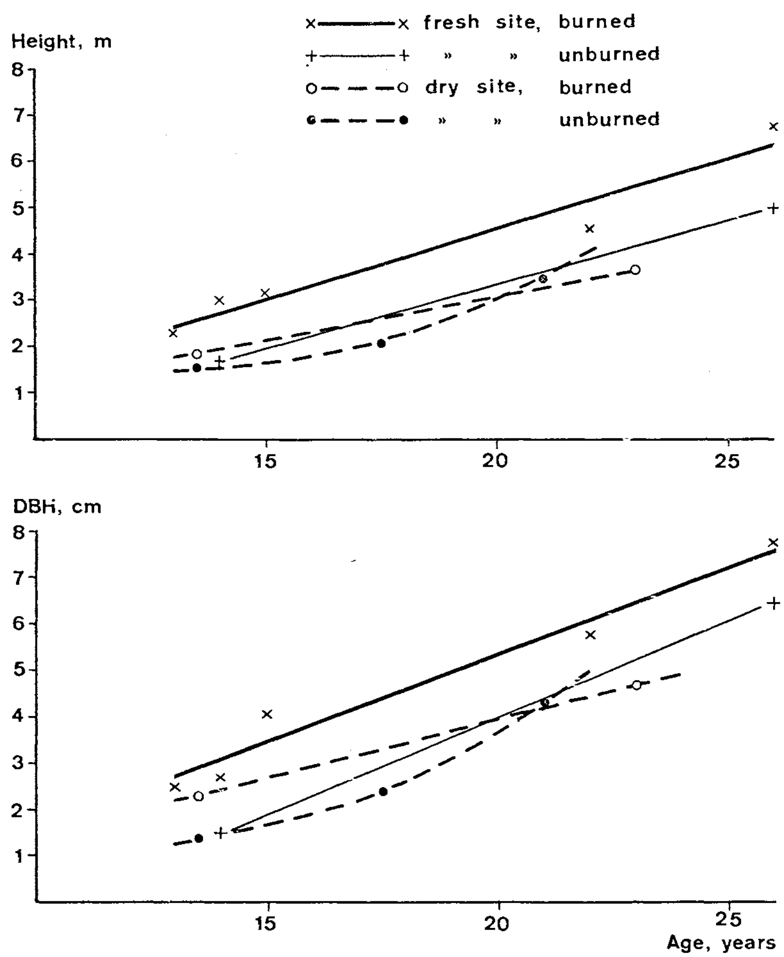


FIG. 9. Height and diameter (DBH) development of pine seedlings on burned and unburned areas.

fresh soil types depends, however, to some degree on future trend of climate development. A long-term warm period would favor the use of fire in pine forest regeneration.

CONCLUDING REMARKS

A renaissance of fire application in Finnish forestry seems possible but remote. Better knowledge about the rational use of weather conditions, modern planning, fire fighting equipment, training burning-crews, cost-reducing methods and a better consciousness of the main aims of the fire application are, however, desirable.

Considering the generally favorable impact of fire on fresh forest sites in Finland, the strong opposition displayed by inadequately informed journalists and Nature Conservation ecologists seems more emotional than rational. The reanimated need of ecologically oriented multiple use production-forestry may, however, bring the renaissance of prescribed burning closer behind the next corner.

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