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EERO KUBIN & LAURI KEMPPAINEN

EFFECT OF CLEARCUTTING OF BOREAL SPRUCE FOREST ON AIR AND SOIL TEMPERATURE CONDITIONS

AVOHAKKUUN VAIKUTUS KUUSIMETSÄN LÄMPÖOLOIHIN

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EFFECT OF CLEARCUTTING OF BOREAL SPRUCE FOREST ON AIR AND SOIL TEMPERATURE CONDITIONS

Avohakkuun vaikutus kuusimetsän lämpöoloihin

Eero Kubin & Lauri Kemppainen

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The present paper deals with the effects of clearcutting on soil and air temperature and the development of temperature conditions during the 12 growing seasons following clearcutting. The temperature measurements were carried out by means of thermographs, Grant measuring devices and minimum and maximum glass thermometers.

Clearcutting had no significant influence on temperatures measured at 2 m above the ground in a meteorological screen and no changes occurred in them during the period studied, while on the ground level and in the adjacent layer of air the daily maxima increased and the daily minima decreased as compared with uncut forest. The greatest difference was over 10°C between the maximum temperatures at 10 cm and almost 8°C between the minimum temperatures. Night frosts were considerably more common at 10 cm above the ground in the clearcut area than in uncut forests.

Temperature differences were smaller in the soil than close to ground level. Day temperatures were 2–3°C higher in the clearcut area than in uncut forests, and differences between night temperatures at this depth were even smaller. Correspondingly, temperatures were 3–5°C higher at depths of 50 cm and 100 cm in the clearcut area during the whole measurement period.

The differences between the temperatures in the clearcut area and uncut forests did not diminish to any significant extent during the 12 years despite the stocking of the former area with seedlings.

Tutkimuksessa tarkastellaan avohakkuun vaikutusta maan ja ilman lämpötilaan ja seurataan lämpöolojen kehitystä avohakkuun jälkeen 12 vuoden ajan. Mittaukset tehtiin kasvukauden aikana. Lämpötilaa mitattiin jatkuvatoimisilla termografeilla, Grant-mittalaitteella ja päivittäin luettavilla ääriarvomittareilla.

Säähavaintokojusta 2 m:n korkeudessa mitattuun lämpötilaan avohakkuulla ei ollut juuri vaikutusta eikä siinä ilmennyt muutoksia tutkimusjakson aikana. Sen sijaan maan pinnan tason ja sen läheisen ilmakerroksen lämpötilaan avohakkuu vaikutti siten, että vuorokausimaksimit kohosivat ja vuorokausiminimit laskivat hakkaamattomaan metsään verrattuna. Suurimmillaan mitattiin maanpinnan lähellä 10 cm:n korkeudessa maksimilämpötilojen eroksi yli 10 astetta ja minimilämpötilojen eroksi lähes 8 astetta. Yöhallat olivat tällä korkeudella huomattavasti yleisempiä avohakatulla alalla kuin hakkaamattomassa metsässä.

Maan sisässä lämpötilojen erot olivat pienempiä kuin maanpinnan läheisessä ilmakerroksessa. Avohakatulla alalla 5 cm:n syvyydessä päivälämpötila oli 2–3°C korkeampi kuin hakkaamattomassa metsässä. Yölämpötilojen erot tällä syvyydellä olivat pienemmät. 50 ja 100 cm:n syvyydessä avohakatulla alalla oli koko mittausjakson ajan 3–5°C lämpimämpää kuin metsässä.

Avohakatun ja hakkaamattoman metsän lämpötilojen erot eivät oleellisesti pienentyneet 12 vuoden aikana huolimatta avohakatun alan taimettumisesta.

Keywords: boreal spruce forest, clearcutting, air temperature, soil temperature.
FDC 111 + 23

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Contents

1. Introduction

Temperature conditions are of crucial significance in northern Finland for forest regeneration and growth and for the formation of the humus layer in the forest. Clearcutting causes considerable changes in the temperature conditions of the forest. Net radiation energy is bound in the tree layer and soil in an uncut forest, while after clearcutting radiation warms up the soil and the layers of air close to the ground. On account of the increased albedo, net radiation energy decreases after clearcutting (Odin 1978, Kimmins 1987).

The earliest soil temperature investigations in Finland were performed at the end of the 1800's, when Homén (1896) measured the soil temperature in Southern Finland and found it higher in open forest land than in a spruce stand. The next soil temperature survey was carried out by Keränen (1920) in a small opening in a forest and then by Lukkala (1946) in spruce swamps and clearcut strips, obtaining the results that the soil temperature was slightly lower in these strips than in the uncut forest between them. Soil and air temperature investigations in forests were then continued by Kauttu (1952), who measured temperature variations in different layers of a spruce crown cover, and Vaartaja (1954), who studied the effect of protection by the canopy and surface cover on the temperature of the soil surface and the air above it. Yli-Vakkuri (1963) determined the effects of a dense canopy and its opening on the temperature of the humus layer as part of a tree seedling study, observing the temperature to be higher after the opening up the stand.

Vaartaja (1954) did his work partly in northern Finland and the description of northern temperature conditions was continued by Sirén (1955) as part of an extensive investigation into the development of spruce forests, and by Franssila (1960), who published soil temperature results for various forest and mire types. Later on, temperature measurements in a natural spruce forest were carried out as part of the International Biological Programme in the late 1960's and early 1970's (Havas & Kubin 1983). These measurements also included wintertime conditions.

Temperature measurement became more intensive in Finland only when it was connected with research into forest cutting and regeneration (Leikola & Pylkkö 1969, Turtiainen & Valtanen 1970, Mälkönen 1972, Leikola 1974, Kauppila & Lähde 1975, Ritari & Lähde 1978, Leikola & Rikala 1983, Kubin 1990, Tolvanen & Kubin 1990). Many of the above works are concerned mainly with the effects of site preparation, but a number contain comparisons between an untreated clearcut area and uncut forest.

Temperature measurements in forests also began at an early stage in the other Nordic countries. Ronge (1928) and Ångström (1936–1937) demonstrated that thinning of a forest raised its soil temperature and drew attention to the relation between snow and soil frost and to the insulating effect of the humus layer. Mork (1933) combined temperature research with the question of seed germination and also studied the effect of clearcutting on soil temperatures. The surface soil layers in particular were found to be warmer in a clearcut area than in an uncut forest, and the same was also observed in a mountain forest (Mork 1968) and in numerous other later investigations (e.g. Bjor 1971, 1972, Söderström 1976, Lundmark et al. 1978, Odin 1978). Bjor & Huse (1987) noted that clearcutting had the effect of raising annual maximum temperatures even as far as a depth of six metres and that the effect of diurnal variations in incoming and outgoing radiation extended to a depth of half a metre. Thus a good deal of research information is available on temperature changes under the influence of clearcutting in the boreal coniferous forest zone, whereas little research has been done into the reversal of this effect. The most significant work so far on the latter topic has been that of Bjor & Huse (1987) in which comparisons were made between measurements taken at an interval of 19 years.

The aim of this paper is to determine the effects of clearcutting on soil and air temperatures and to examine changes during the following 12 growing seasons. It forms part of a programme of intensified research into forest regeneration which has been taking place in northern Finland, and especially in the Kivesvaara research area since the 1970's. The Kivesvaara area is one of the most intensively studied in Finland with respect to forest regeneration and its ecological effects.

Research into forest regeneration was encouraged under the leadership of Professor Risto Sarvas in the early 1970's, and the experimental site at Kivesvaara was founded as part of this comprehensive investigation by Jukka Valtanen, director of the Research Station at Muhos, in 1972. Research carried out at the site has characteristically been of a comprehensive nature, experiments being based on comparisons between the properties of uncut forest and clearcut areas and between various site preparation methods.

Valuable aid was provided by Pertti Matila, from the Department of Physics at the University of Oulu, at the initial stages of temperature measurement, and the help given by Kajaani Oy (later Yhtyneet Paperitehtaat Oy), the owner of the land, in the selection of the site, and in the practical work of preparing it and performing the measurements was of paramount importance. Olli Sarantola, Chief Forester of the company, and Risto Nederström, Forest Economy Manager, have in particular followed the progress of the investigation at all stages with great interest. Professors Matti Leikola, Yrjö Vuokila, Gustaf Sirén, Erkki Lähde and Eero Paavilainen, who have acted periodically as members of the administrative committee for joint research between the company and the Finnish Forest Research Institute, have also followed the progress of the project and contributed to it.

The present investigation formed part of a research programme for the Department of Silviculture at the Finnish Forest Research Institute being carried out at the Muhos Research Station. Eero Kubin was responsible for obtaining the material and Lauri Kemppainen from the Department of Biophysics at the University of Oulu for its processing and the drawing up of the preliminary manuscript, which was then worked up for publication jointly. The manuscript was reviewed prof. Kristian Bjor, prof. Matti Leikola and director Jukka Valtanen. The final version was processed for printing with the assistance of Merja Moilanen and Irene Murtovaara, and translated into English by Sirpa Vellonen and Malcolm Hicks. Financial support for the processing of the material and drawing up of the manuscript was granted by the Academy of Finland. We express our sincerest thanks to all the people and organizations who supported this work, including the many people not mentioned here who assisted at various stages.

2. Material and methods

21. The experimental area

The forest area studied here is situated in the middle boreal coniferous forest zone, i.e. in the Ostrobothnia-Kainuu forest zone within the phytogeographical zonation of Finland (Kalela 1962). According to the classification of Cajander (1949), the forest is predominantly of the *Vaccinium-Myrtillus* type (VMT), but with certain features typical of the Peräpohjola forest zone, where the corresponding type is *Hylocomium-Myrtillus* (HMT). The principal data on the climate and soil of the Kivesvaara forest are set out in Table 1a and the experimental plot is depicted in Fig. 1.

According to Sauramo (1926), the highest ancient shoreline at Kivesvaara runs at 178 m. The differences in climate between this site and the meteorological stations at Kajaani and Vaala are due to its elevation and open hill conditions. Kajaani lies approx. 15 km south of Kivesvaara and Vaala approx. 40 km west. The mean annual temperature for this forest site is lower than that at either of the meteorological stations. Also the snow cover is deeper and it lasts longer in the spring. The soil at the site is a well-developed podsol type with underlying till (Table 1a). The forest was clearcut at an age of approx. 140–150 years and had a growing stock of 115.8 solid m^3/ha, measured after harvesting, 95.4 % of which was Norway spruce, *Picea abies* (Kubin 1977). The growing stock of the plots of uncut forest (Fig. 1), assessed after the temperature measuring period in 1988, was about 140 solid m^3/ha (Table 1b).

22. Temperature measurement

Daily temperatures were measured with thermograph plotters in the meteorological screens and with a Grant device at other levels. The latter measurements were made by means of sensors in which the resistance altered with temperature and the changes were recorded on a temperature scale on paper. The device was battery-operated, however, and was thus subject to electrical interference of various kinds, e.g. from thunderstorms. This meant that apart from background noise, occasional peaks appeared in the recordings. Since these were so few, however, in relation to the large numbers of observations made, no attempt was made to remove them individually, but they tend to stand out as erroneous readings, especially in the recordings made at substantial depths in the soil.

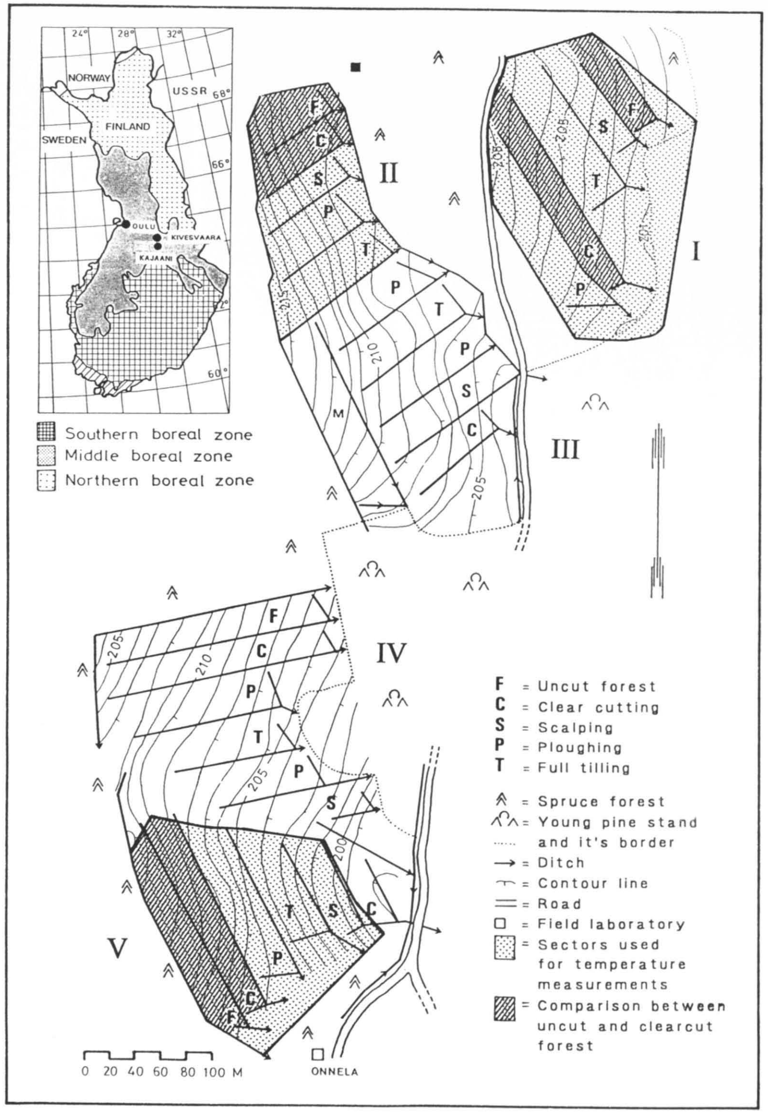


Figure 1. The phytogeographical zonation for Finland and the location of the Kivesvaara site. Clearcutting 1973–1974, soil preparation 1974, plantings in 1975 and 1976. Sectors I, II and V were used for temperature measurements.

The thermograph plotters were operating constantly while the Grant devices measured temperature six times a day at intervals of four hours starting at 4 a.m. Daily extreme temperatures were measured by minimum and maximum glass thermometers, which were read on the five weekday mornings. The sensors and glass thermometers, at a height of +10 cm, were protected by radiation shields painted white and insulated from below with

Table 1a. Location of the forest studied and general features of the climate and soil. Climatic data after Kolkki (1966) and Helimäki (1967), soil properties from Kubin (1975).

Variable	Value
Location	64°28'N, 27°33'E
Height	200–210 m
Mean annual temperature	Kajaani 1.9°C, Vaala 2.2°C
Effective temperature sum	Kajaani 1033 dd., Vaala 1051 dd.
Growing season	Kajaani 149 days, Vaala 149 days
Rainfall	Kajaani 564 mm, Vaala 525 mm
Mineral substrate	Fine sandy till
Soil type	podsol
–	Raw humus 6.7 cm
–	Eluvial horizon 11.3 cm
–	Illuvial horizon 23.7 cm
Depth of root penetration	0–70 cm

Table 1b. Data on the tree stand at the site. Measurements from 1988.

Stand properties	Dominant trees			Undergrowth			Seedlings
	Spruce	Birch	Asp	Spruce	Alder	Rowan	Spruce
Number of stems (per ha)	800	11	11	609	55	22	509
Mean height (m)	11.8	12.8	15.8	3.0	4.4	7.5	–
Basal area (m^2/ha)	17.0	0.2	0.4	–	–	–	–
Stem volume (m^3/ha)	138	1.1	2.9	2.6	0.3	0.2	–
Diameter at breast height (cm)	16.5	14.4	20.6	3.8	4.4	7.5	–

plastic foam.

When examining changes in temperatures at different altitudes and depths in a forest, the selection of the zero level for measurements is difficult (Leikola 1974, 1976). In this case the boundary between the living and dead moss layers was selected. Exposure of the meters and sensors installed at 10 cm above the zero level to direct sunshine was prevented by means of radiation shielding, while measurements at 2 m above ground level were carried out in a meteorological screen. The + sign in the presentation of the results indicates heights above the zero level (+10 cm, +2 m) and the – sign depths below the zero level (–5, –50 and –100 cm). When using the Grant instrument for temperature measurement, four sensors were placed at each measurement point except –100 cm, where there was only one. The instrument recorded the mean value for these sensors directly on the paper.

23. Calculation of temperatures

The temperature results were usually calculated as averages of sectors I, II and V (Fig. 1.) if results for all three sectors were available. Not all sectors had meters every year, however. Calculation and processing was carried out on the IBM-3083 computer at the University of Oulu using specially designed programs in Fortran, separate classification programs and the IBM SAS software. The figures were constructed chiefly by means of DISSPLA software.

The temperature sums were calculated on the dd (degree day) principle, using a threshold value of +5°C. The distribution of daily variations was obtained by subtracting the mimimum temperature on each day in June, July and August from the maximum one, placing the differences in increasing order of magnitude and plotting them on a system of coordinates. The distributions were divided into suitable intervals for tabulation purposes, each consisting of percentages to a total of 100. Distribution curves for individual years can be drawn relatively accurately on the system of coordinates on the basis of the tabulation data if necessary.

Distributions for the temperature observations were formed by classifying the figures for June, July and August in descending order of magnitude and plotting them on the system of coordinates. The distributions, which were also divided into suitable intervals for tabulation purposes, consisted of percentages to a total of 100.

The use of official temperature records from the Finnish Meteorological Institute's station in Kajaani, including long-term means, plays a crucial role in the generalizability of the results. The temperature sums and daily extreme temperatures used here were obtained from the monthly reviews of the Meteorological Institute. Daily temperatures for the Kajaani meteorological station were obtained by joining the minimum and maximum temperatures for each day with a cosine curve divided into regular four-hour intervals (Gupta et al. 1981) to correspond to the daily temperature measurements at Kivesvaara, the daily maximum being set at 4 p.m. and the minimum at 4 a.m. (Helminen 1987).

3. Results

31. Comparison of air temperature conditions at the site with those at the Kajaani meteorological station

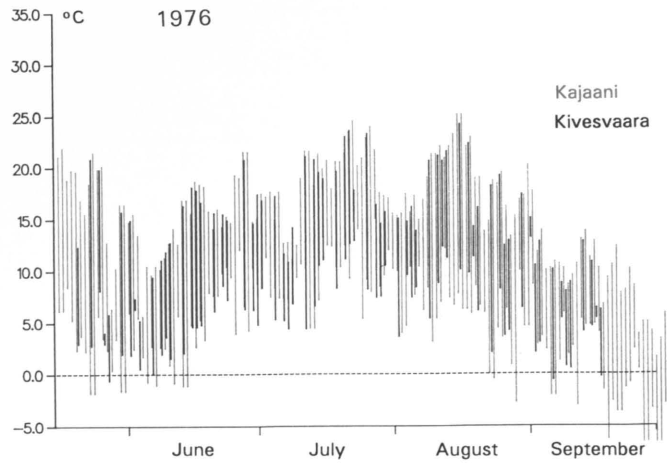
Both the monthly temperature sums and the total sum for the summer months in the screens 2 m above ground were higher in Kajaani than at Kivesvaara (Table 2). The greatest difference between the temperature sums for the summer months during the period studied occurred in 1984, when the result for Kajaani was 135 dd higher, and the smallest, 41 dd., in 1975. The temperature sums were highest in the summer months of 1980, when the difference between Kajaani and Kivesvaara was 63 dd, close to the arithmetic mean of the differences over the measurement period. During the coldest summer, 1976, the temperature sum was 49 dd higher at Kajaani than at Kivesvaara. The differences between the monthly temperature sums vary between 10 and 47 dd in June, between 11 and 51 dd in July, and between 1 and 46 dd in August.

Daily maximum temperatures were usually 1–3°C higher in Kajaani than at Kivesvaara (Fig. 2). The result should be studied by comparing one pair of columns at a time, the black column on the left representing Kivesvaara and the red column on the right Kajaani. There were many cases, however, in which the maximum temperatures of both sites were similar. The situation is slightly more variable in the case of daily minimum temperatures. It was colder in Kajaani at the end of June 1976, and colder at nights at Kivesvaara at the beginning of August 1985, the differences between the respective night temperatures being usually 1–5°C. The number of days when the minimum temperatures were similar was also high.

Daily temperatures at Kivesvaara and in Kajaani followed a similar rhythm in time (Fig. 3), i.e. warm and cold periods occurred in similar sequences. The daily maximum temperatures in Kajaani were consistently higher than those at Kivesvaara, while the differences in daily minimum temperatures varied. During a warm period which occurred in August 1976, the daily maximum temperatures were approximately similar, while the respective minimum temperatures were considerably lower in Kajaani than at Kivesvaara.

Table 2. Temperature sums (threshold 5°C) at the height of +2 m in weather screens at the meteorological station in Kajaani and at the Kivesvaara site in 1974–1985.

Year	Kajaani June	Kajaani July	Kajaani August	Kajaani Total	Kivesvaara June	Kivesvaara July	Kivesvaara August	Kivesvaara Total
1974	274	351	282	907	248	315	249	812
1975	207	322	226	755	197	304	213	714
1976	159	283	251	691	139	253	250	642
1977	237	317	218	772	212	286	188	686
1978	239	304	205	748	215	293	188	696
1979	274	320	289	883	243	289	258	790
1980	345	332	246	923	318	218	224	860
1981	191	360	227	778	163	325	190	678
1982	124	344	260	728	111	317	229	657
1983	237	355	239	831	190	314	197	701
1984	237	312	236	785	199	261	190	650
1985	231	319	288	838	206	287	248	741



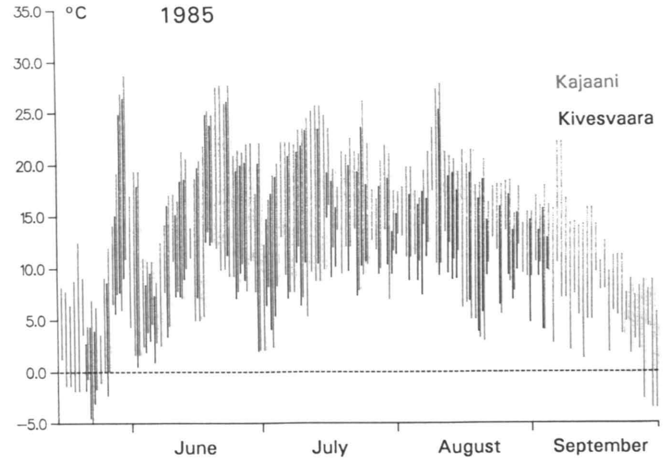


Figure 2. Daily maximum and minimum temperatures at +2 m in screens at the meteorological station in Kajaani (red column on the right) and at the Kivesvaara site (black column on the left) in summer 1976 and 1985.

32. Effects of clearcutting on air temperature

321. Daily extreme temperatures

Daily extreme temperatures in the weather screens in the forest and clearcut area differed by less than 1°C (Fig. 4), a situation which remained similar in both warm and cold periods. Extreme temperatures at a height of 10 cm above the ground differed to a great extent between the forest and clearcut area, the difference being several degrees in favour of clearcut area during the day and of the forest at night (Fig. 5). The number of frosty nights in the summer months of 1976 was 13 in the clearcut

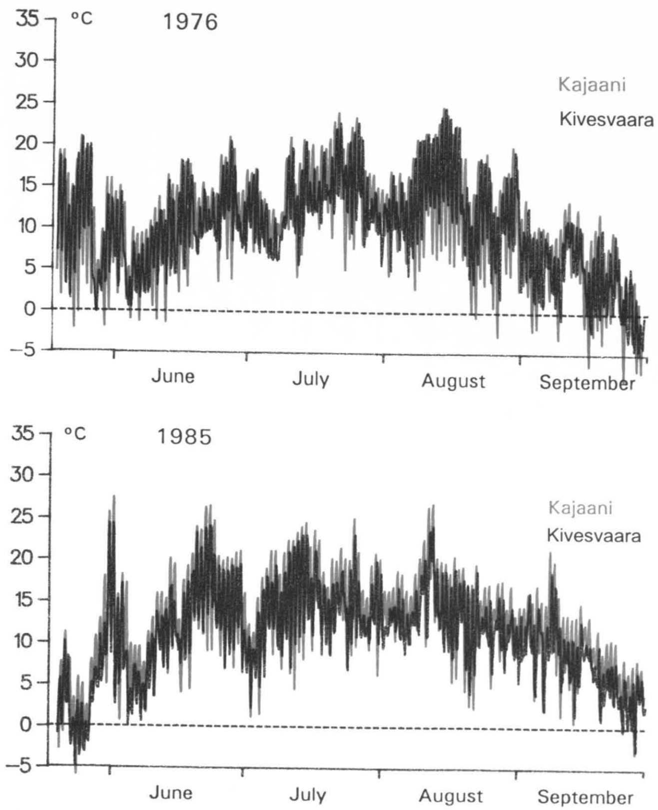


Figure 3. Daily temperatures at +2 m in the weather screens at the meteorological station in Kajaani (red line) and at the Kivesvaara site (black line) in summer 1976 and 1985.

area and two in the forest. Maximum temperatures at 10 cm above the ground in the clearcut area were over 35°C.

The relations between the extreme temperatures recorded in the weather screens remained the same in later years as in the year 1976 (Table 3). Also the relations at the height of 10 cm were similar in later years as in the year 1976. The number of frosty nights at +2 m varied usually in the range 0–3 depending on the year over the period 1974–1985 in both the clearcut area and the forest, and that at +10 cm usually in the range 3–16 in the clearcut area and 0–3 in the forest. Summer 1982 was exceptional in that there were five frosty nights at +2 m in the forest and four in the clearcut area, while the corresponding number at +10 cm was 19 in the clearcut area and six in the forest. The majority of these cold nights occurred at the beginning of June, with a long period which was very cold for the time of year.

The highest number of days when maximum temperatures at +10 cm exceeded 30°C was 18 in the clearcut area in 1980, and of the same order in the forest. The number of such days per year during the whole period 1974–1985 was 1–18 in the clearcut area and 0–6 in the forest, with corresponding figures of 3–19 in the clearcut area and 0–6 in the forest for temperatures below 0°C.

The daily temperatures measured in the weather screen 2 m above the ground did not exceed

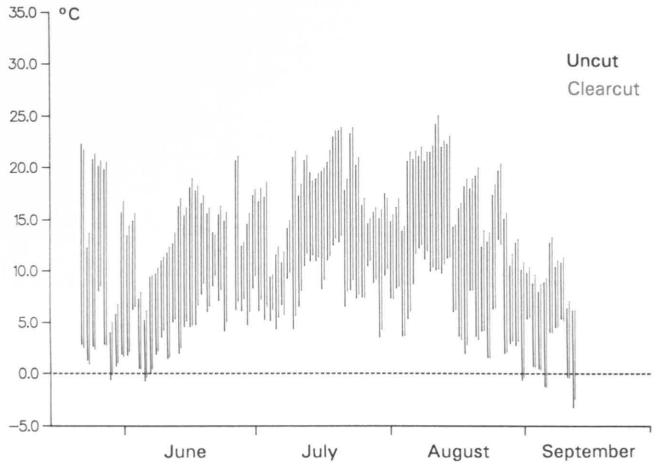


Figure 4. Daily maximum and minimum temperatures at +2 m in screens in the forest (black column) and clearcut area (red column) at the Kivesvaara site in summer 1976.

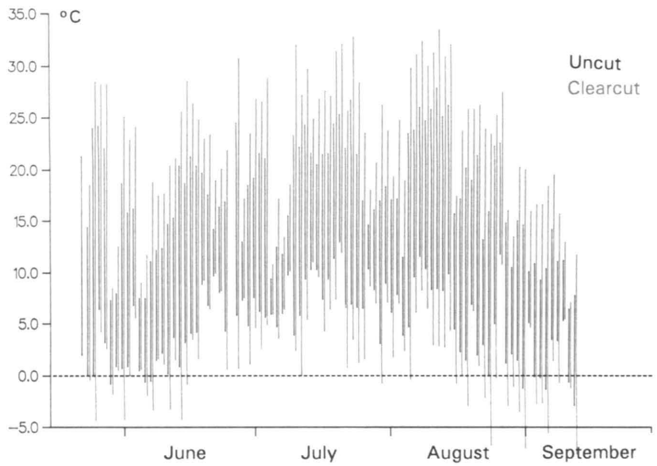


Figure 5. Daily maximum and minimum temperatures at +10 cm in the forest (black column) and clearcut area (red column) at the Kivesvaara site in summer 1976.

30°C during the period of measurement either in the forest or in the clearcut area (Table 3), while the corresponding number of days when the temperature fell below 0°C was 0–5 per summer. The differences between the forest and clearcut area in this case were very small.

The real numbers of days when the temperature reached the above extremes may have been somewhat higher, in that the maximum-minimum thermometers were read only five times a week, on working days, so that the maximum read on Monday is that for Friday, Saturday and Sunday combined and the minimum that for Saturday, Sunday and Monday combined.

Table 3. Numbers of occasions during the summer mounths on which daily maximum temperatures exceeded 30°C and 25°C and minimum temperatures fell below 5°C and 0°C at heights of +2 m and +10 cm during the period examined. C = clearcut, U = uncut forest.

Year	Above 30°C C	Above 30°C U	Above 25°C C	Above 25°C U	Below 5°C C	Below 5°C U	Below 0°C C	Below 0°C U
				+2 m, screen				
1974	0	0	8	8	7	7	0	0
1975	0	0	3	3	22	23	1	1
1976	0	0	0	0	18	22	1	1
1977	0	0	6	7	22	24	1	1
1978	0	0	2	1	15	15	1	1
1979	0	0	2	2	5	8	0	0
1980	0	0	12	14	14	15	2	2
1981	0	0	1	1	10	10	3	1
1982	0	0	4	5	18	18	4	5
1983	0	0	3	2	16	16	0	0
1984	0	0	3	2	16	15	1	1
1985	0	0	2	2	9	9	0	0
Max	0	0	12	14	22	24	4	5
Min	0	0	0	0	5	7	0	0
				+10 cm				
1974	8	6	22	10	24	10	6	1
1975	10	0	28	8	37	20	12	0
1976	11	0	31	7	41	25	13	2
1977	9	4	21	10	42	26	16	1
1978	10	1	27	11	32	25	6	3
1979	5	1	37	6	34	15	3	0
1980	18	0	37	25	29	15	9	1
1981	1	0	22	2	26	13	5	3
1982	5	1	25	6	53	27	19	6
1983	6	0	25	5	32	20	14	3
1984	3	0	24	6	33	15	13	3
1985	3	0	23	5	35	12	8	1
Max	18	6	37	25	53	27	19	6
Min	1	0	21	2	24	10	3	0

322. Daily temperatures

Daily temperatures in the meteorological screens in the clearcut area and the forest as measured at intervals of four hours did not differ to a great extent (Fig. 6), the differences being less than one degree, nor did the situation vary much according to the weather conditions.

Daily temperatures at height +10 cm differed to a considerable extent. The maximum temperatures were without exception higher in the clearcut area than in the forest, the differences being approx. 10°C at their greatest. As far as minimum temperatures are concerned, the situation was more variable, the daily minimum temperatures were sometimes being the same or even lower in the forest than in the clearcut area.

The prevailing weather type had an influence on the extent of the differences in minimum temperatures, and often minimum temperatures were lower in the clearcut area. Night frost often occurred during the growing season.

Weather conditions in summer varied to a great extent during the period examined (Appendix 2). Various cold periods occurred in the summers, June 1982 being very cold and the beginning of June 1984 also much colder than normal, while end of May 1984 and August 1976 were warmer than usual. Some summers (1975, 1977 and 1983) were characterized by a rapid alternation of cold and warm periods.

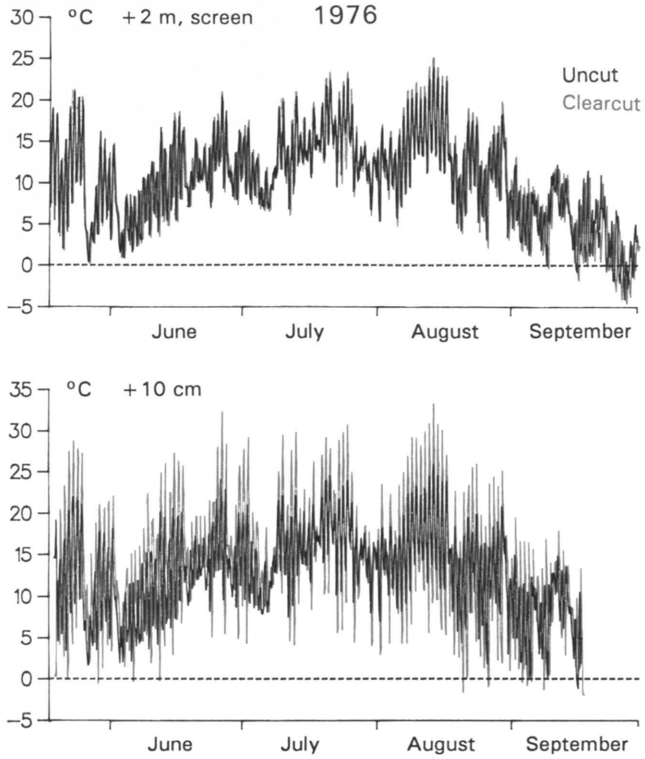


Figure 6. Daily temperatures at +2 m and +10 cm in summer 1976. Black line is for the forest, red for the clearcut area.

323. Monthly mean temperatures

The differences in monthly mean temperatures at height +2 m between the forest and clearcut area were very small (Table 4) being little larger in the clearcut area mainly in June and lower in July and August. The differences were also small at +10 cm, the greatest difference measured being 2.5°C in July 1978. The higher monthly temperatures at +10 cm occurred in the clearcut area.

324. Distributions of the daily variations

The differences between the distributions of the daily variations were small at +2 m in both the clearcut and uncut area and this was also the case at +10 cm in the uncut forest (Fig. 7). The maximum daily variation was approx. 12°C and the minimum approx. 3°C and there was little difference between +2 m and +10 cm. The distribution of temperature variations at +10 cm in the clearcut area differed from that in the uncut forest at the same height to a great extent, the maximum being over 25°C and the minimum approx. 4°C. All the distributions were fairly linear.

The differences in the distributions of the daily variations remained similar during the years (Table 5, cf. Fig. 7). Those between the forest and clearcut area at +2 m were small, while those at +10 cm were great, particularly on account of the high variation. Variation exceeding 20°C did not occur in the forest at + 10 cm, except in 1977, when 1 % of the variation was over 20°C. The proportions of the variation ex-

Table 4. Monthly mean temperatures at heights of +2 m and +10 cm during the period examined.

Year	Uncut, +2 m June	Uncut, +2 m July	Uncut, +2 m August	Clearcut, +2 m June	Clearcut, +2 m July	Clearcut, +2 m August	Uncut, +10 cm June	Uncut, +10 cm July	Uncut, +10 cm August	Clearcut, +10 cm June	Clearcut, +10 cm July	Clearcut, +10 cm August
1974	–	–	–	14.3	15.8	13.4	13.2	15.2	12.7	15.2	16.4	13.5
1975	11.2	14.6	11.6	11.4	14.8	11.9	–	–	–	–	–	–
1976	9.9	13.5	13.3	9.5	13.2	13.0	12.0	15.5	14.7	13.3	16.0	14.3
1977	12.3	14.8	11.9	12.0	14.2	11.1	13.7	15.8	12.6	15.3	17.3	13.9
1978	13.0	15.1	11.0	12.1	14.4	11.0	13.0	14.4	10.5	14.0	16.9	11.9
1979	12.4	13.7	12.7	13.1	14.3	13.3	14.1	15.0	13.7	14.8	15.8	13.7
1980	15.3	14.7	11.7	15.6	15.3	12.2	15.7	15.3	12.5	16.9	16.1	12.0
1981	10.2	15.6	11.4	10.2	15.5	11.1	10.6	15.7	11.9	11.4	16.6	12.5
1982	7.9	15.2	12.6	8.0	15.2	12.4	8.0	14.4	11.5	9.3	15.4	12.0
1983	11.1	15.2	11.3	11.3	15.1	11.3	11.1	14.3	10.5	12.6	15.7	11.4
1984	11.4	14.1	11.8	11.5	13.4	11.1	11.0	13.0	10.4	12.7	14.5	11.4
1985	12.6	15.2	13.9	11.7	14.2	13.0	10.8	13.1	12.3	13.0	14.6	12.3

Table 5. Distributions of daily variation 10 cm and 2 m above the ground in uncut (u) and clearcut (c) areas during the summer months of 1974–1985 as percentages of total observations assigned to different temperature classes. Minimum, maximum and mean ($\bar{x}$) values for variation during the same period are shown on the right. – = no observations.

Year	Height	Site	0–3°C	3–5°C	5–10°C	10–12.5°C	12.5–15°C	15–20°C	Over 20°C	$\bar{x}$	Min °C	Max
			percent of total									
1974	+2 m	u	–	–	–	–	–	–	–	–	–	–
		c	7	7	67	19	0	0	0	7.8	1.0	12.5
	+10 cm	u	5	7	40	25	10	13	0	10.0	1.0	19.8
		c	2	5	14	9	16	31	23	15.4	2.0	29.5
1975	+2 m	u	2	11	48	29	10	0	0	9.0	2.5	15.0
		c	3	9	51	34	3	0	0	8.6	2.5	13.4
	+10 cm	u	–	–	–	–	–	–	–	–	–	–
		c	–	–	–	–	–	–	–	–	–	–
1976	+2 m	u	11	7	58	24	0	0	0	7.8	1.7	12.5
		c	8	9	57	21	5	0	0	8.0	1.8	13.3
	+10 cm	u	1	11	48	23	17	0	0	9.1	2.2	14.1
		c	1	3	16	7	12	32	29	16.0	3.0	26.8
1977	+2 m	u	11	22	52	10	5	0	0	6.7	0.8	14.5
		c	7	15	53	21	4	0	0	7.7	1.2	14.0
	+10 cm	u	3	17	43	22	12	3	0	8.8	1.9	15.3
		c	1	3	16	14	15	28	23	15.1	2.2	27.6
1978	+2 m	u	14	20	58	7	1	0	0	6.5	0.7	15.5
		c	10	11	50	26	2	1	0	7.6	1.0	15.7
	+10 cm	u	7	8	36	16	22	11	0	10.0	1.2	18.0
		c	3	4	12	25	15	30	11	13.5	2.0	23.5
1979	+2 m	u	10	14	66	7	3	0	0	6.9	1.2	13.0
		c	5	11	63	20	1	0	0	7.9	1.8	13.0
	+10 cm	u	2	9	52	28	9	0	0	9.0	2.6	14.1
		c	0	3	15	7	20	28	27	15.8	4.1	26.8

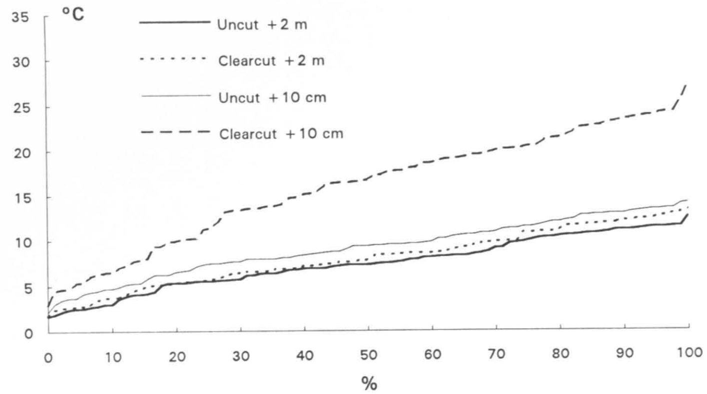


Figure 7. Distributions of daily variation 10 cm and 2 m above the ground in uncut and clearcut areas during the summer months in 1976.

Table 5 continued

Year	Height	Site	0–3°C	3–5°C	5–10°C	10–12.5°C	12.5–15°C	15–20°C	Over 20°C	$\bar{x}$	Min °C	Max
			percent of total									
1980	+2 m	u	12	8	48	23	9	0	0	8.1	1.0	14.2
		c	5	9	52	29	5	0	0	8.6	1.2	14.7
	+10 cm	u	5	5	37	29	22	2	0	9.8	1.5	16.5
		c	3	2	10	11	7	28	39	17.3	1.9	28.4
1981	+2 m	u	19	22	47	12	0	0	0	6.0	1.1	12.5
		c	14	17	52	16	1	0	0	6.7	1.6	12.9
	+10 cm	u	4	19	46	23	5	3	0	8.0	1.6	16.2
		c	3	3	27	17	8	26	16	13.4	2.1	24.7
1982	+2 m	u	4	14	46	17	15	4	0	8.8	1.8	17.8
		c	4	15	48	23	7	3	0	8.5	1.9	17.2
	+10 cm	u	2	4	47	22	17	8	0	9.9	2.2	16.9
		c	0	2	11	12	8	27	40	17.7	3.7	27.9
1983	+2 m	u	11	9	70	10	0	0	0	6.9	1.0	12.4
		c	4	9	60	24	3	0	0	8.1	1.4	14.1
	+10 cm	u	4	9	45	38	4	0	0	8.9	2.2	14.5
		c	0	3	10	8	10	41	28	16.8	3.6	27.4
1984	+2 m	u	13	28	51	8	0	0	0	5.9	1.1	11.8
		c	5	14	65	14	2	0	0	7.4	1.6	14.5
	+10 cm	u	3	11	54	22	8	2	0	8.5	2.3	16.0
		c	0	4	12	13	13	35	23	15.6	3.7	26.8
1985	+2 m	u	8	16	56	15	5	0	0	7.4	2.4	14.6
		c	3	15	57	21	4	0	0	7.7	2.7	14.7
	+10 cm	u	3	11	53	21	11	1	0	8.4	2.6	16.5
		c	0	5	15	22	9	28	21	14.8	3.8	29.1

ceeding 20°C at + 10 cm in the clearcut area varied in the range 11–39 %, the arithmetic mean being 25 %. The proportion exceeding 15°C at +10 cm in the forest was also small, the average being 4 %, but that exceeding 15°C at +10 cm in the clearcut area ranged between 40 % and 69 %, the greatest variation being almost 30°C.

325. Distributions of observations

The distributions of temperature observations made during the summer months at height +2 m in the meteorological screens differed very little between the clearcut area and forest (Fig. 8), while differences at +10 cm were distinct in the case of both high and low temperatures. Temperatures in the forest did not rise over 25°C, but those in the clearcut area exceeded 30°C. The temperature did not drop below 0°C in the forest, but the lowest temperature recorded by the Grant equipment in the clearcut area was –2°C.

The temperature distributions at height +2 m did not differ between the clearcut area and the forest to any great extent (Table 6, cf. Fig.8). The relation remained similar throughout the measurement period. Differences between the clearcut area and forest were considerable at +10 cm, however, and persisted throughout the measurement period. The temperature exceeded 30°C and fell below 0°C at +10 cm in the clearcut area every year, but this occurred rarely in the forest. Years 1981, 1982 and 1984 were exceptions when a cold period occurred at the beginning of June.

Table 6. Distributions of temperature observations. For details, see Table 5.

Year	Height	Site	Under 0°C	0–5°C	5–10°C	10–15°C	15–20°C	20–25°C	25–30°C	Over 30°C	x̄	Min	Max
1974	+2 m	u	–	–	–	–	–	–	–	–	–	–	–
		c	0	2	13	42	32	8	3	0	14.5	2.6	29.5
	+10 cm	u	1	3	20	39	28	7	2	0	13.7	–0.7	30.5
		c	1	7	15	29	25	15	5	3	15.0	–2.3	37.6
1975	+2 m	u	0	9	29	35	19	8	0	0	12.5	1.0	26.0
		c	0	5	30	34	21	9	1	0	12.7	0.1	26.0
	+10 cm	u	–	–	–	–	–	–	–	–	–	–	–
		c	–	–	–	–	–	–	–	–	–	–	–
1976	+2 m	u	0	6	25	44	20	5	0	0	12.3	0.9	24.0
		c	0	7	26	44	17	6	0	0	11.9	0.4	24.7
	+10 cm	u	0	4	16	37	32	10	0	0	14.1	1.8	25.8
		c	1	9	16	29	23	14	7	1	14.6	–2.0	32.9
1977	+2 m	u	0	2	25	41	25	5	2	0	13.0	2.0	27.1
		c	0	8	24	39	23	4	2	0	12.5	0.5	28.3
	+10 cm	u	0	1	21	38	29	8	3	0	14.0	4.2	28.5
		c	1	7	13	26	28	17	5	3	15.5	–2.3	35.0
1978	+2 m	u	0	2	29	37	21	11	0	0	13.0	1.0	25.4
		c	0	4	30	36	21	9	0	0	12.5	–1.6	25.8
	+10 cm	u	1	7	28	32	22	9	1	0	12.6	–1.0	26.4
		c	1	8	21	30	16	16	8	0	14.3	–4.0	31.7
1979	+2 m	u	0	2	19	52	23	4	0	0	13.0	3.4	23.8
		c	0	0	19	47	28	6	0	0	13.6	3.6	24.8
	+10 cm	u	0	1	16	41	34	8	0	0	14.3	3.1	25.5
		c	1	8	15	30	21	18	6	1	14.8	–2.1	32.1

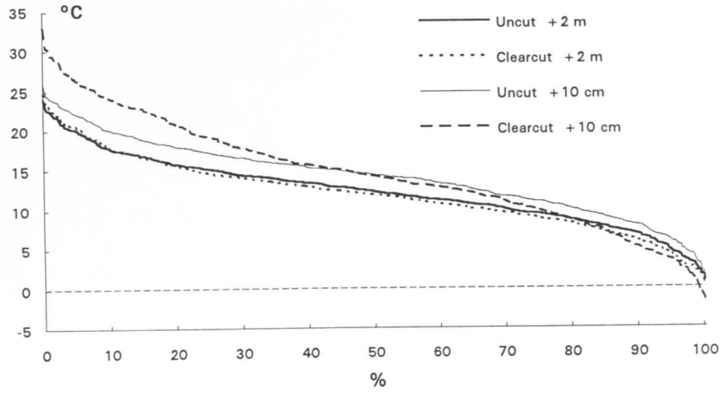


Figure 8. Distributions of temperature observations 10 cm and 2 m above the ground in uncut and clearcut areas during the summer months in 1976.

Table 6 continued

Year	Height	Site	Under 0°C	0–5°C	5–10°C	10–15°C	15–20°C	20–25°C	25–30°C	Over 30°C	x̄	Min	Max
1980	+2 m	u	0	3	19	41	25	12	0	0	13.9	1.8	25.2
		c	0	3	16	39	28	12	2	0	14.4	2.3	26.3
	+10 cm	u	0	3	16	38	27	13	3	0	14.5	0.4	27.0
		c	3	8	17	25	18	14	12	3	15.0	–3.6	32.7
1981	+2 m	u	0	5	25	42	24	4	0	0	12.5	–0.9	25.0
		c	0	5	28	40	22	5	0	0	12.3	–1.0	25.7
	+10 cm	u	1	4	24	39	26	6	0	0	12.8	–3.0	25.5
		c	2	7	22	28	26	11	4	0	13.5	–4.5	30.4
1982	+2 m	u	1	12	23	34	23	5	2	0	12.0	–1.7	28.0
		c	1	12	23	35	23	5	1	0	11.9	–1.1	27.9
	+10 cm	u	2	12	28	33	18	6	1	0	11.4	–1.7	27.2
		c	5	17	19	24	17	13	6	1	12.3	–4.0	31.6
1983	+2 m	u	0	5	26	42	20	7	0	0	12.5	2.0	24.9
		c	0	5	26	40	20	9	0	0	12.6	1.1	25.7
	+10 cm	u	0	8	25	41	20	6	0	0	12.0	–0.5	23.5
		c	5	9	19	25	23	13	5	1	13.3	–3.7	32.9
1984	+2 m	u	0	5	24	42	24	5	0	0	12.5	0.1	24.0
		c	0	8	26	40	21	5	0	0	12.0	–1.0	24.1
	+10 cm	u	2	7	32	37	18	4	0	0	11.5	–1.2	23.3
		c	5	8	22	30	19	11	5	0	12.9	–5.0	31.0
1985	+2 m	u	0	3	14	46	29	7	1	0	13.9	1.9	26.0
		c	0	5	20	44	24	7	0	0	13.0	0.1	24.4
	+10 cm	u	0	6	24	45	21	4	0	0	12.1	–0.1	23.6
		c	2	9	19	31	23	11	4	1	13.3	–1.7	31.7

33. Effect of clearcutting on soil temperature

331. Daily temperatures

Daily temperatures at the ±0 cm level in the clearcut area and forest differed in a distinct manner (Fig. 9). Day temperatures in the clearcut area were higher than those in the forest, the differences being fairly even and amounting to approx. 10°C at most. The weather had a distinct effect on the degree of difference. Night temperatures differed only slightly, and the influence of the weather was insignificant. The differences in day and night temperatures were similar in both autumn and spring.

Differences in temperature at a depth of –5 cm in the soil were distinct in spring in that the temperature was approx. 5°C higher in the clearcut area. The differences levelled out in August, and at the end of the month temperatures were higher in the forest than in the clearcut area at times.

The difference in temperatures at a depth of –50 cm between the clearcut area and the forest was approx. 5°C in spring, but diminished towards the autumn, so that temperatures were similar by the end of August. The difference at –100 cm was approx. 3°C in spring, but levelled out by the end of August.

332. Monthly mean temperatures

Monthly mean temperatures at the ±0 cm level and at depths of –5 cm, –50 cm and –100 cm were almost invariably lower in the forest than in the clearcut area throughout the period studied (Table 7), although the mean temperature at –5 cm was the same in the forest and clearcut area in August 1980. The differences were in the range 0.2–4.1°C at 0 cm, 0–4.1°C at –5 cm, 1.0–3.9°C at –50 cm and 0.8–3.5°C at –100 cm.

333. Distributions of daily variations

The differences between the clearcut area and the forest in the distribution of the daily variations in temperature were considerable at 0 cm, the maximum in the clearcut area being approx. 20°C and that in the forest approx. 10°C (Fig. 10). The corresponding minimum values were

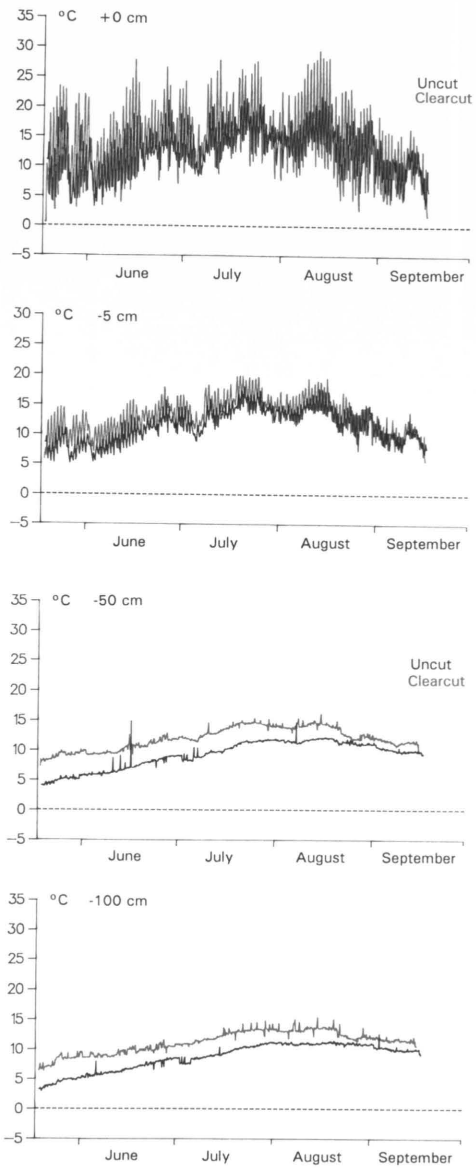


Figure 9. Daily temperatures at depths of ±0, –5, –50 and –100 cm in clearcut (red line) and uncut forest (black line) in summer 1976.

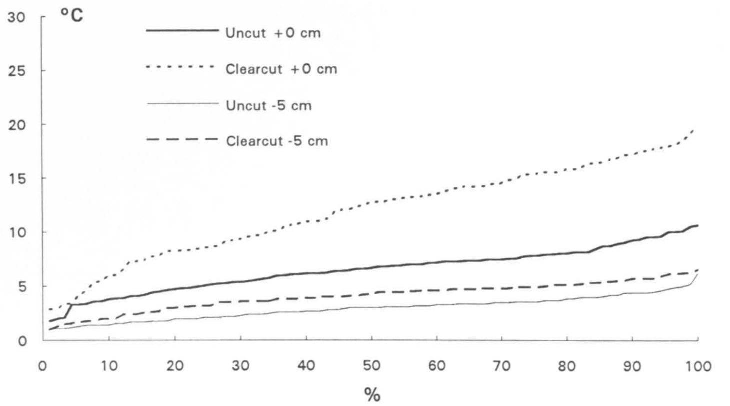


Figure 10. Distributions of daily variation at ± 0 cm and -5 cm in uncut and clearcut areas during the summer months in 1976.

Table 7. Monthly mean temperatures at depths of ±0, –5, –50 and –100 cm during the summer months in 1974–1985.

Year	±0 cm Uncut June	July	August	Clearcut June	July	August	–5 cm Uncut June	July	August	Clearcut June	July	August
1974	7.9	12.5	12.1	10.1	14.2	13.2	6.6	11.4	10.7	11.2	15.0	14.1
1975	–	–	–	–	–	–	–	–	–	–	–	–
1976	11.5	14.9	14.4	13.0	15.7	14.6	10.0	13.7	13.7	11.5	14.6	13.8
1977	11.3	14.4	12.5	15.4	16.9	14.4	9.3	12.9	11.8	12.9	15.6	14.2
1978	11.7	13.7	10.6	–	–	–	9.4	12.5	11.2	12.3	15.7	12.0
1979	11.9	13.7	13.1	15.0	16.2	14.1	9.6	12.5	12.7	11.6	14.0	12.9
1980	12.8	13.4	12.0	15.6	15.7	12.8	10.5	12.1	12.0	12.8	13.5	12.0
1981	9.5	14.3	11.9	11.8	16.3	13.5	8.5	12.9	12.0	10.1	14.6	12.9
1982	7.2	12.3	10.7	9.7	14.5	12.0	6.6	10.8	10.3	8.5	12.9	11.5
1983	9.8	12.8	10.4	12.2	15.0	11.9	8.7	11.4	10.4	10.5	13.6	11.5
1984	9.5	11.9	10.2	12.3	14.2	11.9	8.4	10.7	10.2	10.9	13.0	11.5
1985	7.3	10.5	11.3	10.9	13.3	12.4	5.3	9.1	10.8	9.4	12.0	11.9

Year	–50 cm Uncut June	July	August	Clearcut June	July	August	–100 cm Uncut June	July	August	Clearcut June	July	August
1974	3.3	8.0	9.3	5.7	10.4	11.4	2.2	6.5	8.3	3.7	8.4	10.0
1975	–	–	–	–	–	–	–	–	–	–	–	
1976	7.2	10.2	11.6	9.0	12.0	12.6	6.7	9.4	11.0	7.9	10.6	11.8
1977	5.8	8.9	9.7	9.6	12.5	13.2	5.0	7.6	8.8	8.2	10.8	12.0
1978	5.1	8.1	8.3	8.2	12.0	10.9	3.5	6.6	7.5	6.3	10.1	9.7
1979	5.9	9.1	10.1	7.4	10.9	11.3	4.8	8.0	9.3	6.1	9.7	11.1
1980	6.7	9.1	10.3	9.0	10.8	11.7	5.4	8.0	9.6	6.8	9.3	10.4
1981	6.2	9.7	10.6	8.3	12.2	12.2	5.5	8.7	9.9	6.9	10.3	11.6
1982	5.5	8.0	8.3	7.0	10.1	10.2	4.8	6.9	7.7	6.5	9.1	9.6
1983	6.4	8.7	9.0	8.6	11.5	11.1	6.4	8.4	9.0	7.2	9.7	10.1
1984	6.2	8.2	8.9	8.9	11.0	10.8	6.2	8.3	9.2	7.4	9.4	10.3
1985	3.1	6.6	9.0	6.5	9.3	10.4	2.8	6.1	8.4	6.1	9.0	10.8

approx. 3°C at both sites. Differences were small at –5 cm, in that the maximum value was approx. 7°C in the clearcut area and approx. 5°C in the forest. Minimum values were approx. 1°C at both sites. Distributions were fairly even at –5 cm at both sites and at 0 cm in the forest, but the early part of the distribution curve rises quite rapidly and the middle and end remain even at 0 cm in the clearcut area.

The daily variation in temperature at 0 cm in the clearcut area exceeded 20°C in 1977, 1979 and 1980 (Appendix 1), whereas that in the forest did not exceed 15°C, nor even 12.5°C. Variation exceeding 10°C occurred in 1976, 1977, 1978 and 1982. The daily variation at –50 cm and –100 cm was minor in extent and was difficult to determine exactly on account of noise in the measurement device. The individual high values are due to various sources of error.

334. Distributions of temperature observations

The distributions of temperature observations at depth –5 cm differed slightly between the clearcut area and the forest in terms of both maximum and minimum temperatures (Fig. 11), the difference being approx. 1°C in both. The distributions differed distinctly more at 0 cm, especially at high temperatures. The difference in maximum temperatures was approx. 6°C and that in minimum temperatures approx. 1°C.

The differences in temperature distribution between the forest and the clearcut area were distinct at various depths (Appendix 3). Temperature differences in the forest at 0 cm depth were concentrated in the range 0–15°C and those in the clearcut area in the range 5–20°C. Observations of over 30°C were recorded only at 0 cm in the clearcut area in 1977 and 1979. Temperatures below 0°C occurred in three years: at –100 cm in the forest in 1974, at 0 cm in the forest in 1978, and at –100 cm in the forest and at 0 cm in the clearcut area in 1985.

34. Effect of clearcutting on cumulative effective temperature sum

The differences between the forest and the clearcut area in temperature sums calculated on the basis of the 1976 measurements were distinct at various levels (Fig. 12). The temperature sum is highest at +10 cm in the clearcut area and lowest at +2 m, also in the clearcut area. The differences between the temperature sums at various levels increased constantly during the summer, with the exception of those measured in the screen at +2 m, which were slightly greater than those measured at –5 cm in the uncut forest up to the beginning of August, but lower in September.

The temperature sums accumulated slowly in the soil at all depths in summer 1985, and re-

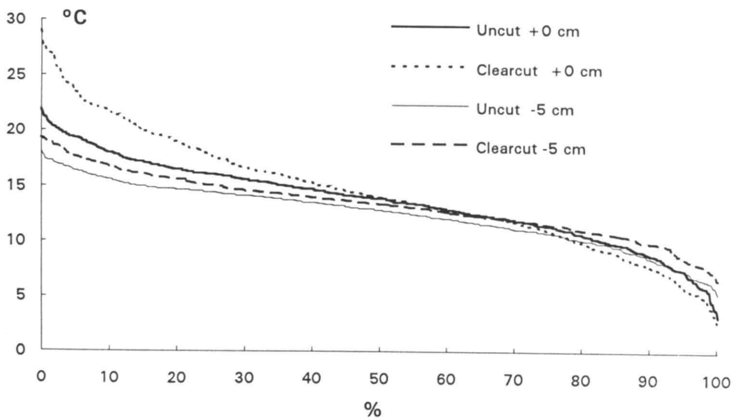


Figure 11. Distributions of temperature observations at ±0 cm and –5 cm in uncut and clearcut areas during the summer months in 1976.

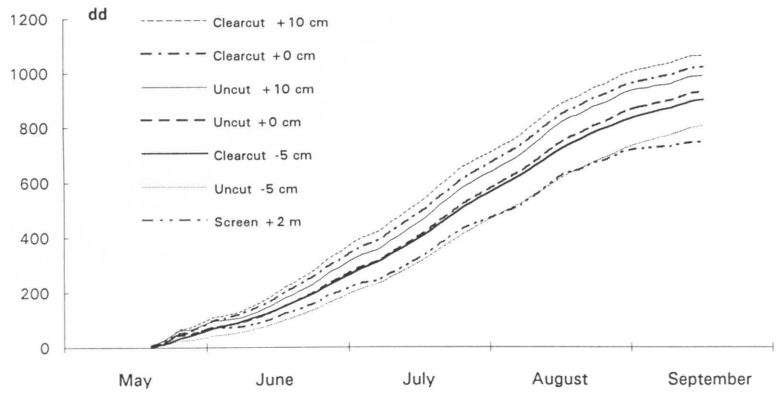


Figure 12. Cumulative effective temperature sums at heights of +2 m and +10 cm and depths of 0 and –5 cm in the clearcut area and uncut forest in summer 1976. Calculations of temperature sums were started on 19th May.

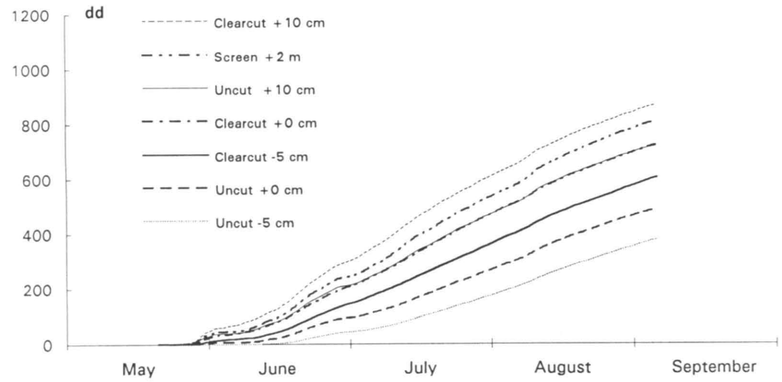


Figure 13. Cumulative effective temperature sums at heights of +2 m and +10 cm and depths of 0 and –5 cm in the clearcut area and uncut forest in summer 1985. Calculations of temperature sums were started on 20th May.

mained below 400 dd at –5 cm in the forest (Fig. 13). The temperature sum in the screen was similar to that at +10 cm in the clearcut area. Comparison of the temperature sums in the soil and the screen between the various years shows them to have been lower in 1985 than in 1976. This effect may be due to the depth of the soil frost, the deepest value for which was recorded in winter 1984–85 27 cm in the uncut area and 40 cm in the clearcut area. In general there was little or no soil frost.

The differences in the monthly temperature sums were small at +2 m in the clearcut area and in the forest (Table 8), the sum at the latter site being sometimes smaller and sometimes higher than that at the former. On the other hand, the temperature sum was consistently higher in the clearcut area than in the forest at +10 cm in June and July, with a difference of 76 dd at the most and 6 dd at the least. Similar differences were also recorded at other depths. The difference between the temperature sums for the clearcut

Table 8. Cumulative effective temperature sums during the summer months in uncut (U) and clearcut (C) forest at various levels.

Year	+2 m		+10 cm		0 cm		–5 cm		–50 cm		–100 cm	
	U	C	U	C	U	C	U	C	U	C	U	C
June												
1974	–	248	248	311	97	155	79	178	4	40	0	9
1975	190	197	–	–	–	–	–	–	–	–	–	–
1976	150	139	212	250	195	241	150	194	66	121	51	88
1977	220	212	260	310	188	319	129	239	31	135	13	92
1978	240	215	240	270	202	–	132	218	15	96	0	40
1979	224	243	273	294	207	301	138	199	32	72	12	42
1980	310	318	322	358	233	319	167	235	54	120	23	60
1981	163	163	170	193	135	204	105	152	37	101	19	58
1982	110	111	112	144	75	142	53	107	16	61	5	45
1983	184	190	183	230	144	216	111	166	43	109	43	64
1984	196	199	182	232	137	219	104	178	36	116	36	72
1985	229	206	178	241	84	179	41	131	3	51	0	39
July												
1974	–	315	316	353	233	286	212	299	94	168	47	107
1975	297	304	–	–	–	–	–	–	–	–	–	–
1976	265	253	326	341	306	331	269	299	161	218	136	175
1977	303	286	336	378	291	360	245	317	120	226	82	167
1978	312	293	293	369	270	–	232	333	95	217	49	159
1979	270	289	310	336	268	349	233	279	126	182	92	147
1980	301	318	320	345	260	331	221	265	126	178	93	134
1981	331	325	334	359	287	349	245	296	146	221	114	163
1982	315	317	292	323	226	297	179	246	93	158	59	127
1983	316	314	289	332	242	311	199	268	115	202	106	148
1984	283	261	249	294	214	284	178	249	98	187	102	138
1985	318	287	251	297	171	259	129	217	50	134	34	122
August												
1974	–	249	240	263	219	253	197	266	134	197	103	156
1975	204	213	–	–	–	–	–	–	–	–	–	–
1976	256	250	302	289	291	297	269	274	205	234	187	210
1977	214	188	235	283	232	294	211	289	145	256	118	218
1978	185	188	171	213	174	–	193	218	103	182	78	145
1979	240	258	269	268	252	282	238	247	159	194	132	190
1980	207	224	234	222	219	242	217	218	164	208	141	167
1981	198	190	214	234	215	265	219	246	174	224	152	204
1982	237	229	201	217	178	217	165	200	104	161	86	144
1983	195	197	172	201	168	213	167	203	125	189	125	159
1984	211	190	169	199	161	214	161	203	122	181	130	163
1985	277	248	227	228	197	229	180	213	124	169	106	181

area and the forest at +10 cm was markedly smaller in August than in June and July, and the temperature sum at this height in the forest was even higher than that in the clearcut area in August 1976, 1979 and 1980.

No temperature sum above +5°C accumulated at all at –100 cm in the forest in June in three years, and the sum for the clearcut area was always higher than that in the forest at 0 cm, –5 cm, –50 cm and –100 cm. The difference between the temperature sums in the forest and in the clearcut area was greatest, 122 dd, at –50 cm in July 1978.

The temperature sum for the summer months was higher in the clearcut area than in the forest throughout, with the exception of the height of +2 metres (Table 9), where the temperature sums in the forest and the clearcut area were similar and sometimes that in the former was even higher than that in the latter. The differences between the various years were fairly distinct at all heights and depths. The largest absolute difference between the years occurred at 0 cm, where the temperature sum was 452 dd in 1985 and 792 dd in 1976, a difference of 340 dd. Almost as large a difference between years, 338 dd, occurred at –5 cm.

Table 9. Cumulative effective temperature sums for the summer months in uncut (U) and clearcut (C) forest at various levels.

Year	+2 m		+10 cm		0 cm		–5 cm		–50 cm		–100 cm	
	U	C	U	C	U	C	U	C	U	C	U	C
1974	–	812	804	927	549	694	488	743	232	405	150	272
1975	691	714	–	–	–	–	–	–	–	–	–	–
1976	671	642	840	880	792	869	688	767	432	573	374	473
1977	737	686	831	971	711	973	585	845	296	617	213	477
1978	737	696	704	852	646	–	557	769	213	495	127	344
1979	734	790	852	898	729	932	609	725	317	448	236	379
1980	818	860	876	925	712	892	605	718	344	506	257	361
1981	692	678	718	786	637	818	569	694	357	546	285	425
1982	662	657	605	684	479	656	397	553	213	380	150	316
1983	695	701	644	763	554	740	477	637	283	500	274	371
1984	690	650	600	725	512	717	443	630	256	484	268	373
1985	824	741	656	766	452	667	350	561	177	354	140	342

35. Alteration in temperature conditions over twelve successive years after cutting

351. Sapling development

The tree stand was fairly sparse in terms of both small and large trees in the planted area of sector I (Fig. 14). Only four planted pines had survived inside the circle, as there were no planted seedlings near the measurement equipment. The number of naturally generated spruces was small, as also was that of silver and pubescent birches. Natural spruces were abundant, but the number of birches was small in the patch sowing area in sector II (Fig. 15). Patch sowing tufts were relatively numerous, with a concentration in the NW part of the site, where the trees were small. Birches and other deciduous trees occurred fairly densely, and spruces were also abundant, while only two planted pines survived in the planted area in sector V (Fig. 16). The trees in this sector were fairly tall compared with those of sector II. The number of planted pines and patch sowing pines decreased during the period studied (Table 10).

352. Changes in the distribution of daily temperature variation

Clearcutting led to a considerable increase in daily variations in temperature at ground level and at height +10 cm (Figures 6 and 9). The succession of the vegetation and trees (Table 10, Figures 14–16) gradually levels out this variation and will finally result in the conditions prevailing in a natural spruce forest (Table 11).

The trend in temperature conditions during the measurement period (1974–1985) will be discussed in the following by means of changes in the percentage of high variation in the distribution of daily temperature variation, which is used here to refer to variation exceeding the selected threshold value as a percentage of all the days examined (= 100 %). The measurements were carried out in June, July and August every year. The threshold value was selected in such a manner that the percentage of high variation was never zero during the period studied, being nevertheless as small as possible.

The threshold values used were 10°C (uncut area +2 m and clearcut area +2 m), 20°C (clearcut area +10 cm), 12.5°C (uncut area +10 cm), 12.5°C (clearcut area 0 cm), 5°C (uncut area 0 cm), 5°C (clearcut area –5 cm) and 3°C (uncut area –5 cm). The value was constant at each measurement site throughout the period, and may be different or the same at different levels in the uncut and clearcut area, depending on the differences in the daily variations in temperature between these areas.

The curves representing the percentages of high variation in the uncut area (+2 m) and

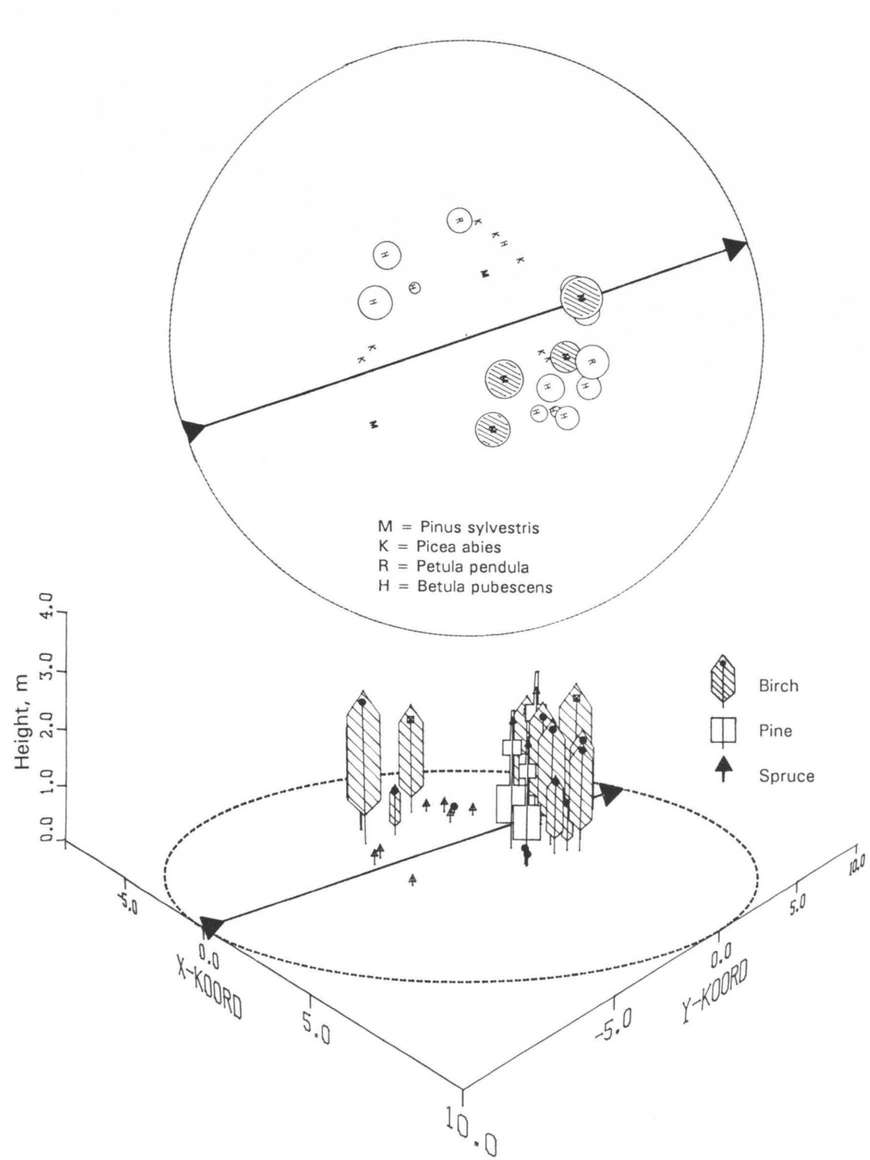


Figure 14. Distribution of the tree cover in 1986 in the part of sector I of the clearcut area occupied by the sensors of the measurement devices. Scots pine seedlings were planted in 1976. Trees are measured within a radius of 5.0 m.

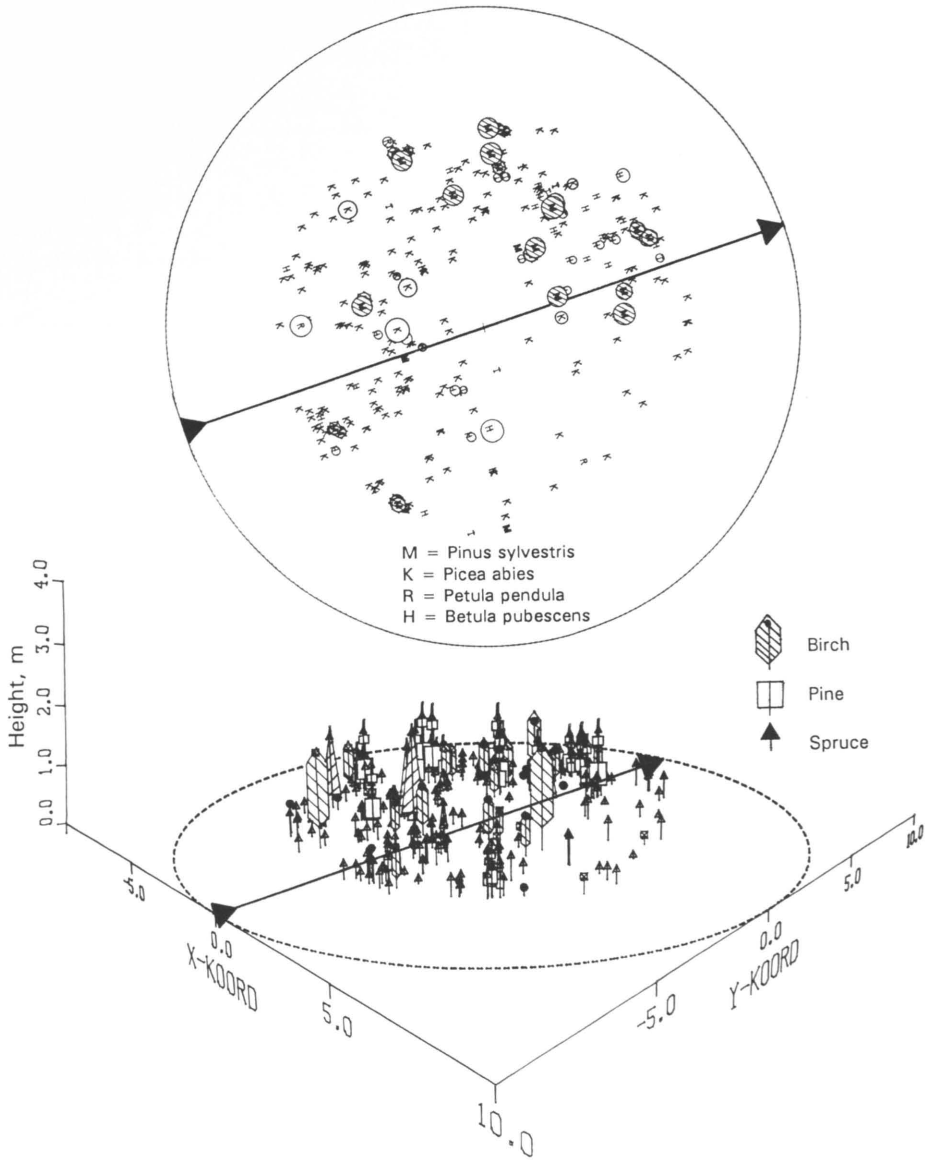


Figure 15. Tree cover in 1986 in the part of sector II of the clearcut area occupied by the sensors of the measurement devices. Patch sowing of pine was performed in 1976. Single trees are measured within a radius of 6.7 m.

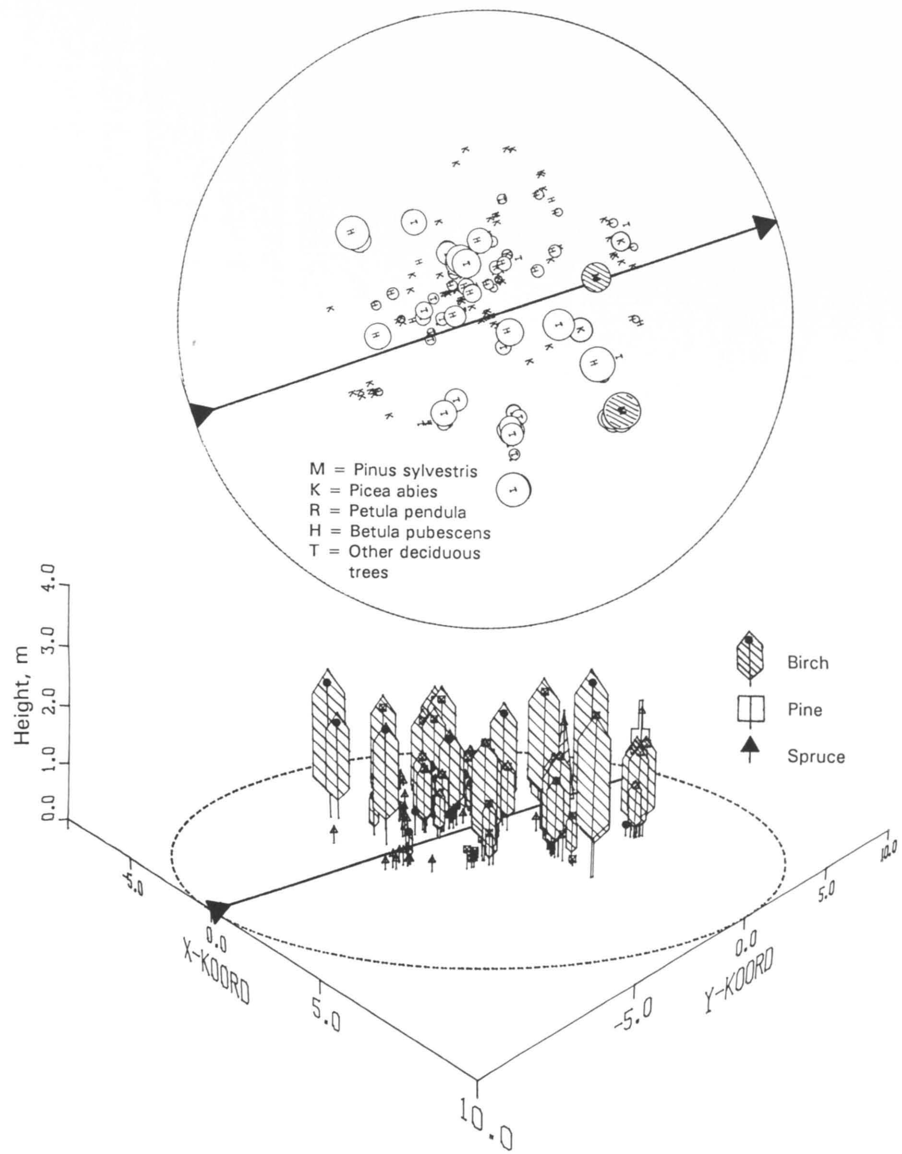


Figure 16. Tree cover in 1986 in the part of sector V of the clearcut area occupied by the sensors of the measurement devices. Scots pine seedlings were planted in 1976. Single trees are measured within a radius of 6.4 m.

clearcut area (+2 m) had two maximum points, in 1980 and in 1982 (Figures 17 a and b). The same points also occur in the curves for +10 cm in the uncut and clearcut areas (Figures 17 c and d). No downward or upward trends occur in the curves for +2 and +10 cm in the uncut area and clearcut area, while a clear downward trend occurs in the curves for ground level (0 cm) at both sites after 1980 (Figures 17 e and f), as is the case for the curves representing the percentages at depth –5 cm at both sites (Figures 17 g and h). The maximum years 1980 and 1982 can also be observed at the levels of 0 cm and –5 cm.

353. Changes in the distributions of temperature observations

Clearcutting caused a considerable change in the distribution of temperature observations at the ground level and at +10 cm (Figures 8 and 11). The following is a description of trends in temperature conditions during the period of measurement by means of the percentages of high and low temperatures in the distribution of temperature observations.

The percentage of high temperatures in the distribution of temperature observations refers to the observations exceeding a selected threshold value as a percentage of all observations (100 %) and the percentage of low temperatures to those remaining under a selected threshold value as a percentage of all observations (100 %). The measurements were carried out in June, July and August every year, and the threshold value was selected in such a manner that the percentage of high or low temperature observations was never zero during the period studied, being nevertheless as small as possible.

The threshold values used for the percentages of high temperatures were 20°C (uncut area +2 m, clearcut area +2 m, and uncut area +10 cm), 25°C (clearcut area +10 cm), 15°C (uncut area +0 cm), 20°C (clearcut area 0 cm), 12.5°C (uncut area –5 cm) and 15°C (clearcut area –5 cm). The threshold values used for the percentages of low temperatures were 5°C (uncut area +2 m, clearcut area +2 m, uncut area +10 cm and clearcut area +10 cm), 10°C (uncut area 0 cm), 5°C (clearcut area 0 cm) and 10°C (uncut area – 5 cm and clearcut area –5 cm). The value is constant at each measurement site throughout the period, and may be different or the same at different levels in the uncut and clearcut area, depending on the differences in the distributions of temperature observations between these areas.

The curves representing the low temperatures have one maximum point at 1982, the remainder being relatively smooth (Fig. 18 a and b). The curves for +10 cm in the uncut and clearcut areas are similar to that for +2 m (Figures 18 c and d). The trend in the percentage of high temperatures in the distribution of temperature observations at 0 cm was fairly even from 1976 to 1980 (Figure 18 f), after which a radical fall occurred. The curve depicting the percentage of low temperatures is smooth with the exception of the maximum year 1982. A maximum point in the corresponding curve for +2 m occurred during the same year. The curves for –5 cm in the uncut and clearcut areas were similar in terms of the percentages of both high and low temperatures.

Table 10. Data on the tree stand in the clearcut sectors. Planting density in 1976 is the mean of planted pines in the sectors I and V. – = no inventory. Sowing (sector II) has been done to the patches.

Year	Planted pines	Sowed pines	Natural spruces	Natural birches
	number of trees per hectare			
1976	2200	–	–	–
1982	1900	34000	–	–
1986	700	8000	11800	8400

Table 11. Data on the tree stand in the vicinity of the measurement points in the forest sectors (I, II and V) in 1988. dbh = diameter at breast height, h = average height, n = number of trees per hectare.

Sectors and tree species	Dominant trees dbh,cm	h,m	n	Undergrowth dbh,cm	h,m	n	Seedlings h,m	n
I spruce	18.0	11.5	1000	4.5	3.3	442	0.3–1.3	100
II spruce	15.0	11.2	1100	4.7	3.6	973	0.3–1.3	700
birch	14.4	12.8	100	–	–	0	–	0
V spruce	22.4	16.6	900	5.1	3.8	177	–	0

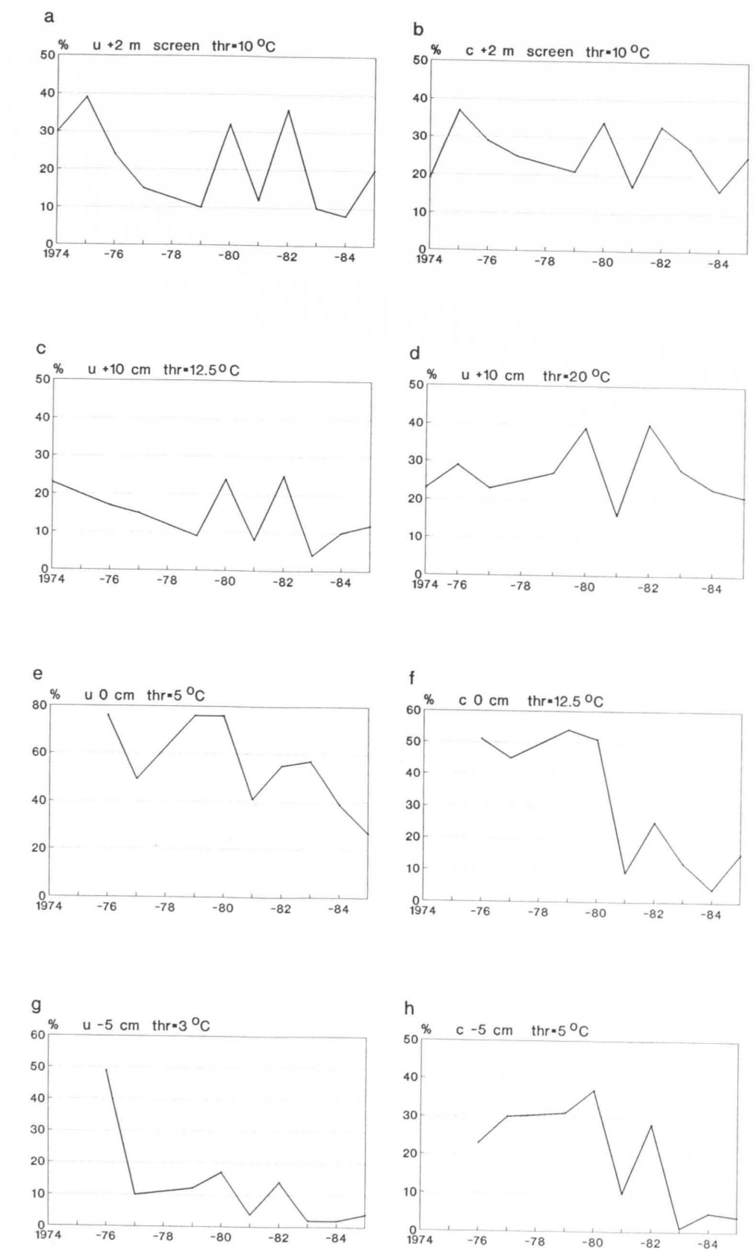


Figure 17. Trends in the proportion of high daily temperature variations at various heights and depths in uncut (u) and clearcut (c) areas. thr = threshold value for high daily temperature variation.

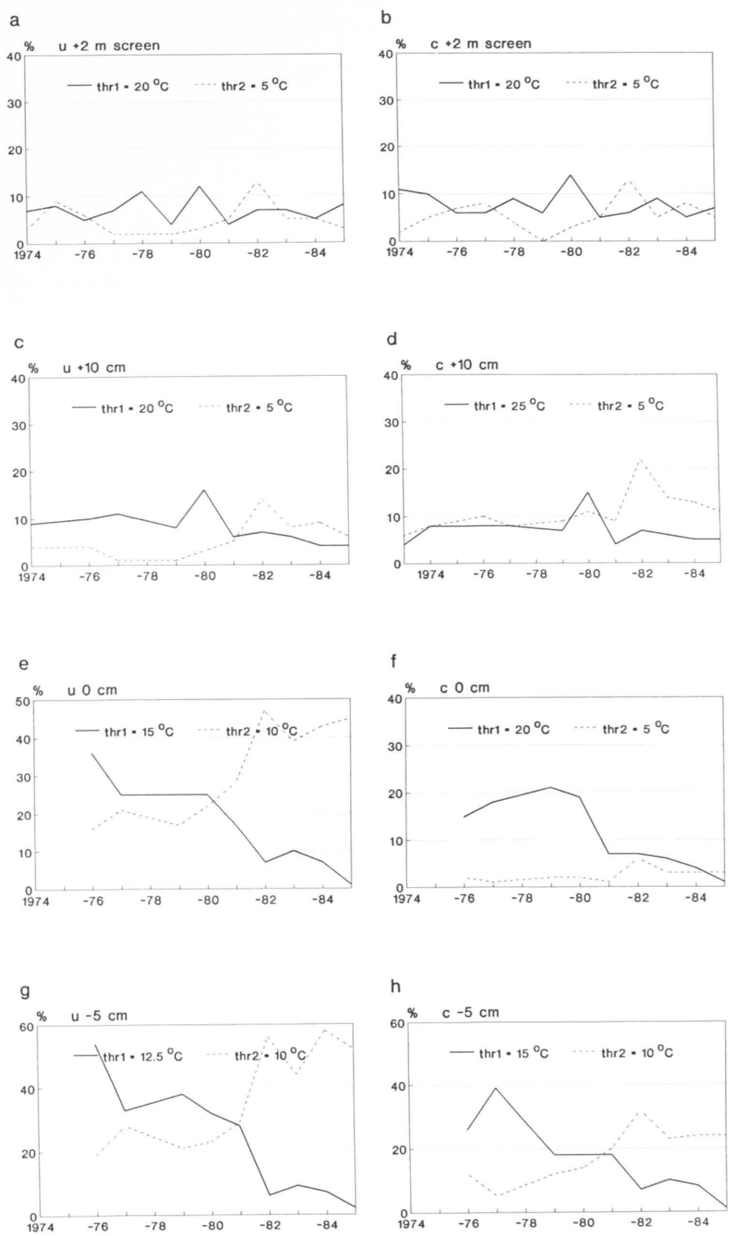


Figure 18. Trends in the proportions of high (—) and low (-----) temperature observations at various heights and depths in uncut (u) and clearcut (c) areas. thr_1 = threshold value for high temperatures, thr_2 = threshold value for low temperatures.

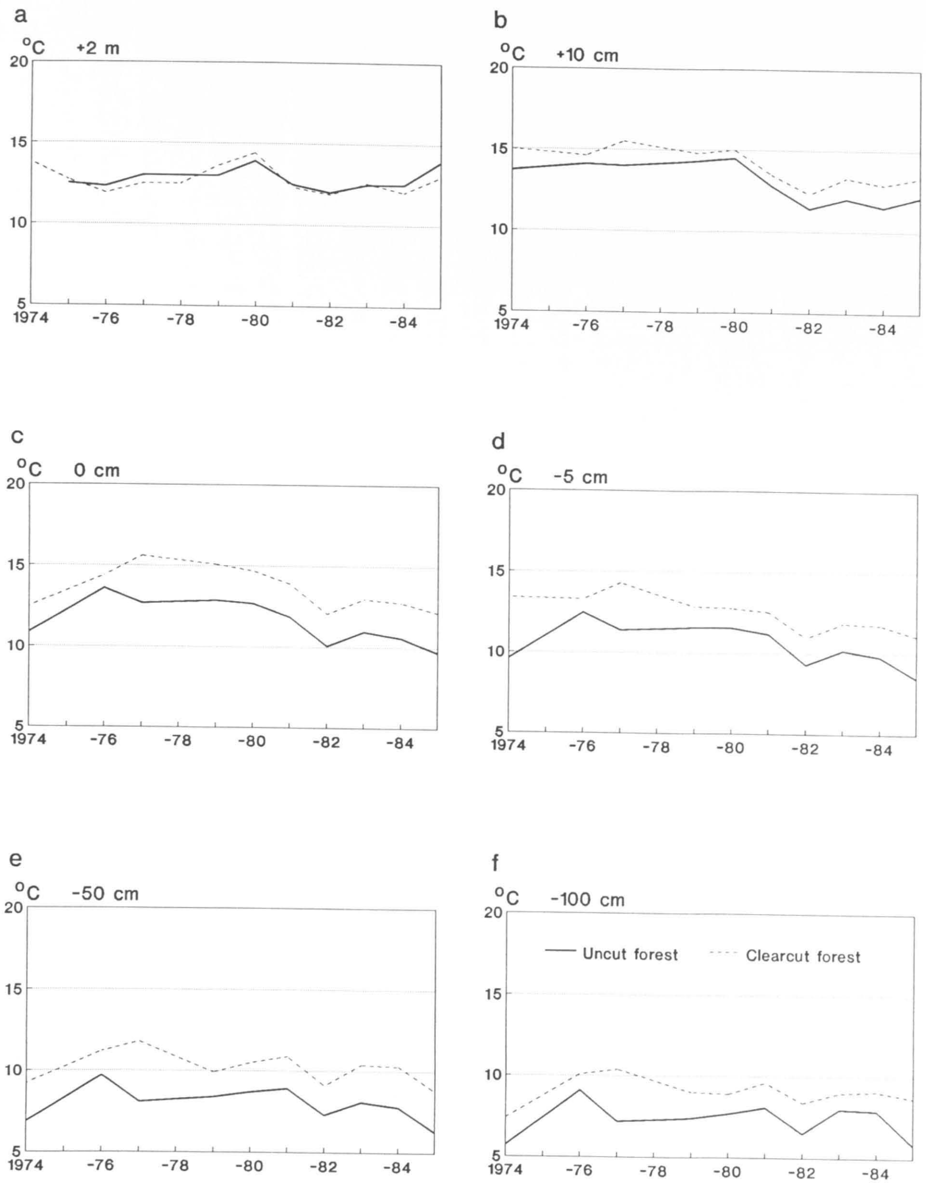


Figure 19. Mean summer temperatures at various heights and depths in uncut (—) and clearcut (- - -) areas.

354. Mean summer temperatures

The mean summer temperatures (June, July and August) in 1974–1985 for the uncut and clearcut area do not differ to any significant extent at a height of +2 metres (Fig. 19), and the differences were also fairly small at +10 cm. At the other levels the differences were marked and the mean temperatures for the sites did not come close to each other during the measurement period. The minimum point in the mean temperature curves lies in 1982 at all levels, and mean temperatures were also low in 1985 at 0 cm, –5 cm, –50 cm, and –100 cm. A distinct maximum at +2 metres occurred in 1980 in both the forest and the clearcut area, but no maxima occurred in that year at other heights. The maximum point at the various depths occurred in 1977 in the clearcut area and in 1976 in the forest. The measurements in 1974 were not comparable with those for the other years at 0 cm and –5 cm because the positions of the measurement points were a little different in that year.

4. Discussion

The fact that temperature sums were consistently lower at Kivesvaara than at the meteorological station at Kajaani throughout the period investigated may be explained by the approx. 70 m greater altitude of the Kivesvaara site, since temperatures usually decrease by 0.6°C for every additional 100 m in height (Odin 1975; Huovila 1987). Such a calculation would suggest, however, that the temperature sum should be 14 dd lower, whereas the discrepancy in fact varied within the range 1–55 dd during the period studied. The difference in temperature between Kivesvaara and Kajaani thus cannot be attributed entirely to topography but must be more complicated in its constitution and dependent on weather conditions. Afternoon temperatures, for instance, have been observed to decrease by as much as 1°C for each additional 100 m of altitude (Odin et al. 1990), as also has the mean maximum summer temperature (Odin 1975). Similarly Perttu (1972) notes on the basis of mean monthly temperature data that the generally accepted figure of 0.6°C does not hold good under all conditions. These findings, together with the high incidence of night frosts in Kajaani in early and late summer, serve to explain the above temperature sum discrepancies, although minimum temperatures in Kajaani are higher than those at Kivesvaara at times in the middle of summer.

Clearcutting altered temperatures in the meteorological screens at +2 m remarkably little. The differences in extreme temperatures, daily temperatures and monthly mean temperatures were indeed small, as also were those in the distributions of temperature variations and readings, but maximum temperatures were slightly higher in the clearcut area, as reported elsewhere (Bjor 1971, Leikola 1975, Odin 1978, Tolvanen & Kubin 1990). Mork (1968), however, failed to find any marked difference in mean maximum temperatures on west-facing mountain forest slopes between a clearcut strip 100 m in width and a forest clearing of size 50 ha whereas the maximum temperature recorded on the corresponding eastern slope was 0.7°C lower. The clearcut areas on Kivesvaara varied in size from 2 to 5 ha and were located on a gentle SE-facing slope.

Although the present mean temperatures for the summer months varied from one month and year to another, the difference between the clearcut area and the forest was at a height of 2 meters very small. The clearcut area will naturally have received more radiation energy than the forest floor (Odin 1978), but this will have affected air temperatures to a notable degree only in the layers close to the ground, the effect decreasing rapidly in an upwards direction, so that the change at a vertical distance of 2 m is minimal (Franssila 1949). At this height, of course, the thermometer in the clearcut area was shielded by a meteorological screen and that in the forest by both a screen and the forest canopy, as a consequence of which the screen located in the open place may have become warmer than that in the forest, just as different screens may affect the interior temperatures in different ways (Bjor 1967). The meteorological screens employed here were nevertheless all of a standard design.

Temperature differences between the clearcut area and the forest close to the ground surface, at a height of +10 cm, were dependent on the weather and were considerable at times of pronounced incoming or outgoing radiation. These extreme conditions were evident especially in the distributions of diurnal variations and temperature readings. The daily maximum was markedly higher in the clearcut area and the daily minimum lower. A comparable trend for more extreme temperatures following clearcutting has also been observed on many occasions previously (Bjor 1971, Odin & Perttu 1978, Tolvanen & Kubin 1990), so that attempts have been made to compensate for it by strewing branches on the ground in order to improve seed germination and the growth of seedlings (Bjor 1972). A further extreme effect of clearcutting at this latitude is an increase in frosty nights (Tolvanen & Kubin 1990), which may have a marked influence on seedling growth up to a height of 2 m (Brække 1972). The existence of a protective tree canopy will reduce the occurrence of night frosts considerably (Leikola & Rikala 1983). The difference in mean temperatures for the summer months between the clearcut area and the forest was small, however, and the mean for the former was slightly higher than that for the latter.

A clearcut area will receive more solar radiation at times of incoming radiation than a corresponding forest area, causing the surface layers of the soil to warm up more, but more pronounced cooling takes place when outgoing radiation prevails. This means a diurnal variation in soil temperatures at the 0 cm level and at –5 cm, this being greater in the clearcut area than in the forest. According to the results of Bjor (1971), the difference may be even greater at the boundary of the humus layer than that measured here at the interface between the dead and live mosses. The present results correspond well to the differences recorded by Söderström (1976) at a depth of 10 cm, and higher temperatures have also been recorded at the same depth in the soil of a clearcut area under mountain conditions (Mork 1968).

No obvious diurnal variation in temperature is to be found at greater depths in the soil, e.g. at 50 cm, as also noted by Bjor & Huse (1987). The mean temperature for the summer months was regularly higher in the clearcut area than in the forest at this depth, as reported by many other authors (Odin 1978, Lundmark et al. 1978, Bjor & Huse 1987). Bjor & Huse (1987) also found annual maximum temperatures to be higher in a clearcut area than in a forest down to a depth of 6 m, whereas scarcely any difference existed in minimum temperatures. The Kivesvaara measurements were pursued only down to a depth of 1 m, where mean monthly temperatures were consistently higher in the clearcut area than in the forest in all the summer months. A comparable situation is reported by Jeffrey (1963) for August at depths of 30 cm, 46 cm and 91 cm. Apart from clearcutting, thinning of the forest is also known to lead to a rise in soil temperatures (Ronge 1928, Ångström 1936–1937).

The effect of clearcutting is also seen in a rise in monthly mean temperatures for the summer months, in that the distributions of diurnal variation and of temperature readings in the clearcut area differed markedly between the 0 cm level and the other measurement depths. An obvious difference in the distribution of temperatures at 0 cm was seen between the clearcut area and the forest in the higher part of the range.

The warming effect of clearcutting was also reflected in the temperature sums for the summer months, which were higher in the clearcut area than in the forest at all depths measured. A comparable situation is reported by Leikola (1975) for the summer months at depths of 5 and 10 cm. Similarly the temperature sum in the layer of air immediately adjacent to the ground, i.e. at a height of 10 cm, was usually higher in the clearcut area, although it was higher in the forest in the August of some years. In uncut forest the temperature sum at the depth of 5 cm was highest in July, but in the south near the northern coniferous forest zone it has observed highest in August (Pork et.al. 1977). The temperature sums for individual months and for the whole summer period measured in the screens were practically the same in the clearcut area and the forest, in contrast to the observations of Ritari & Lähde (1975) and Kauppila & Lähde (1978), who found the temperature sum to be slightly higher in clearcut areas.

The present examination of mean temperatures and the distribution of temperature readings and of daily variations over 12 consecutive summers leads us to the conclusion that the altered temperature conditions in the clearcut area had not begun to return to the level for the forest plot within this space of time. The somewhat sparse young sapling stand which had developed from the plantings and the slow growth of natural seedlings had not yet succeeded in forming a sufficiently uniform cover for the results to be seen in a normalization of temperature conditions in the soil and the adjacent air layers. On the other hand, it is also the case that for practical reasons no planting or seeding had been attempted in the immediate vicinity of the sensors. This was of no significance at the early stage in the research, as the small seedlings would not have cast much shade in any case, but a slightly greater extent of shading would undoubtedly have been involved at the later stages. It should be noted, however, that there were many other comparable sites with no appreciable seedling growth within the area studied.

It should also be noted that no cleaning of the regenerating stand had been necessary at any time on two of the three clearcut plots studied here, while at the third this had only been done once, at the beginning of the period (Kubin 1978). It is evident that the higher temperature and altered ecological conditions in the regenerating forest of the clearcut area will have reduced the thickness of the humus layer or destroyed it entirely, and it seems that under the circumstances prevailing here a period of more than 12 years is needed before any return to something like forest conditions can be expected.

References

Ångström, A. 1936–37. Jordtemperaturen i Bestånd av olika täthet. Meddelelser från Statens Skogsförsöksanstalt 29: 187–218.

Bjor. K. 1967. Radiation shelters made of foam plastic for air temperature measurement. Meddelelser fra det Norske Skogforsøksvesen 23: 223–232.

— 1971. Forstmeteorologiske, jordbunnsklimatiske og spireøkologiske undersøkelser. Meddelelser fra det Norske Skogforsøksvesen 28: 429–526.

— 1972. Micro-temperature profiles in the vegetation and soil surface layers on uncovered and twig-covered plots. Meddelelser fra det Norske Skogforsøksvesen 30: 203–218.

— & Huse, M. 1987. Soil temperature variations at the field station Nordmoen. Variasjoner i jordtemperatur ved Nordmoen feltstasjon. Meddelelser fra Norsk institutt for skogforskning. 40(2). 12 p.

Brække, F. 1972. Varmehusholdning og mikroklima på ulike myrtyper. Meddelelser fra det Norske Skogforsøksvesen 30. 134 p.

Cajander, A.K. 1949. Forest types and their significance. Posthumous publication. Acta Forestalia Fennica 56. 60 p.

Franssila, M. 1949. Mikroilmasto-oppi. Otava. Helsinki. 257 p.

— 1960. On the measurement of soil temperature in forests and swamps. Finnish meteorological office contributions 52. 20 p.

Gupta, S., Radke, J. & Larson, W. 1981. Predicting temperatures of bare and recidue covered soils with and without a corn crop. Soil Science Society of America Journal 45: 405–412.

Havas, P. & Kubin, E. 1983. Structure, growth and organic mater content in the vegetation cover of an old spruce forest in Northern Finland. Annales Botanici Fennici 20: 115–149.

Helimäki, U.I. 1967. Taulukoita ja karttoja Suomen sadeoloista kaudelta 1931–1960. Liite Suomen meteorologiseen vuosikirjaan 1966. Tables and maps of precipitation in Finland, 1931–1960. Supplement to the Meteorological Yearbook of Finland, 1966.

Helminen, V.A. 1987. Lämpöolot. Suomen kartasto. Vihko 131: 4–10. Maanmittaushallitus, Suomen maantieteellinen seura.

Homén, T. 1896. Über die Bodentemperatur in Mustiala. Acta Societatis Scientiarum Fennicae. Tom. XXI nro 9. 184 p. III Pl.

Huovila, S. 1987. Pienilmasto. Suomen kartasto. Vihko 131: 23–24. Maanmittaushallitus, Suomen maantieteellinen seura.

Jeffrey, W.W. 1963. Soil temperature measurements in forests of Northwestern Canada. Ecology 44(1): 151–153.

Kalela, A. 1962. Metsäkasvillisuusvyöhykkeistä ja niiden ilmastollisista rinnakkaistyypeistä. Metsätaloudellinen Aikakauslehti 79(4): 158–160.

Kauppila, A. & Lähde, E. 1975. Koetuloksia maan käsittelyn vaikutuksesta metsämaan ominaisuuksiin Pohjois-Suomessa. Summary: On the effects of soil treatments on forest soil properties in North-Finland. Folia Forestalia 230. 29 p.

Kauttu, K. 1952. Havaintoja valaistuksen, ilman lämpötilan ja suhteellisen kosteuden vaihteluista eräässä kuusikossa. Referat: Beobachtungen über Schwankungen von Belichtung, Lufttemperatur und Relativer Feuchtigkeit in einem Fichtenbestand. Communicationes Instituti Forestalis Fenniae 40(31). 21 p.

Keränen, J. 1920. Über die Temperatur des Bodens und die Scheedecke in Sodankylä nach Beobachtungen mit Thermoelementen. Annales Academiae Scientiarum Fennicae. A–13.7.

Kimmins, J.P. 1987. Forest Ecology. 531 p. Macmillian Publishing Company. New York.

Kolkki, O. 1966. Taulukoita ja karttoja Suomen lämpöoloista kaudelta 1931–1960. Liite Suomen meteorologiseen vuosikirjaan 1965. Tables and maps of temperature in Finland during 1931–1960. Supplement to the Meteorological Yearbook of Finland, 1965.

Kubin, E. 1975. VMT-kuusimetsän kasvipeitteestä, maan fysikaalisista ja kemiallisista ominaisuuksista Palta-

mon Kivesvaaralla, Kainuussa. Pro gradu. 81 p. Oulun yliopiston kasvitieteen laitos. Oulu.
— 1977. Paljaaksihakkuun vaikutus kuusimetsän ravinnetilaan Pohjois-Suomessa (64°28'N). Summary: The effect of clear cutting upon the nutrient status of a spruce forest in northern Finland (64°28'N). Acta Forestalia Fennica 155. 40 p.
— 1978. Lehtipuiden luontainen uudistuminen erilaisilla maanmuokkausaloilla. Metsä ja Puu 4: 16–17.
— 1990. Lumi-, routa- ja lämpöolot eri tavoin muokatussa metsämaassa Kuusamossa. Abstract: The effect of site preparation on snow, soil frost and temperature conditions at a site near Kuusamo. Silva Fennica 24(1): 35–45.
Leikola, M. 1974. Muokkauksen vaikutus metsämaan lämpösuhteisiin Pohjois-Suomessa. Summary: Effect of soil preparation on soil temperature conditions of forest regeneration areas in northern Finland. Communicationes Instituti Forestalis Fenniae 84(2). 64 p.
— 1975. Verhopuuston vaikutus metsikön lämpöoloihin Pohjois-Suomessa. Summary: The influence of the nurse crop on stand temperature conditions in northern Finland. Communicationes Instituti Forestalis Fenniae 85(7). 33 p.
— 1976. Näkökohtia metsikköekologisten ympäristötekijöiden mittaamisesta. Summary: Measuring environmental factors in a forest ecosystem. Silva Fennica 10(2): 148–156.
— & Pylkkö, P. 1969. Verhopuuston tiheyden vaikutus metsikön minimilämpötiloihin hallaöinä. Summary: On the influence of stand density on the minimum temperatures during frost nights. Silva Fennica 3: 20–32.
— & Rikala, R. 1983. Verhopuuston vaikutus metsikön lämpöoloihin ja kuusen taimien menestymiseen. Summary: The influence of the nurse crop on stand temperature conditions and the development of Norway spruce seedlings. Folia Forestalia 559. 33 p.
Lukkala, O.J. 1946. Korpimetsien luontainen uudistaminen. Referat: Die natürliche Verjüngung der Bruchwälder. Communicationes Instituti Forestalis Fenniae 34(3). 150 p.
Lundmark, T., Odin, H. & Söderström, V. 1978. En orienterande studie av marktemperaturen på ett par lokaler inom Vindelns försöksparker. Institutionen För Skogsföryngring, Rapporter och Uppsatser 97. 41 p.
Mälkönen, E. 1972. Näkökohtia metsämaan muokkauksesta. Summary: Some aspects concerning cultivation of forest soil. Folia Forestalia 137. 11 p.
Mork, E. 1933. Temperaturen som foryngelsesfaktor i de nordtrøenderske granskoger. Meddelelser fra det norske skogforsøksvesen 5. 156 p.
— 1968. Økologiske undersøkelser i fjellskogen i Hirkjølen forsøksområde. Meddelelser fra det norske skogforsøksvesen 25: 467–614.
Odin, H. 1975. Topografins och expositionens roll för lokalklimatet. Inst för skogsgenetik, Rapporter och Uppsatser 17: 39–53.
— 1978. Meteorology in forest operations. VMO symposium on forest meteorology in Ottawa 21–25 August 1978. Reprint from WHO. No 527. pp. 167–177.
— & Perttu, K. 1978. Den skogsmeteorologiska forskning vid Skogshögskolan. Raporter och Uppsatser 98. 15 p.
— , Löfvenius, M. & Åman, K. 1990. Klimatstudier på ett nordligt högläge. Sveriges Lantbruksuniversitet. Institutionen för skoglig ståndorslära. Stencil 12. 25 p.
Perttu, K. 1972. Skogsgränsens beroende av olika klimatologiska och topografiska faktorer. Institutionen för Skogsföryngring, Rapporter och Uppsatser 34. 91 p.
Pork, K., Arold, V. & Lutsar, V. 1977. Precipitation, evaporation, soil temperature and moisture in 1970 and 1971. In: Frey, T. (ed.). Spruce forest ecosystem structure and ecology. Estonian IBP Report 11: 55–82.
Ritari, A. & Lähde, E. 1978. Effect of site preparation on physical properties of the soil in a thick-humus spruce stand. Seloste: Muokkauksen vaikutus paksusammalkuusikon maan fysikaalisiin ominaisuuksiin. Commununicationes Instituti Forestalis Fenniae 92(7). 36 p.
Ronge, E. 1928. Kort redogörelse för vissa skogliga försök, verkställda under åren 1914–1928 å Kramfors Aktiebolags skogar, och resultatens praktiska tillämpning i skogsbruket. Norrlands skogsvårdsförbunds tidskrift. p. 308–356.
Sauramo, M. 1926. Suomen geologinen yleiskartta. Maalajikartan selitys. Lehti C 4 Kajaani. Helsinki. 80 p.
Sirén, G. 1955. The development of spruce forest on raw humus sites in Northern Finland and its ecology. Lyhennelmä: Pohjois-Suomen paksusammalkankaiden kuusimetsien kehityksestä ja sen ekologiasta. Acta Forestalia Fennica 62. 408 p.
Söderström, V. 1976. Analys av markberedningseffekterna vid plantering på några färska hyggen. Summary: Analysis of the effects of scarification before planting conifers on some newly clearfelled areas in Sweden. Sveriges Skogsvårdsförbunds Tidsskrift 2–3: 59–333.
Tolvanen, A. & Kubin, E. 1990. The effect of clearcut and site preparation on microclimate, soil frost and forest regeneration at elevated sites in Kuusamo. Aquilo Ser. Botanica 29: 77–86.
Turtiainen, M. & Valtanen, J. 1970. Metsäaurauksen vaikutus maan lämpötilaan. Metsä ja Puu 87(12): 10–12.
Vaartaja, O. 1954. Temperature and evaporation at and near ground level on certain forest sites. Canadian Journal of Botany 32: 760–783.
Yli-Vakkuri, P. 1963. Kokeellisia tutkimuksia taimien syntymisestä ja ensi kehityksestä kuusikoissa ja männiköissä. Summary: Experimental studies on the emergence and initial development of tree seedlings in spruce and pine stands. Acta Forestalia Fennica 75. 122 p.

Total of 51 references

Appendix 1. Distributions of daily variation at depths of 0, –5, –50 and –100 cm in uncut (u) and clearcut (c) areas during the summer months in 1974–1985 as percentages of total observation divided to different temperature classes. On the right there are also minimum, maximum and mean ($\bar{x}$) values of variation during the same period. 1975 no observations.

Year	Depth	Site	0–3°C	3–5°C	5–10°C	10–12.5°C	12.5–15°C	15–20°C	Over 20°C	$\bar{x}$	Min	Max
			percents of total							°C		
1974	+0 cm	u	95	5	0	0	0	0	0	1.9	0.2	5.0
		c	21	53	26	0	0	0	0	4.1	0.3	7.0
	–5 cm	u	50	42	8	0	0	0	0	3.1	0.3	6.0
		c	30	53	17	0	0	0	0	3.8	0.9	7.8
	–50 cm	u	100	0	0	0	0	0	0	0.4	0.1	2.8
		c	99	0	1	0	0	0	0	0.5	0	6.0
	–100 cm	u	98	2	0	0	0	0	0	0.4	0	3.4
		c	100	0	0	0	0	0	0	0.4	0	1.9
1976	+0 cm	u	3	21	73	3	0	0	0	6.5	1.8	10.6
		c	2	4	29	14	24	27	0	12.0	2.9	19.7
	–5 cm	u	51	47	2	0	0	0	0	3.0	11.1	6.2
		c	20	57	23	0	0	0	0	4.1	1.0	6.5
	–50 cm	u	99	1	0	0	0	0	0	0.5	0	3.9
		c	100	0	0	0	0	0	0	0.6	0.1	2.6
	–100 cm	u	100	0	0	0	0	0	0	0.3	0	2.3
		c	100	0	0	0	0	0	0	0.7	0	2.6
1977	+0 cm	u	15	36	48	1	0	0	0	4.9	1.1	10.5
		c	1	5	28	21	21	13	11	12.3	2.3	23.4
	–5 cm	u	90	7	3	0	0	0	0	2.0	0.3	5.6
		c	22	48	30	0	0	0	0	4.3	0.8	9.3
	–50 cm	u	100	0	0	0	0	0	0	0.5	0	2.5
		c	94	3	3	0	0	0	0	0.8	0	5.4
	–100 cm	u	100	0	0	0	0	0	0	0.6	0	2.7
		c	95	5	0	0	0	0	0	1.0	0	4.6

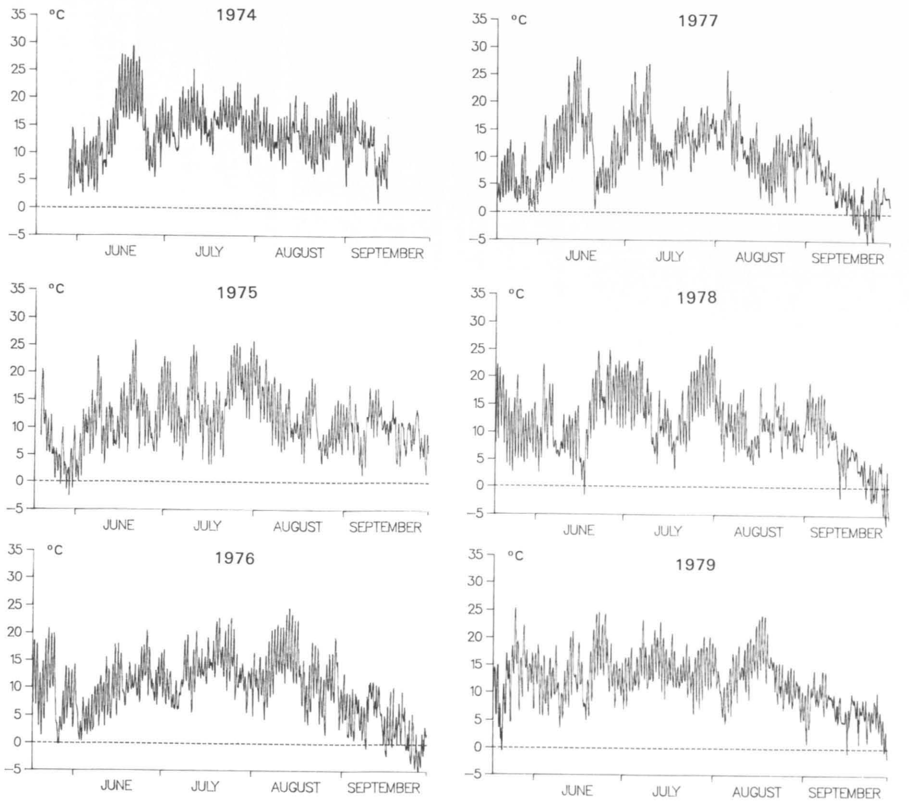
Appendix 1. Continued.

Year	Depth	Site	0–3°C	3–5°C	5–10°C	10–12.5°C	12.5–15°C	15–20°C	Over 20°C	$\bar{x}$	Min	Max
			percents of total							°C		
1978	+0 cm	u	9	5	56	27	0	0	0	8.1	1.5	12.3
		c	–	–	–	–	–	–	–	–	–	–
	-5 cm	u	47	42	11	0	0	0	0	3.4	0.9	8.8
		c	14	23	62	1	0	0	0	5.6	1.1	10.4
	-50 cm	u	91	9	0	0	0	0	0	1.1	0	4.0
		c	100	0	0	0	0	0	0	0.4	0	2.7
	-100 cm	u	99	1	0	0	0	0	0	0.9	0	3.5
		c	99	0	1	0	0	0	0	0.6	0	5.3
1979	+0 cm	u	4	20	76	0	0	0	0	6.2	2.3	9.8
		c	0	5	20	21	13	30	11	13.5	3.9	23.0
	-5 cm	u	88	11	1	0	0	0	0	2.1	0.7	5.3
		c	23	46	30	1	0	0	0	4.4	1.2	10.3
	-50 cm	u	100	0	0	0	0	0	0	0.6	0.1	2.4
		c	98	2	0	0	0	0	0	1.1	0.2	4.5
	-100 cm	u	99	1	0	0	0	0	0	0.8	0.1	3.4
		c	97	3	0	0	0	0	0	0.9	0.1	4.6
1980	+0 cm	u	9	15	76	0	0	0	0	6.2	1.3	9.1
		c	2	4	26	16	23	26	3	12.1	1.9	21.5
	-5 cm	u	83	17	0	0	0	0	0	2.4	0.3	3.6
		c	17	46	37	0	0	0	0	4.4	1.1	7.2
	-50 cm	u	100	0	0	0	0	0	0	0.5	0	3.0
		c	98	1	1	0	0	0	0	0.8	0.1	5.7
	-100 cm	u	100	0	0	0	0	0	0	0.6	0	2.7
		c	99	1	0	0	0	0	0	0.7	0.1	3.4
1981	+0 cm	u	22	37	41	0	0	0	0	4.8	1.1	9.6
		c	5	19	54	13	9	0	0	7.6	1.4	14.8
	-5 cm	u	96	4	0	0	0	0	0	1.7	0.3	3.2
		c	60	30	10	0	0	0	0	2.9	0.6	7.9
	-50 cm	u	98	2	0	0	0	0	0	0.5	0	3.5
		c	100	0	0	0	0	0	0	0.6	0.1	2.7
	-100 cm	u	98	2	0	0	0	0	0	0.5	0	3.8
		c	100	0	0	0	0	0	0	0.5	0.1	1.4

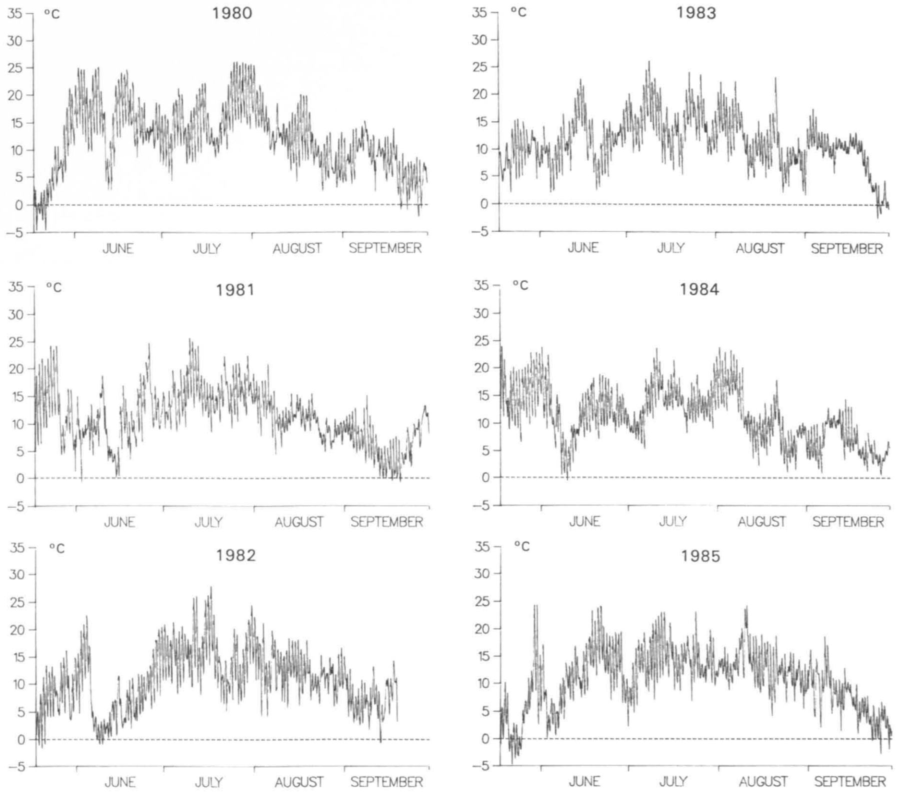
Appendix 1. Continued.

Year	Depth	Site	0–3°C	3–5°C	5–10°C	10–12.5°C	12.5–15°C	15–20°C	Over 20°C	$\bar{x}$	Min	Max
			percents of total							°C		
1982	+0 cm	u	10	35	54	1	0	0	0	5.4	1.4	10.7
		c	0	8	44	23	24	1	0	9.8	3.3	15.2
	-5 cm	u	86	11	3	0	0	0	0	2.1	0.5	6.6
		c	27	45	28	0	0	0	0	3.9	1.2	6.5
	-50 cm	u	99	1	0	0	0	0	0	0.4	0	3.5
		c	100	0	0	0	0	0	0	0.4	0	1.7
	-100 cm	u	98	2	0	0	0	0	0	0.6	0	3.5
		c	100	0	0	0	0	0	0	0.4	0	2.4
1983	+0 cm	u	12	32	56	0	0	0	0	5.1	1.4	7.5
		c	2	10	43	33	12	0	0	9.3	2.6	14.4
	-5 cm	u	98	2	0	0	0	0	0	1.5	0.3	4.3
		c	41	58	1	0	0	0	0	3.2	0.7	5.4
	-50 cm	u	99	1	0	0	0	0	0	0.3	0	3.3
		c	100	0	0	0	0	0	0	0.3	0	1.8
	-100 cm	u	100	0	0	0	0	0	0	0.3	0	2.6
		c	100	0	0	0	0	0	0	0.2	0	1.7
1984	+0 cm	u	15	46	39	0	0	0	0	4.6	1.3	8.4
		c	4	9	64	19	4	0	0	8.1	2.1	13.9
	-5 cm	u	98	2	0	0	0	0	0	1.4	0.3	5.0
		c	47	48	5	0	0	0	0	3.2	0.9	5.7
	-50 cm	u	99	1	0	0	0	0	0	0.3	0	5.0
		c	100	0	0	0	0	0	0	0.3	0.1	1.6
	-100 cm	u	98	2	0	0	0	0	0	0.4	0	3.5
		c	100	0	0	0	0	0	0	0.2	0	0.8
1985	+0 cm	u	33	40	27	0	0	0	0	4.0	1.2	10.0
		c	5	23	57	12	3	0	0	7.1	1.4	13.4
	-5 cm	u	96	4	0	0	0	0	0	1.4	0.4	4.6
		c	61	35	4	0	0	0	0	2.9	0.5	6.2
	-50 cm	u	98	2	0	0	0	0	0	0.4	0	3.7
		c	99	0	1	0	0	0	0	0.5	0	5.5
	-100 cm	u	100	0	0	0	0	0	0	0.3	0	1.8
		c	99	1	0	0	0	0	0	1.0	0	3.5

Appendix 2. Daily temperature in the weather screen 2 m above the ground in the clearcut area at Kivesvaara site in 1974–1985.



Appendix 2. Continued.



Appendix 3. Distribution of temperature observation at depths of 0, –5, –50 and –100 cm in uncut (u) and clearcut (c) areas during the summer months in 1974–1985. Legend see Appendix 1.

Year	Depth	Site	Under 0°C	0–5°C	5–10°C	10–15°C	15–20°C	20–25°C	25–30°C	Over 30°C	x̄	Min	Max
			percents of total								°C		
1974	+0 cm	u	0	7	17	75	1	0	0	0	10.9	2.1	15.3
		c	0	3	14	63	20	0	0	0	12.5	2.6	18.1
	-5 cm	u	0	11	33	56	0	0	0	0	9.6	2.0	15.6
		c	0	1	12	56	31	0	0	0	13.4	4.7	18.9
	-50 cm	u	0	22	78	0	0	0	0	0	6.9	0.1	10.1
		c	0	14	30	56	0	0	0	0	9.2	2.3	12.2
	-100 cm	u	4	32	64	0	0	0	0	0	5.7	-0.4	9.0
		c	0	22	61	17	0	0	0	0	7.4	0.5	10.7
1976	+0 cm	u	0	1	15	48	33	3	0	0	13.6	3.2	21.9
		c	0	2	18	38	27	12	3	0	14.4	2.2	28.9
	-5 cm	u	0	0	19	67	14	0	0	0	12.5	5.3	18.1
		c	0	0	12	62	26	0	0	0	13.3	6.6	19.3
	-50 cm	u	0	0	49	51	0	0	0	0	9.7	5.6	12.0
		c	0	0	26	74	0	0	0	0	11.2	7.7	14.0
	-100 cm	u	0	0	54	46	0	0	0	0	9.1	5.1	10.5
		c	0	0	44	56	0	0	0	0	10.1	6.8	13.1
1977	+0 cm	u	0	0	21	54	25	0	0	0	12.7	5.8	20.3
		c	0	1	15	33	33	14	3	1	15.6	3.2	30.2
	-5 cm	u	0	0	28	69	3	0	0	0	11.4	4.4	17.0
		c	0	0	5	56	39	0	0	0	14.3	6.9	21.2
	-50 cm	u	0	9	76	15	0	0	0	0	8.1	3.2	11.0
		c	0	0	18	82	0	0	0	0	11.8	6.9	14.8
	-100 cm	u	0	17	83	0	0	0	0	0	7.2	2.9	9.8
		c	0	0	38	62	0	0	0	0	10.4	5.9	13.4

Appendix 3. Continued.

Year	Depth	Site	Under 0°C	0–5°C	5–10°C	10–15°C	15–20°C	20–25°C	25–30°C	Over 30°C	x̄	Min	Max
			percents of total								°C		
1978	+0 cm	u	0	5	32	38	20	5	0	0	12.0	-0.2	23.6
		c	–	–	–	–	–	–	–	–	–	–	–
	-5 cm	u	0	1	32	63	4	0	0	0	11.1	3.5	18.0
		c	0	0	20	51	26	3	0	0	13.3	4.0	21.3
	-50 cm	u	0	21	77	2	0	0	0	0	7.2	3.0	15.5
		c	0	0	38	62	0	0	0	0	10.4	5.8	13.0
	-100 cm	u	0	31	68	1	0	0	0	0	5.9	1.0	14.5
		c	0	2	66	32	0	0	0	0	8.7	3.8	12.4
1979	+0 cm	u	0	0	17	58	25	0	0	0	12.9	4.4	20.2
		c	0	2	17	33	27	16	4	1	15.1	2.0	31.4
	-5 cm	u	0	0	21	76	3	0	0	0	11.6	3.2	18.4
		c	0	1	11	70	18	0	0	0	12.9	3.6	18.5
	-50 cm	u	0	10	74	16	0	0	0	0	8.4	1.8	11.5
		c	0	2	39	59	0	0	0	0	9.9	3.5	12.6
	-100 cm	u	0	18	79	3	0	0	0	0	7.4	0.4	12.0
		c	0	6	51	43	0	0	0	0	9.0	1.5	12.3
1980	+0 cm	u	0	1	21	53	24	1	0	0	12.7	3.9	21.1
		c	0	2	19	33	27	15	4	0	14.7	2.8	28.6
	-5 cm	u	0	0	23	71	6	0	0	0	11.6	6.4	16.8
		c	0	0	14	68	18	0	0	0	12.8	6.3	18.4
	-50 cm	u	0	3	68	29	0	0	0	0	8.7	3.7	11.5
		c	0	0	31	69	0	0	0	0	10.5	6.6	17.4
	-100 cm	u	0	12	86	2	0	0	0	0	7.7	2.6	10.3
		c	0	8	64	28	0	0	0	0	8.9	3.1	13.3
1981	+0 cm	u	0	3	25	55	17	0	0	0	11.9	1.4	21.0
		c	0	1	17	45	30	7	0	0	13.9	1.8	23.5
	-5 cm	u	0	0	29	70	1	0	0	0	11.2	4.7	15.9
		c	0	0	20	62	18	0	0	0	12.6	5.1	21.0
	-50 cm	u	0	3	54	43	0	0	0	0	8.9	4.8	12.0
		c	0	0	28	72	0	0	0	0	10.9	6.6	14.5
	-100 cm	u	0	9	84	7	0	0	0	0	8.1	4.1	11.7
		c	0	0	47	53	0	0	0	0	9.6	5.0	12.5

Appendix 3. Continued.

Year	Depth	Site	Under 0°C	0–5°C	5–10°C	10–15°C	15–20°C	20–25°C	25–30°C	Over 30°C	x̄	Min	Max
			percents of total								°C		
1982	+0 cm	u	0	10	37	46	7	0	0	0	10.1	1.2	19.9
		c	0	6	29	37	21	7	0	0	12.1	1.7	24.7
	-5 cm	u	0	8	49	43	0	0	0	0	9.3	3.3	16.0
		c	0	2	30	61	7	0	0	0	11.0	4.4	18.0
	-50 cm	u	0	10	90	0	0	0	0	0	7.3	4.4	12.3
		c	0	0	59	41	0	0	0	0	9.1	5.7	11.0
	-100 cm	u	0	23	77	0	0	0	0	0	6.5	2.7	11.0
		c	0	0	100	0	0	0	0	0	8.4	4.0	10.0
1983	+0 cm	u	0	2	37	51	10	0	0	0	11.0	3.3	18.0
		c	0	3	22	42	27	6	0	0	13.0	3.0	24.6
	-5 cm	u	0	0	44	56	0	0	0	0	10.2	6.3	13.8
		c	0	0	23	67	10	0	0	0	11.9	6.6	18.4
	-50 cm	u	0	0	100	0	0	0	0	0	8.1	5.0	10.1
		c	0	0	37	63	0	0	0	0	10.4	6.9	12.4
	-100 cm	u	0	0	99	1	0	0	0	0	8.0	4.2	10.2
		c	0	0	74	26	0	0	0	0	9.0	5.9	11.0
1984	+0 cm	u	0	4	39	50	7	0	0	0	10.6	2.3	18.4
		c	0	3	22	48	23	4	0	0	12.8	2.4	22.3
	-5 cm	u	0	0	58	42	0	0	0	0	9.8	5.2	15.9
		c	0	0	24	68	8	0	0	0	11.8	6.0	17.3
	-50 cm	u	0	0	100	0	0	0	0	0	7.8	5.2	13.9
		c	0	0	48	52	0	0	0	0	10.3	7.5	12.9
	-100 cm	u	0	0	98	2	0	0	0	0	7.9	3.8	14.8
		c	0	0	67	33	0	0	0	0	9.1	6.3	11.2
1985	+0 cm	u	0	9	36	54	1	0	0	0	9.7	0.2	17.3
		c	0	3	24	53	19	1	0	0	12.2	-0.3	21.6
	-5 cm	u	0	13	46	41	0	0	0	0	8.5	0.2	13.7
		c	0	2	22	75	1	0	0	0	11.1	4.3	15.9
	-50 cm	u	0	25	75	0	0	0	0	0	6.3	0.3	11.2
		c	0	10	57	33	0	0	0	0	8.8	4.0	12.4
	-100 cm	u	0	39	61	0	0	0	0	0	5.8	-0.9	9.3
		c	0	11	57	32	0	0	0	0	8.7	3.2	14.5

Instructions to authors — Ohjeita kirjoittajille

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Manuscripts should be sent to the editors of the Society of Forestry as three full, completely finished copies, including copies of all figures and tables. Original material should not be sent at this stage.

The editor-in-chief will forward the manuscript to referees for examination. The author must take into account any revision suggested by the referees or the editorial board. Revision should be made within a year from the return of the manuscript. If the author finds the suggested changes unacceptable, he can inform the editor-in-chief of his differing opinion, so that the matter may be reconsidered if necessary.

Decision whether to publish the manuscript will be made by the editorial board within three months after the editors have received the revised manuscript.

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