SPATIAL AND TEMPORAL VARIABILITY IN FOREST SOIL FROST DEVELOPMENT IN WESTERN MONTANA

By

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INTRODUCTION

Conditions at the ground surface and immediately below it are the major determinants of the amounts and rates of water entering the various pathways of the land phase of the hydrologic cycle (Dingman 1975). Whether we are seeking better understanding of mountain hydrologic (or related) phenomena ranging from rain-on-frozen-ground floods and snowmelt runoff to mass wasting and forest "redbelt" development, frost is one of the more important ground conditions to consider. Seasonally frozen ground is apparently highly variable in space and time. A 1984 literature search conducted by the U.S.A.C.E. Cold Regions Research and Engineering Laboratory located 438 references dealing with frost development, depth, duration and distribution. None of the studies had been conducted in the forested areas of the northern Rocky Mountains. While the studies allow establishment of certain generalizations about soil frost development, they don't provide sufficient information to allow quantitative application of results to our region.

The purpose of this study was to begin assembling the information needed to provide quantitative answers to questions concerning soil frost development in the northern Rocky Mountains. The study was designed to compare spatial and temporal characteristics of soil frost development between adjacent clearcut and thinned forest stands replicated at two elevations in western Montana.

DESCRIPTION OF STUDY SITES

Study sites were located on or near the Lubrecht Experimental Forest, approximately 60 kilometers east of Missoula, Montana. The lower site (1250 m) is a 55-year-old, 3.85-ha lodgepole pine stand in a Douglas-fir/dwarf huckleberry (PSME/VACA) habitat type. In 1982, approximately 20% of the stand was clearcut and 20% was thinned to a basal area of about 17 sq. m./ha. Average slope in the stand is less than 10% and the primary aspect is northwest. Climatological data obtained at the Lubrecht Forest Headquarters (3 km west and 30 meters lower than the stand) since 1957 reveal an average annual temperature of 4 degree C, 45.4 cm average annual precipitation, and an average of 241 days per year with a minimum temperature of 0 degrees C or below.

The higher site (1800 m) is about 6 km east from the lower site in an extensive uneven-age lodgepole pine/Douglas-fir stand in a Douglas-fir/blue huckleberry (PSME/VAGL) habitat type. The site was thinned in 1975 and now carries a basal area of about 20 sq. m./ha.. In 1985, half of the study area was clearcut. Average slope in the study area is less than 10% and the primary aspect is northwest.

METHODS

Soil frost presence and development was measured using methylene blue frost tubes, which were constructed, installed and used following the instructions given by McCool and Molnau (1984), with slight performance modifications described by Hepler (1984). Tubes were installed on the study sites using a hydraulic-driven power auger to a depth of at least 1 m unless bedrock was reached sooner. We anticipated greater frost variability in the managed stands than the clearcuts. Consequently, a total of 31 frost tubes were installed in each of the study stands, and 16 frost tubes were installed in each of the study clearcuts. Thus, a total of 47 frost tubes were installed on each site. Any litter or duff disturbed during installation was returned to as natural a condition as possible, and total organic matter depth was recorded at each tube to be used as an independent variable in later analyses.

Spatial variability of frost development was looked at in both "macroscale" and "microscale" by installing the tubes in systematic sampling grids. Microscale grids consisted of a cluster of three tubes spaced 50 cm apart. Three frost tube clusters

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[1/] School of Forestry, University of Montana, Missoula, MT 59812 were placed at random macroscale grid positions in the clearcut and the managed stand at each elevation site. Macroscale grids had individual tubes or clusters at 5 m intervals. The sampling grids were all randomly placed on the study sites, at least a full tree height from any stand/clearcut border, but remember that the sites were chosen for their similar slopes and aspects. In only a couple of instances did grid positions have to be offset because of trees or stumps, and then consistent offset rules were obeyed.

A self-adhesive metric tape was placed on each tube so that snow depth could easily be measured when frost depths were taken. A standard instrument shelter, which housed a recording thermometer to obtain daily average, maximum and minimum temperatures, was placed in both clearcuts.

DATA COLLECTION AND ANALYSES

After two months of well above normal precipitation, data collection began on October 28, 1985. Subsequent sampling frequency varied with stage of frost development. During the onset of freezing (Oct. 28 - Nov. 22), sites were sampled twice per week. During the period when frost depths were stable (Dec. 1 - Feb. 28), sites were visited once per week. During the period of thaw (Mar. 1 - Apr. 30), sites were again sampled twice per week.

One of the major objectives for this study is to develop predictive capabilities using multivariate statistical techniques. This paper, however, presents graphical analyses to demonstrate the spatial and temporal variability in soil frost development observed on our study sites. Figure 1 is a SYMAP computer graphics plot of the spatial distribution of soil frost development in the 1800 m stand on March 15, 1986. Figure 2 is a graphical presentation of mean frost depth on each site from freezing onset through March 15. Figure 3 is a graphical presentation of the relative variability in frost depth, as measured by the coefficient of variation, on each site through the same time period. Figure 4 presents mean snow depth on each site. In figures 2, 3, and 4, "sampling day" refers to the number of days from the start of data collection.

OBSERVATIONS

1. Soil frost was first observed at the high elevation site two weeks earlier than at the lower site, but once development began on the lower site, frost penetration quickly surprassed that on the high site.

2. There is an unquestionably strong relationship between snow accumulation and underlying frost development. The deeper the snow, the shallower the frost penetration. Consequently, the influences of forest canopy on snow accumulation resulted in greater frost depth in both the high and low elevation stands than in the adjacent clearcuts. Most other studies have found that canopy presence reduces frost penetration.

After four weeks, mean snow depths in the 1800 m stand and 1250 m clearcut were nearly the same. Nevertheless, frost penetration continued to increase at low elevation, while the higher elevation had reached the seasonal maximum. There appeared to be almost an 80 day difference in the timing of maximum frost penetration between the two sites.

3. SYMAP graphics show mosaics of frost development which seem similar in both clearcuts and stands. The relative variability in frost depth seems to be influenced by site characteristics other than canopy presence. The coefficients of frost depth variation were nearly identical and constant through the three stages of frost development in the low elevation treatments.

In the high elevation treatments, the relative variabilities in frost depth were not constant through the three stages of development. Relative variability within treatments was nearly the same, however, until the third stage of development. Then relative variability in frost penetration in the 1800 m clearcut began to differ from that in the adjacent stand.

4. At the high elevation site, it appears as though frost will be gone before snow has completely melted. At the low elevation site, snow was gone almost before frost had begun the third stage of development.

ACKNOWLEDGEMENTS

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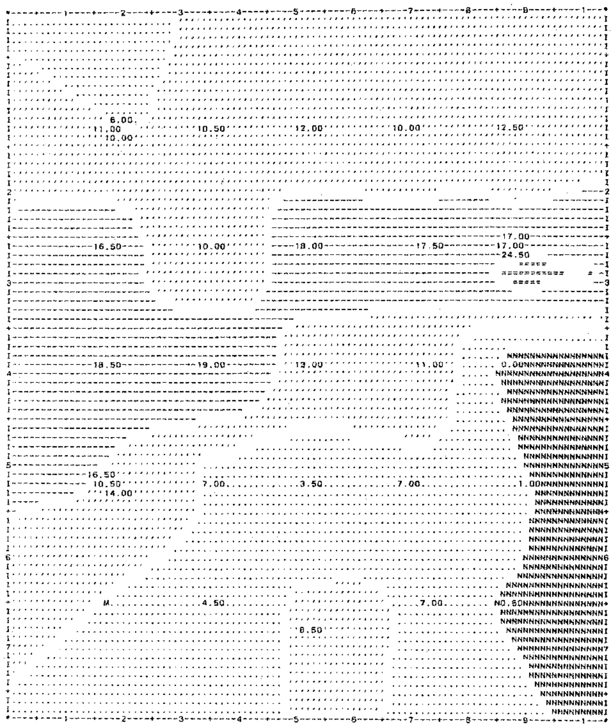
REFERENCES

Dingman, S.L. 1975. Hydrologic effects of frozen ground: literature review and synthesis. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory. Special Report 218. Hanover, New Hampshire. 55 pp.

Hepler, J.A. 1984. Winter measurements of frost penetration at Sleepers River Research Watershed, Winter 1983-1984. USACE CRREL, (unpublished manuscript) 34 pp.

McCool, D.K. and M. Molnau. 1984. Measurements of frost depth. IN: Proc. WSC. 1984: pp 33-42. Sun Valley, ID.



SOIL FROST DEVELOPMENT
1800 METER STAND
MARCH 15, 1986

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DATA VALUE EXTREMES ARE          0.00        24.50

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)
  MINIMUM      BELOW      1.00       7.80      14.60      21.40
  MAXIMUM       1.00      7.80      14.60      21.40      28.20

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL          L          1          2          3          4
            ==============================================================
             NNNNNNNNN  .........  ''''''''''  ---------  =========
             NNNNNNNNN  .........  ''''''''''  ---------  =========
  SYMBOLS    NNNNNNNNN  ....1....  ''''2'''''  ----3----  ====4====
             NNNNNNNNN  .........  ''''''''''  ---------  =========
             NNNNNNNNN  .........  ''''''''''  ---------  =========
            ==============================================================
  FREQ.          2          7          12         8          1
          1   INNNNNI    I..1..I    I''2''I    I--3--I    I==4==I
          2   INNNNNI    I..1..I    I''2''I    I--3--I
          3              I..1..I    I''2''I    I--3--I
          4              I..1..I    I''2''I    I--3--I
          5              I..1..I    I''2''I    I--3--I
          6              I..1..I    I''2''I    I--3--I
          7              I..1..I    I''2''I    I--3--I
          8                         I''2''I    I--3--I
          9                         I''2''I
         10                         I''2''I
         11                         I''2''I
         12                         I''2''I
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Figure 1. SYMAP frost distribution. March 15, 1986.

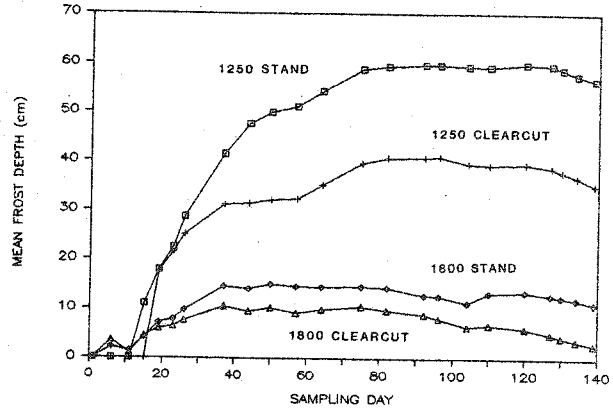

Figure 2. Mean frost depth

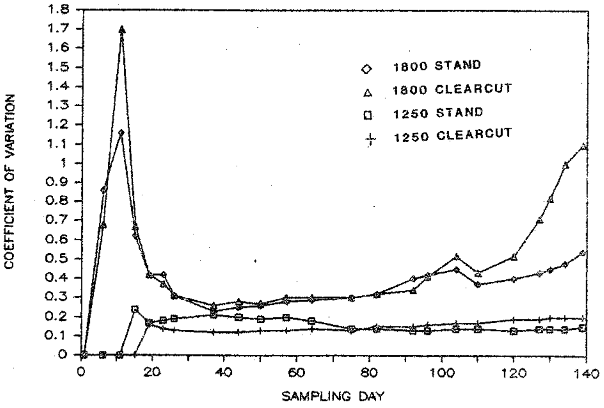

Figure 3. Relative frost variability

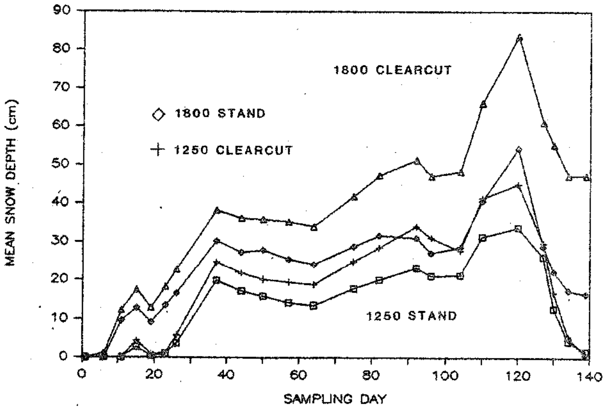

Figure 4. Mean snow depth