United States
Department of
Agriculture

Forest Service

Pacific Northwest
Forest and Range
Experiment Station

Research Note
PNW-396
January 1982

Control of Depth to Permafrost and Soil Temperature by the Forest Floor in Black Spruce/Feathermoss Communities

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Abstract

Changes in depth to permafrost and soil temperature were investigated for 4 years after treatment of the forest floor on small plots by fire and mechanical removal of half the forest floor layer and the entire layer. The only treatments to show a consistent, statistically significant effect were the mechanical removals. Fire treatments usually did not have a statistically significant effect on depth to permafrost and soil temperature in summer; fire consumed only small amounts of the forest floor because of wet conditions at the time of burning. Treated plots showed an almost constant drop in permafrost depth at the end of each summer with no evidence that this rate was decreasing. Thicknesses of mean active layers at the end of the fourth summer after treatment were as follows: control, 26.2 cm; lightly burned, 31.8 cm; heavily burned, 49.6 cm; half the forest floor removed, 85.0 cm; and entire forest floor layer removed, 137.5 cm. Changes in vegetation on the plots are also reported.

Keywords: Forest floor, soil temperature, permafrost, fire effects, mechanical control, taiga, Alaska (interior).

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Introduction

Forest-floor layers under black spruce in interior Alaska are mainly moss remains. As stands increase in age, forest-floor layers build to considerable proportions, sometimes reaching 50 cm in thickness. Barney and Van Cleve (1973) found that almost 85 percent of the total weight of plant materials (including the trees and shrubs) on a lowland black spruce site was contributed by the forest floor. Scientists and land managers have become increasingly aware of the importance of the forest floor in controlling many important processes, especially in black spruce at northern latitudes. For example, this organic layer is the principal medium for plant roots, the repository of most soil nutrients—many in unavailable forms, and a highly efficient insulating layer maintaining low soil temperatures and often a shallow permafrost table.

The effects of fire in black spruce ecosystems depend on how much of the forest-floor layer is consumed by the fire. The relation of patterns in forest-floor burning to revegetation have been studied after wildfire and experimental, controlled fire at the Washington Creek Fire Ecology Experimental Area north of Fairbanks (Viereck et al. 1979, Viereck and Dyrness 1979). The effect of burning on thawing of permafrost has also been studied. Three years after the Wickersham Dome Fire, the active layer (depth of thawed soil) was 84 cm thick in the burned area and only 47 cm in the unburned control (Viereck and Dyrness 1979). Measurements after a wildfire near Inuvik gave similar results (Mackay 1970). Thickness of the active layer had increased from about 50 cm to about 100 cm 4 years after the fire.

Removal of the entire forest-floor layer, as would be expected, exerts profound changes in the thermal regime of the soil. For example, forest-floor removal by fireline construction at the Wickersham fire area resulted in an active layer 132 cm thick (compared to 47 cm in an undisturbed area) 3 years after construction (Viereck and Dyrness 1979). Brown et al. (1969) reported similar results after tractor removal of surface organic matter; they stress that melting permafrost often leads to serious problems with erosion.

Our study was designed to compare the effects of a variety of disturbance treatments of the forest floor in an area of typical black spruce/feathermoss vegetation on a soil characterized by a shallow permafrost table. Specific objectives were:

- To determine the effect of varying degrees of removal of a thick, surface organic layer both by fire and mechanically, on soil temperature and depth to permafrost table.
- To follow changes in these soil characteristics with time as revegetation occurs.

The study was part of a larger research effort to gain better understanding of the structure and function of a black spruce forest in relation to other taiga ecosystems.

Experimental Area

The study was conducted in the Washington Creek Fire Ecology Experimental Area, in the Yukon-Tanana Uplands about 45 km north of Fairbanks. The general terrain is unglaciated and gently rolling; the entire area is loess mantled and underlain by Precambrian schist. The experimental site is on a 10-percent south-facing slope with a silt loam Histic Pergelic Cryaquept soil. The soil (Saulich series) is both poorly drained and poorly developed. It has a thin (6-cm) A horizon over a massive, generally mottled and water-saturated C horizon. Soil texture is uniformly silt loam. The forest floor (01 and 02 horizons) averages about 30 cm in thickness. This site is typical of a large area within the Yukon-Tanana Uplands physiographic province; results of this study should apply on comparable soils within the province.

Tree age in the area is about 140 years. The upper portion of the study area supports stands representative of the closed black spruce/feathermoss community (Viereck and Dyrness 1980). Principal tall shrubs are *Ledum groenlandicum* and *Vaccinium uliginosum;* low shrubs and herbs include *Calamagrostis canadensis, Vaccinium vitis-idaea,* and *Equisetum sylvaticum.* The moss layer on the surface of the forest floor is especially luxurious and largely made up of *Pleurozium schreberi* and *Hylocomium splendens.*

The lower part of the area is made up of a small-scale mosaic of two forest communities—open black spruce/feathermoss-Cladonia and open black spruce/ *Sphagnum.* The feathermoss-Cladonia community dominates on slight rises, and open black *spruce/Sphagnum* dominates in lower positions. Dominant shrub species in this portion of the study are *Ledum groenlandicum* and *Vaccinium uliginosum,* and once again, important species in the herb layer are *Vaccinium vitis-idaea* and *Calamagrostis canadensis.* Mosses and lichens carpet virtually 100 percent of the forest floor.

For a more complete description of the soil and vegetation of the study area, refer to Dyrness and Grigal (1979).

[1]Authority for binomials is included in table 6, page 16.

Methods

Three blocks of six plots each were located in the study area. Each set of plots was laid out on the contour to remove effects of position on slope. All overstory trees were felled and removed from the experimental site before treatments were applied to remove the effect of shade. The upper blocks (1 and 2) were within the closed black spruce/feathermoss community, and the lower (block 3) was in the open black *sprucel(feathermoss-Cladonia)-(Sphagnum)* intergrade area.

The experimental plots were 3 x 3 m and were arranged in a randomized block design. A 2-m-wide buffer with undisturbed organic layer was left between treated plots. In each of the three blocks, five forest-floor treatments and a control were randomized among the plots. The planned treatments were as follows:

- Very light burn (the surface of the moss layer blackened)
- Medium burn (about half the organic layer consumed)
- Severe burn (organic layer consumed down to mineral soil)
- Half of the organic layer removed mechanically
- All of the organic layer removed mechanically
- Undisturbed control.

During July 1976, a propane torch was used for burning treatments, and hand clippers were used for mechanical removal. Because the forest-floor layer is susceptible to disturbance by trampling, a portable platform was used during plot measurement.

Before plots were treated, vegetative cover on each plot was intensively inventoried. Plots were divided with string into square-meter grids. Cover for all plant species was recorded for each square meter (9 per plot), and the location of each woody stem was plotted. After plot treatment, the vegetation inventory was repeated each year (1977 through 1979) during late July or early August.

Soil temperature and permafrost measurements were largely confined to the central square meter of each plot. Posttreatment measurements began in late July 1976 and ended for the season at the end of September. Measurements during subsequent growing seasons (1977 through 1979) were started in early June and extended until mid-September. Soil-temperature measurements were obtained at two locations per plot at weekly intervals and by 5-cm depth increments until permafrost was reached. Permafrost table depth was also measured weekly at five locations within the central square meter.

To investigate the nature of the surface of the permafrost table, we measured the elevation of the surface of the forest floor (if any) and permafrost from a level plane at 40 points equally distributed over the entire 9-m^2 plot. The level plane was established by hand level at the corners of the plot. These measurements were made on all plots during mid-September, 1976 and 1977.

The experimental design is a randomized block-split-plot in time. Differences in permafrost depths and growing-season soil temperatures in the surface 10 cm of mineral soil were compared by analysis of variance. These data were analyzed in two ways—with years pooled to determine the overall treatment effect, and by year-to-year increments to determine the significance of the changes over the 4 years of the study. The Tukey test indicated the significance of differences among individual treatments.

Results

The forest-floor layer was extremely moist when the plots were treated. As a result, heat from the propane torch did not penetrate deeply into the layer. Consequently, in each block we effectively had only two burning treatments-one plot lightly burned and two plots heavily burned. On the lightly burned plots, the surface vegetation was scorched and killed but the surface was not appreciably blackened. On the heavily burned plots, the surface was thoroughly charred and, in some areas, several centimeters of the surface material consumed. Because of the wet conditions, however, effects of the burning treatment never even approached the surface of the mineral soil.

In summary, the plots after treatment were in the following conditions: lightly burned; heavily burned (two plots per block); half the organic layer removed mechanically; total organic layer removed mechanically; and undisturbed control. Table 1 summarizes the forest-floor depth (measured from the surface of the forest floor to the interface between organic and mineral soil) after the treatments were applied. Because of the normal substantial variability in thickness of the undisturbed forest floor, these data are difficult to interpret. The light burn apparently resulted in only a slight decrease in forest-floor thickness, but the heavy burn caused a decrease of about 5 to 10 cm (table 1). Comparing values for the half-removal plots with control plots indicates that perhaps more than half of the organic layer was removed in block 1 and less than half in block 3. The average of all three blocks, however, appears to be fairly close to half removal.

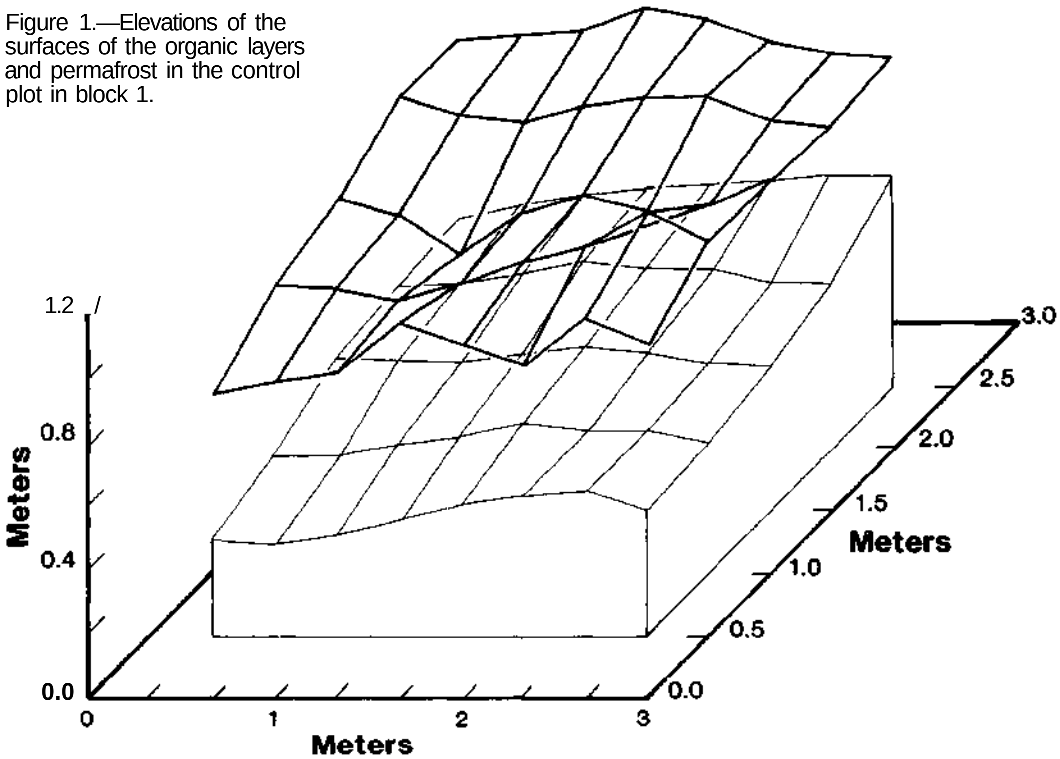
Table 1—Average depth of forest floor in the central square meter of experimental plots after treatment

Treatment	Block 1	Block 2	Block 3	Mean
		centimeters		
Lightly burned	28.2	31.1	25.4	28.2
Heavily burned	26.2	22.1	17.2	21.8
Heavily burned	25.5	31.0	18.1	24.9
Half organic layer removed	9.2	16.5	14.3	13.3
All organic layer removed	0	0	0	0
Control	34.0	37.2	23.2	31.5

Permafrost

The configuration of the surface of the permafrost table in mid-September for a typical control plot is shown in figure 1. Although the surface of the permafrost is by no means smooth, it does not faithfully reflect the topography of the surface of the forest floor. As expected, the September 1977 data for plots on which the entire forest floor was removed show considerable dishing (with edges higher than the middle) of the permafrost surface because of edge effect. This confirmed the necessity to confine measurements to the central square meter of the plot to assess treatment effects adequately.

Figure 1.—Elevations of the surfaces of the organic layers and permafrost in the control plot in block 1.



The effect of forest-floor treatment on depth of permafrost was striking. Analysis of variance for depth of permafrost measured at the end of the growing season for 4 years shows a highly significant treatment effect (table 2). In addition, the yearly changes in depth to permafrost were also highly significant (as indicated by the analysis of variance for year-to-year increment in table 2). This is a reflection of the continued retreat each year of the permafrost table under treated plots.

Table 2—Analysis of variance by split-block design for end-of-growing season depth to permafrost measured for 4 years (1976-79) after forest-floor disturbance treatments

Source	Degrees of freedom.	Sums of squares	Mean squares	F
Depth to permafrost with years pooled				
Treatment	5	45,331	9,066	30.10*
Block	2	1,384	692	2.30
Error 1	10	3,012	301	
Period	3	12,202	4,067	70.24*
Treatment X period	15	8,558	570	9.85*
Error 2	36	2,085	58	
Depth to permafrost, increments by year (1976-77, 1977-78, 1978-79)				
Increment	2	0.02776	0.01388	6.31*
Treatment X increrment	10	.07052	.00705	3.21*
Error 1	24	.05275	.00220	
Treatment	5	.51957	.10391	9.23*
Block	2	.00607	.00303	0.27
Error 2	10	.11255	.01125	

*Significant at the 1 percent level of probability.

In general, the means of the active-layer thickness (or depth to permafrost) increased with decreasing amounts of forest floor remaining after treatment (fig. 2). By far the greatest increases in depth to permafrost were measured on the plots that had the entire forest-floor layer mechanically removed. In these plots, the average increase in active-layer thickness was almost 7-fold (from about 20 to 137 cm) in the 4 years after treatment (table 3). As might be expected, the plots from which half the original forest floor was removed ranked second in active-layer thickness (an average of 85 cm after 4 years). The heavily burned plots ranked a distant third, with an average of about 50 cm at the end of the 4th year (table 3). Even the control plots showed a small increase in active-layer thickness during the 4-year treatment period. This may be a real difference caused by the removal of the shade from overstory trees. Results of the Tukey test, however, indicated that the only treatments that differed in a statistically significant manner from the other treatments were total and half mechanical removal. By this measure, permafrost depths under the three burning treatments and control were not significantly different from one another.

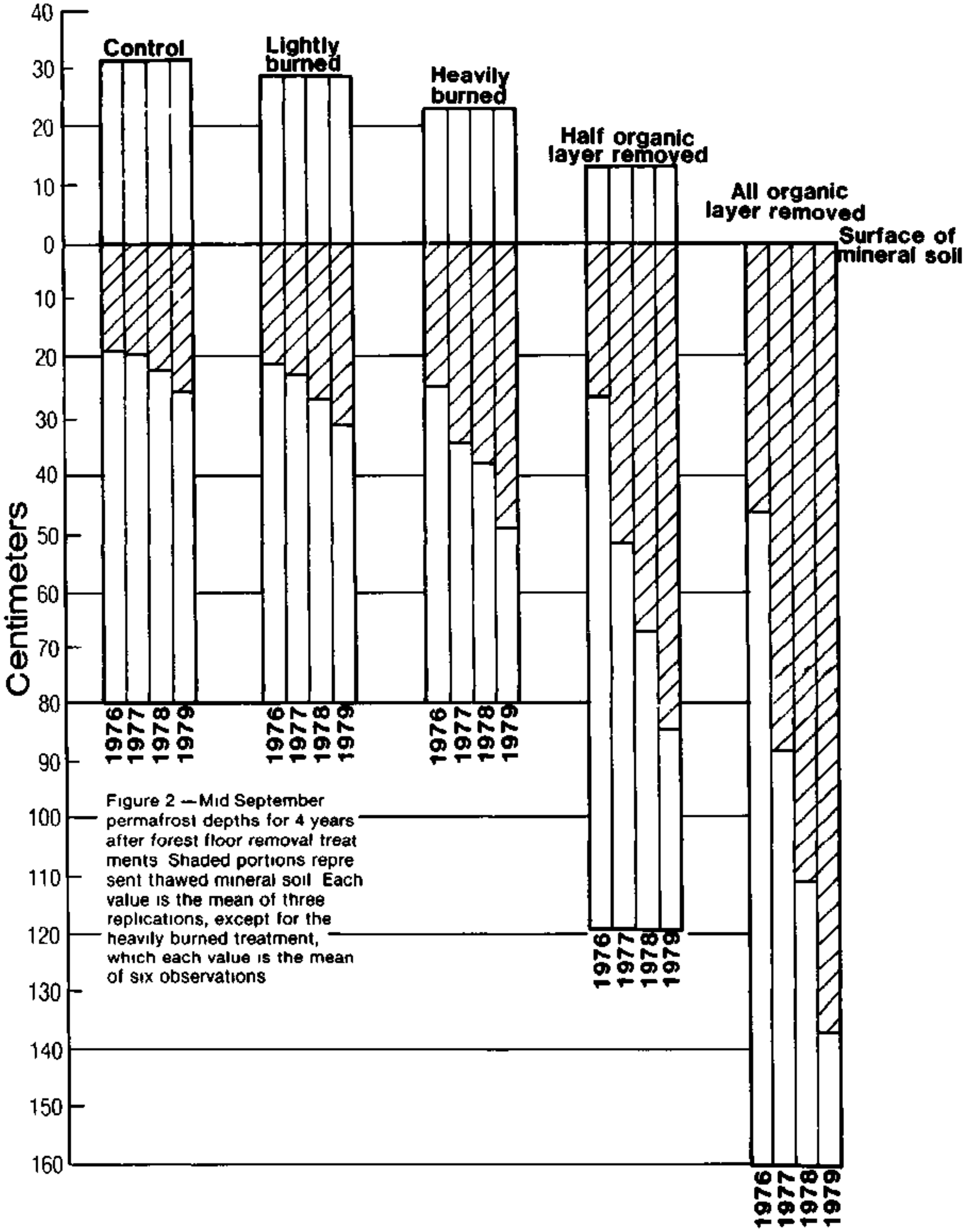


Figure 2 —Mid September permafrost depths for 4 years after forest floor removal treatments Shaded portions represent thawed mineral soil Each value is the mean of three replications, except for the heavily burned treatment, which each value is the mean of six observations

Table 3—Mid-September active-layer thickness (thickness of thawed mineral soil), for 4 years after forest-floor treatment (individual values are based on means of 5 determinations of permafrost depth per plot)

Disturbance treatment	Block	1976	1977	1978	1979
			centimeters		
Undisturbed control	1	16.0	17.4	21.8	24.0
	2	18.3	22.2	20.4	24.8
	3	21.7	18.8	24.6	29.8
	Mean	18.7	19.5	22.3	26.2
Lightly burned	1	25.8	34.0	36.6	40.8
	2	14.9	14.5	19.7	20.9
	3	23.6	19.8	25.2	33.6
	Mean	21.4	22.8	27.2	31.8
Heavily burned	1	24.8	34.4	34.6	40.8
		25.0	29.7	33.7	37.5
	2	22.4	24.9	31.3	37.9
		16.5	26.8	30.6	51.0
	3	23.8	34.4	45.2	59.8
		39.9	57.3	55.3	70.9
	Mean	25.4	34.6	38.4	49.6
Half organic layer removed	1	39.3	54.2	66.8	85.8
	2	22.5	40.9	50.1	58.5
	3	19.7	60.9	85.5	110.7
	Mean	27.2	52.0	67.5	85.0
All organic layer removed	1	42.5	90.4	119.6	125.0
	2	46.0	88.8	112.4	145.0
	3	51.0	84.2	101.0	115.4
	Mean	46.5	87.8	111.0	137.5

The consistent annual increase in active-layer thickness in the 4 years after treatment is shown in figure 2. Especially under plots with half and entire mechanical removal, the year-to-year increases were appreciable, statistically significant, and show no evidence of decreasing. The average annual increase in thickness of the active layer was about 30 cm under plots from which the entire forest floor had been removed, and about 19 cm for the half-removal plots. Increases in depth to permafrost were not as marked on heavily burned plots, where the annual increase averaged only about 8 cm (table 3). These findings are consistent with those of Viereck and Foote (1979) on the nearby Wickersham Dome Fire. They noted a constant increase in depth of thaw on a burned site and a fireline for 5 years after disturbance and observed no indication that the rate was decreasing.

For most of the forest-floor treatments, soil frost appeared to melt more quickly during June than in the remainder of the summer (fig. 3). An exception was with total forest-floor removal, where rate of melting appeared to be fairly constant throughout the summer. By mid-September, depth of permafrost table had stabilized, and melting had virtually ceased (fig. 3).

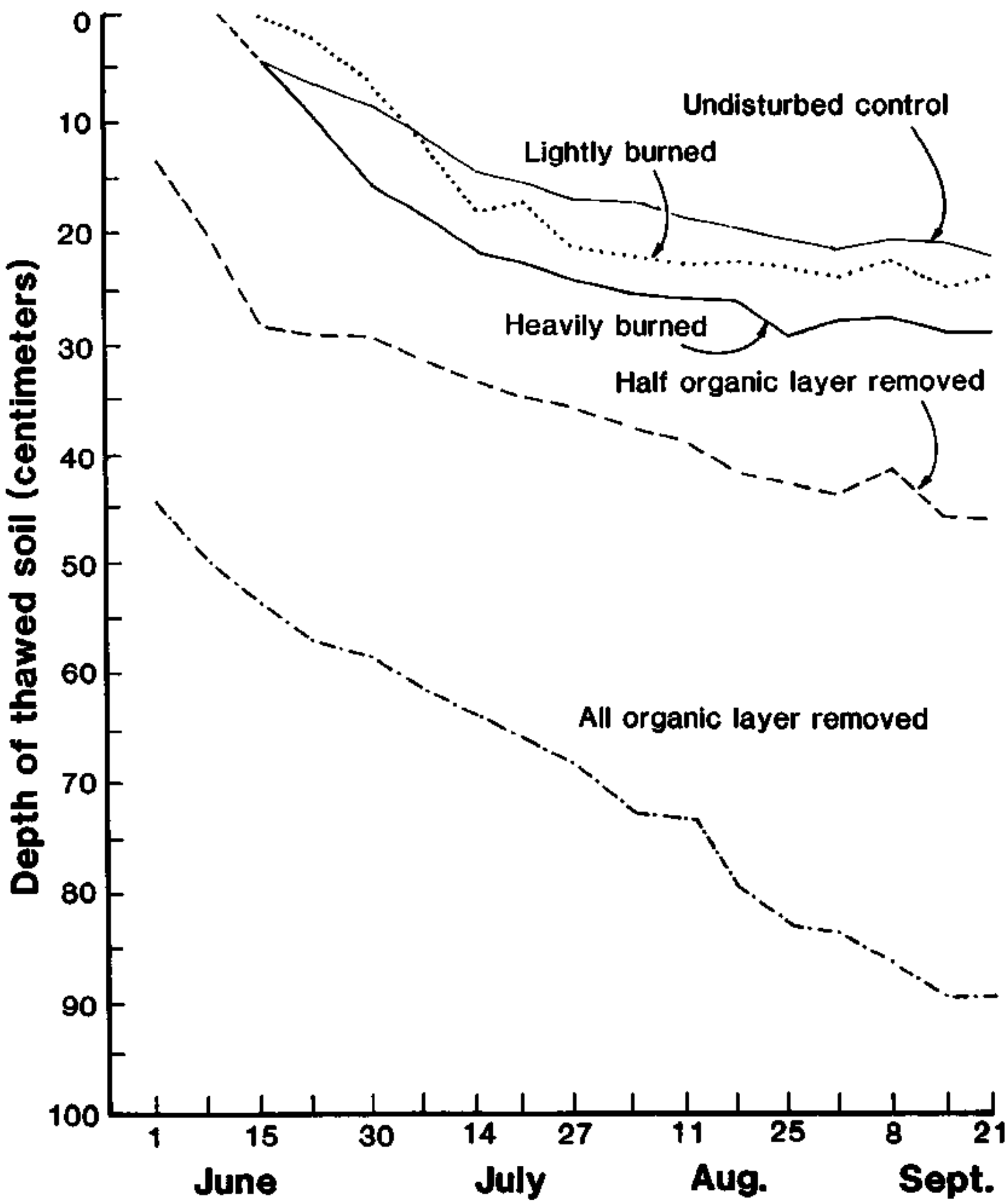


Figure 3.—Average depth of thawed mineral soil (active layer) in four forest-floor treatments during the summer of 1977.

Soil Temperature

Temperature measurements at 5-cm depth-intervals are shown for three 1977 dates in figure 4. Measurements were taken both in organic materials and mineral soil, starting in any forest-floor materials left after treatment. Because of the variable amounts of the organic layer remaining (table 1), comparing treatments is difficult. Temperature decrease with depth is apparently greater in the surface organic layer than in the mineral soil. Therefore, the points of deflection for the July 27 curves are generally related to the thickness of the surface organic layer. In midsummer, the soil at the undisturbed control plot was warmer than the treated plots down to a depth of about 35 cm, the approximate thickness of the forest floor. From 35 to 70 cm, the soil temperature at the plot with the organic layer removed was up to 4 degrees higher than the control (fig. 4).

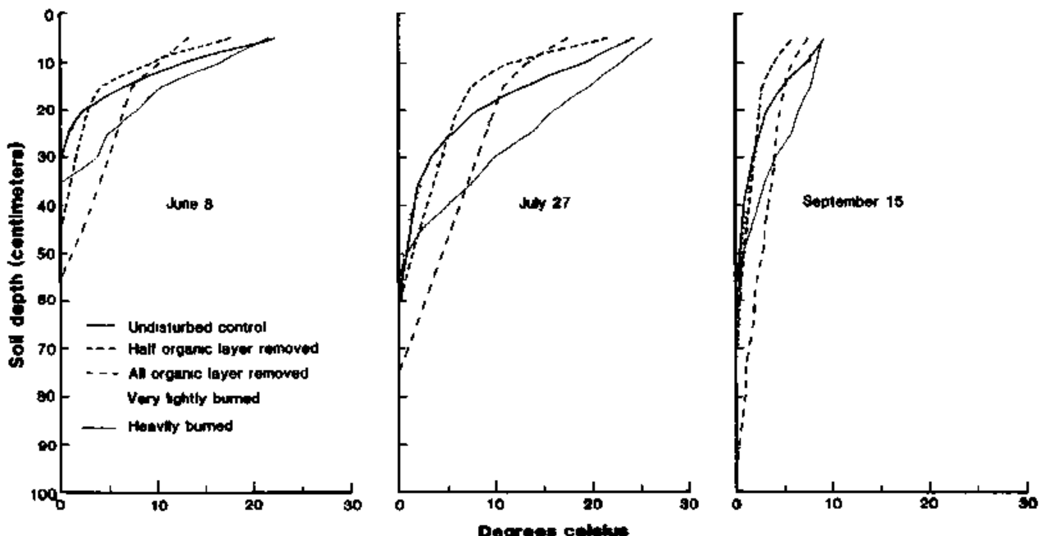


Figure 4 —Changes in soil temperature with depth at three dates during the summer of 1977, for five forest-floor treatments

To compare effects of forest-floor treatments on temperature of mineral soil, cumulative temperatures were determined for the surface 10 cm of mineral soil (two values per week) for the summers of 1977, 1978, and 1979. For example, if forest-floor thickness after treatment was 12 cm, temperatures would be measured weekly at depths of 3 and 8 cm in the mineral soil (because temperatures were measured at 5-cm increments). These mean values, each based on two separate measurements, were then summed for the 15-week period to provide annual cumulative values of the soil temperatures (table 4). Once again, the two treatments that had by far the most effect were the mechanical removals. Differences amounted to more than a 6-fold increase above the control for total removal, and well over a 3-fold increase for the half removal. Heavy burning increased soil temperatures slightly. Light burning, however, reduced the temperature of the surface 10 cm of mineral soil (table 4). That the Tukey tests indicated soil temperatures under both burning treatments cannot be considered significantly different from those in the control is not surprising. Obviously measurement of permafrost retreat under the burning treatments indicates some warming of the mineral soil; our methods of soil-temperature measurements were simply inadequate to portray these differences consistently.

Table 4—Means of cumulative soil temperatures in summer by year and disturbance treatment (temperatures were measured at 2 depths, separated by 5 cm, in the surface 10 cm of mineral soil at weekly intervals)

Disturbance treatment	1977	1978	1979	Mean
		Degrees Celsius		
Undisturbed control	62.0	39.4	49.9	50.4
Lightly burned	35.7	25.2	43.9	34.9
Heavily burned	66.1	52.9	75.3	64.8
Heavily burned	71.8	56.2	75.9	68.0
Half organic layer removed	177.7	180.7	188.3	182.2
All organic layer removed	360.0	347.2	320.3	342.5
Mean	128.9	116.9	125.6	123.8

Analysis of variance for cumulative soil temperatures showed a highly significant treatment effect (table 5). On the basis of the Tukey test, the significant effect of treatment can be attributed to the warming of the soil by mechanical removal of all or half of the forest floor. As with depth to permafrost, the burning treatments did not have a statistically significant effect on soil temperature. Analysis by yearly increments (table 5) indicated no statistically significant year-to-year variation in the cumulative soil-temperature values. This indicates that an expanding active layer is not always accompanied by progressive increases in surface-soil temperature.

Table 5—Analysis of variance by split-block design for cumulative soil temperatures measured at 2 depths within the surface 10 cm of mineral soil for 3 summers (1977-79) after forest-floor treatment (cumulative values for each year represent 15 weekly measurements)

Source	Degrees of freedom	Sums of squares	Mean squares	F
Cumulative temperature with years pooled				
Treatment	5	40,102	128,020	30.49*
Block	2	5,053	2,526	0.60
Error 1	10	41,991	4,199	
Period	2	1,370	685	2.36
Treatment X period	10	3,975	397	1.37
Error 2	24	6,974	291	
Cumulative temperature, increments by (1977-78, 1978-79)				
Increment	1	2,761	2,761	1.98
Treatment X increment	5	2,808	562	0.40
Error 1	12	16,766	1,397	
Treatment	5	5,246	1,049	12.04*
Block	2	558	279	3.20
Error 2	5	872	87	

*Significant at the 1 percent level of probability.

Changes in Vegetation

Trends in plant cover before and for the first 3 years after treatment are shown in table 6. On the control plots (tree layer removed), little change in the vascular plant cover has occurred. The only noticeable changes were a decrease in the cover of *Geocaulon lividum* and a marked increase in *Calamagrostis canadensis* cover. By far the most striking change on the control plots was large-scale mortality of mosses resulting from removal of the shade from overstory trees (table 6). Live moss cover decreased from an average of 92 to 28 percent during the 4 years of the study. Apparently, increased exposure to sunlight results in a drier microhabitat and marginal growing conditions for feathermosses.

The burning treatment killed all above-ground vegetation. In only 3 years after burning, however, the total shrub and herb cover were about what they were before treatment (table 6). The burning treatment caused some marked changes in relative species composition. Plants showing clear increases in cover after treatment include *Calamagrostis canadensis, Equisetum sylvaticum,* and *Rubus chamaemorus.* In contrast, *Geocaulon lividum* and *Vaccinium vitis-idaea* decreased. The recovery of the moss layer has been slow. Three years after burning, moss cover still totaled only about 6 percent (table 6) on the heavily burned plots.

Three years after treatment, plots on which portions of the forest floor were mechanically removed were completely dominated by *Calamagrostis canadensis* and *Equisetum sylvaticum* (table 6). As a result, herb cover on these plots was 2 to 3 times greater than it was before disturbance. Tall shrubs (e.g., *Ledum groenlandicum* and *Vaccinium uliginosum)* were gradually reappearing on these plots, but at a slower pace than on the burned plots. Once again, recovery of moss on these mechanically altered plots was slow.

Almost without exception, revegetation of these severely disturbed plots may be attributed to sprouting of underground plant parts that survived disturbance. Only two species occurred that clearly germinated from seed introduced after disturbance—*Epilobium angustifolium* L. and *Rubus idaeus* L. var. *strigosus*—and they were present in only trace amounts on plots where all of the forest-floor layer was removed. Obviously, the species that responded most positively to disturbance was *Equisetum sylvaticum.* On complete forest-floor removal **plots, *Equisetum* cover 3 years after treatment was almost 7 times greater than** it was before treatment. *Equisetum* has this unique capability because its rhizomes are in the mineral soil rather than in the forest-floor layer.

Table 6—Percent coverage for important plant species on forest-floor treatment plots before and for the first 3 years after treatment, 1977, 1978, 1979 (vaiues are means for three plots, except for heavily burned plots, which are for 6 plots)

Plant species	Undisturbed control				Lightly burned				Heavily burned			
	1976	1977	1978	1979	1976	1977	1978	1979	1976	1977	1978	1979
	- - Percent coverage - -											
UNDERSTORY TREES[1]												
Picea mariana (Mill.) B.S.P. (>6 dm)	2.9	0	0	0	8.9	0.4	0	0	5.6	0	0	0
P. mariana (<6 dm)	4.1	0.5	0.6	0.8	9.6	0.4	0.6	0.4	4.4	0	0	0.1
TALL SHRUBS												
Betula glandulosa Michx.	0.2	0.2	Tr[2]	0.1	1.9	0.3	1.0	1.8	0.2	0.1	0.3	0.6
Ledum decumbens Ait.	0.5	0.3	0.1	Tr	0	0	0	1.6	1.3	0	0.1	1.0
L. groenlandicum Oeder	6.0	3.9	3.7	4.7	7.9	1.8	7.1	7.7	7.4	1.1	4.0	5.9
Rosa acicularis Lindl.	0.6	0.3	0.3	0.5	0	0.2	0.4	0.3	0.5	0.4	0.6	0.8
Salix scouleriana Barratt	0	0	0	0	0	0	0	0	0.7	0.1	0.2	0.4
Vaccinium uliginosum L.	1.4	0.1	0.6	0.6	3.8	1.2	2.3	2.5	3.9	1.3	2.4	4.6
Spiraea beauverdiana Schneid.	1.9	1.3	1.9	3.9	1.7	1.0	1.5	2.3	0	0	0.1	0.3
Total[3]	10.2	6.3	6.6	9.2	14.6	4.1	12.3	14.4	12.4	2.6	7.7	12.0
LOW SHRUBS AND HERBS												
Calamagrostis canadensis (Michx.) Beauv.	1.2	2.4	3.9	6.3	1.1	1.6	14.0	7.6	2.5	2.3	11.1	13.8
Equisetum sylvaticum L.	7.2	5.5	9.2	9.6	3.7	3.1	7.1	8.0	5.3	2.4	7.7	8.9
Geocaulon lividum (Richards) Fern.	6.6	0.7	0.4	0.1	2.3	0	Tr	Tr	2.6	0	Tr	0
Rubus chamaemorus L.	4.3	2.4	2.7	3.5	4.9	5.5	4.0	7.1	3.7	2.8	3.8	6.3
Vaccinium vitis-idaea L.	8.9	6.2	5.1	5.1	9.3	1.6	4.0	4.3	11.4	1.7	1.9	4.1
Total	25.1	14.9	20.4	25.0	19.7	10.9	24.8	23.1	24.4	8.2	24.9	27.7
LICHENS												
Cetraria islandica (L.) Ach.	1.3	1.3	0.9	0.7	0	0	0	0	0.6	0.1	0	0
Cladonia amaurocraea (Florke) Schaer.	0	1.5	0	2.4	0	0	Tr	0	0	0	0	0
C. gracilis (L.) Willd.	1.6	1.2	0.8	0.7	0.9	0	0	0	1.0	0	0	0
C. rangerferina (L.) Web.	3.4	2.9	2.1	2.8	1.0	0	0	Tr	2.0	0	0	0
C. sylvatica (L.) Hoffm.	7.5	5.0	4.1	1.0	2.0	0	Tr	0	3.5	0.1	Tr	0
Nephroma arcticum (L.) Torss.	0.2	0.1	0.1	0.2	0	0	0	0	3.4	0	0	0
Peltigera aphthosa (L.) Willd.	0	0	0	0	0.2	0	0.1	0.1	0	0	0	0
P. canina (L.) Willd.	0.3	0.4	Tr	0	0	0	0	0	0.1	0	Tr	0
Total	13.0	10.9	7.9	7.0	3.6	0	0.1	0.1	10.0	0.2	0.1	0
MOSSES												
Aulacoranium palustre (Hedw.) Schwaegr.	2.6	1.3	0.4	0.3	12.0	0.1	5.6	0	0.7	0.1	0.1	0.4
Hylocomium splendens (Hedw.) Brid.	19.2	16.4	17.6	11.1	15.8	0	0.3	0.6	24.0	0	Tr	0.2
Pleurozium schreberi (Brid.) Mitt.	71.0	70.8	24.3	17.9	53.3	0.2	4.8	4.8	51.4	0	0.4	0.7
Polytrichum juniperinum Hedw.	2.9	1.4	0.6	1.1	6.7	0.4	1.0	2.7	5.2	0.4	1.7	4.8
Sphagnum spp.	2.4	2.1	1.9	1.4	11.3	1.7	5.3	5.7	16.3	0.5	0.8	1.0
Total	91.7	87.4	42.7	28.1	92.7	2.6	11.9	13.0	85.4	0.9	3.4	6.5

Table 6 (continued)—Percent coverage for important plant species on forest-floor treatment plots before and for the first 3 years after treatment, 1977, 1978, 1979 (values are means for three plots, except for heavily burned plots, which are for 6 plots)

Plant species	Half of organic layer removed				All organic layer removed			
	1976	1977	1978	1979	1976	1977	1978	1979
	----------Percent coverage----------							
UNDERSTORY TREES[1]								
Picea mariana (Mill.) B.S.P. (>6 dm)	9.9	0	0	Tr	3.5	0	0	0
P. mariana (<6 dm)	5.8	0	0.1	0.3	2.7	0	0	Tr
Total	15.3	0	0.1	0.3	6.2	0	0	Tr
TALL SHRUBS								
Betula glandulosa Michx.	0.3	0	0	Tr	0.4	0	0	0
Ledum decumbens Ait.	0.7	0	0	0	0.2	0	0.1	0.2
L. groenlandicum Oeder	8.8	0.4	1.1	2.1	4.6	0	0.3	0.7
Rosa acicularis Lindl.	3.2	0.8	1.3	1.8	0.9	0	0.1	0.1
Salix scouleriana Barratt	1.1	0.3	0.4	1.3	0	0	0	0
Vaccinium uliginosum L.	2.0	0.4	0.6	0.9	3.9	0	0.3	0.6
Spiraea beauverdiana Schneid.	0	0	0	0.1	1.1	0	0.3	0.6
Total	15.2	1.6	3.3	6.1	11.1	0	1.4	2.7
LOW SHRUBS AND HERBS								
Calamagrostis canadensis (Michx.) Beauv.	1.3	3.5	9.1	28.5	0.9	1.2	9.3	18.6
Equisetum sylvaticum L.	7.1	7.8	22.8	38.9	5.3	19.6	42.7	36.6
Geocaulon lividum (Richards) Fern.	2.0	0	0	0	3.4	0	0	Tr
Rubus chamaemorus L.	3.3	0.6	1.3	2.0	4.3	0.1	0.5	0.7
Vaccinium vitis-ldaea L.	8.7	0.3	1.1	1.0	10.8	0.1	0.7	1.1
Total	19.8	11.6	33.1	60.4	23.2	20.0	46.3	45.3
LICHENS								
Cetraria islandica (L.) Ach.	0.7	0	0	0	0	0	0	0
Cladonia amaurocraea (Florke) Schaer.	0.1	0	0	0.1	0	0	0	0
C. gracilis (L.) Willd.	1.6	0	0	Tr	0.2	0	0	0
C. rangerferina (L.) Web.	0.8	0	0	0.1	0.3	0	0	0
C. sylvatica (L.) Hoffm.	5.5	0	0	0.1	0.4	0	0	0
Nephroma arcticum (L.) Torss.	0.1	0	0	0	0.2	0	0	0
Peltigera aphthosa (L.) Willd.	0.4	0	0	0	0	0	0	0
P. canina (L.) Willd.	0.7	0	0	Tr	0	0	0	0
Total	8.8	0	0	0.2	1.0	0	0	0
MOSSES								
Aulacomnium palustre (Hedw.) Schwaegr.	1.3	0	0	0.5	2.1	0	0	1.3
Hylocomium splendens (Hedw.) Brid.	25.1	0	Tr	1.8	8.9	0	Tr	2.3
Pleurozium schreberi (Brid.) Mitt.	72.3	0.4	3.1	6.1	66.3	1.4	12.4	4.6
Polytrichum juniperinum Hedw.	2.5	2.0	8.7	14.0	3.5	0.3	3.3	6.1
Sphagnum spp.	3.6	0	0.5	1.3	15.3	0	1.0	0.4
Total	96.7	2.1	13.5	21.5	92.0	1.6	20.2	12.7

[1] Seedlings and saplings originally present in the understory. Overstory trees were removed before forest-floor treatment.

[2] Trace, average cover less than 0.1 percent.

[3] The total coverage for the layer is based on individual estimations. It is generally lower than the arithmetic total because of overlap of plants of different species.

Conclusions

Results of this study agree with observations made in wildfire areas. Disturbance of the forest-floor layer results in retreat of the permafrost table, and the magnitude of this retreat is roughly proportional to the amount of forest floor removed. In this study, plots with half the total depth of forest floor removed showed roughly half the thickness of summer active layer as plots with the forest floor entirely removed. Results of this study also demonstrate the long-term effects of forest-floor removal. Although our depth-to-permafrost measurements were only taken over 4 years, all treatments showed an almost constant drop in permafrost depth at the end of each summer, with no evidence that this rate was decreasing (fig. 2). How long this retreat of permafrost table will persist is open to speculation and obviously depends on the rate at which an insulating layer is reestablished. Because most of the layer is moss remains, the observed slow rate of moss reinvasion after severe disturbance suggests that this period of permafrost retreat may be lengthy.

In this study, the only treatments that had a statistically significant effect on soil temperature and permafrost depth were the two that included mechanical removal of all or a portion of the forest floor. That burning treatments did not have more of an effect on soil temperature is surprising. Despite the fact that burning did not substantially reduce forest-floor thickness, heavy burning thoroughly blackened the surface. Temperature measurements indicated that the effects of decreased albedo apparently did not extend to any depth in the soil. None of the treatments caused large-scale changes in temperatures within the remaining forest floor. Temperature changes were mainly in the mineral soil. Temperature effects of treatments were also observed to be roughly in direct proportion to the amount of forest floor remaining.

Acknowledgments

The author wishes to thank David Grigal, Department of Soil Science, University of Minnesota; Keith Van Cleve, Forest Soils Laboratory, University of Alaska; and Leslie Viereck, Institute of Northern Forestry, Fairbanks, Alaska, for many helpful suggestions. Portions of the work were financed by National Science Foundation grant BMS 75-13998.

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