SNOW ACCUMULATION AND ABLATION UNDER FIRE-ALTERED LODGEPOLE PINE FOREST CANOPIES

by

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ABSTRACT

Clearcut, burned, and undisturbed lodgepole pine forests in southwestern Montana were studied to determine if forest fire increased snow accumulation and ablation rates on the forest floor. Snow depth, snow density, and snow water equivalence data were collected at each plot throughout the ablation period during the 1992 snow season and the accumulation and ablation periods during the 1993 snow season. Forest variables including percent canopy cover, basal area, and tree height were measured during the 1992 summer season to assess the effects of forest cover on snow variables. The burned forest canopy produced a 9 percent increase in snow water equivalence accumulation as compared to that produced by the mature forest stand. Canopy reduction in the burned forest stand resulted in an ablation rate up to 57 percent greater than that in the mature forest stand. The forest structures of the burn and of the clearcut produced similar snow accumulation and ablation responses.

INTRODUCTION

Variations in vegetation canopy should affect total snow accumulation as well as ablation rates by altering the interception of snowfall, wind, and the radiation budget. The objective of this study was to measure the changes in these snow variables after the vegetation canopy was altered by fire. Potts, et al. (1985) and Farnes and Hartman (1989) produced models, based on hydrologic records and some field data for watershed runoff following forest fire, showing an increase in water yields from burned areas. Additional field data, however, was needed to confirm the precise relation of canopy and snow accumulation and ablation. A strong correlation has previously been found between canopy density and the accumulation and ablation patterns of snow (Kittredge, 1953; Farnes, 1971; Packer, 1971; Gary and Troendle, 1982; Potts, 1984; and Hardy and Hansen-Bristow, 1990). Dense, closed canopy, coniferous forests result in minimal snow accumulation and maximum snow retention during the ablation

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Paper presented Western Snow Conference, 1994.

season. Openings within the forest result in greater snow accumulation and higher ablation rates, except where wind scouring removes snow from the ground. We expected fire-altered coniferous canopies to produce snow accumulation amounts and ablation rates similar to those found in forest openings.

STUDY AREA

The study site is adjacent to Hebgen Lake, within the Madison River watershed, on the Gallatin National Forest in southwestern Montana (Figure 1). The Madison River watershed includes an important source of water for much of the region's municipal, agricultural, and hydroelectric needs.

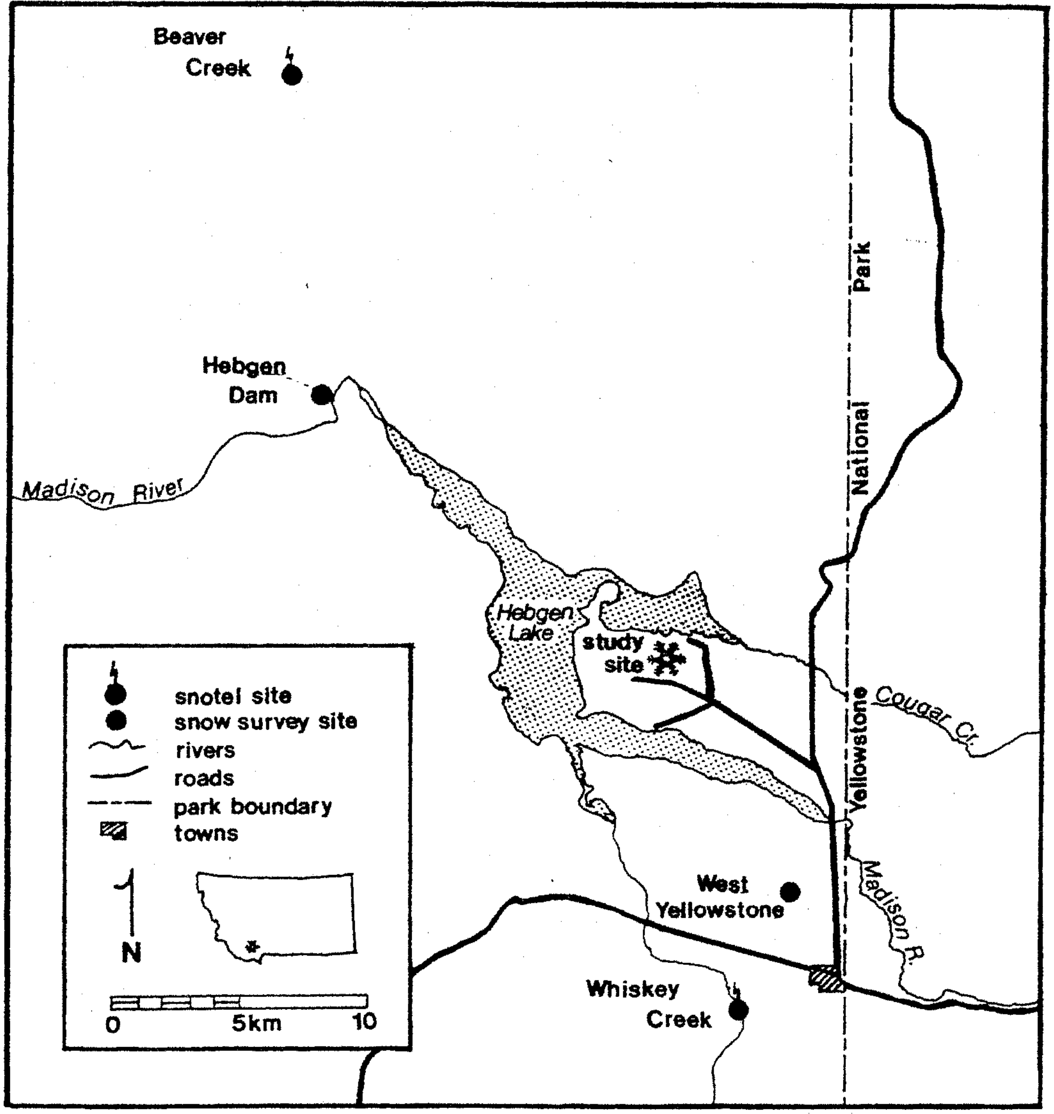

Figure 1. The study site is located within the Madison River watershed, 7 km from Yellowstone National Park in southwestern Montana.

This watershed also provides ecological, recreational, and timber resources. The study area includes clearcut openings, mature lodgepole pine (Pinus contorta var. latifolia) stands, and burned forest stands in a 30 ha area. The terrain is essentially flat (slope of less than 1 degree) and the elevation varies less than 1 m within plots and less than 5 m between plots. Consequently, elevation, aspect, and slope were controlled in this study.

The 25 year (1966-1990) average annual temperature for the Hebgen Dam site is 2.5°C. The average daily maximum temperature is 21°C and the minimum is -27°C (U.S. Soil Conservation Service, 1992). The 25-year average annual precipitation is 75 cm with an average monthly maximum precipitation of 84 mm in January, occurring as snowfall (NOAA, 1992). Peak snow depth on the ground typically occurs in mid-March and averages 116 cm, ranging from 76 cm to 175 cm (U.S. Soil Conservation Service, 1992).

METHODS

Study plots were established in three forest canopy categories: 1) a mature forest stand, 2) a previously mature forest stand which was burned by a crown-fire in 1987, and 3) a clearcut surrounded by an unburned, mature forest (Figure 2). These plots were chosen to measure the effects of a fire-altered canopy on snow water equivalence (SWE) accumulation amounts and ablation rates compared to those in a mature forest and in a clearcut opening.

Sixteen sample points within each plot, spaced at 10 m intervals, were arranged on a square grid. Snow depth and SWE measurements were taken along an arc, 0.5 m from the sample point. The point sampled was moved 15° clockwise from the previous sample point on each subsequent visit to eliminate sampling disturbed snow from the previous sampling visit. Preliminary snowpack data, collected in 1992, were analyzed using a variogram analysis to determine if the sample points were spatially autocorrelated (Isaaks and Srivastava, 1989). During the 1993 sampling season (January through April, 1993), SWE and snow depth data were collected biweekly during the accumulation period and at weekly intervals during the ablation period. Depth and SWE were measured using a U.S. Federal Snow Sampler.

Snow water equivalence, snow depth, and ablation rates for the 1993 accumulation period were individually compared using a Tukey pairwise multiple comparison Anova method (Neter, et al., 1990) to determine the extent of differences between plots. Linear regression analysis (Schaefer and Farber, 1992) was used to examine the relationship between forest canopy coverage and both snow accumulation (SWE and depth) and ablation rates. Weather data (NOAA and SCS) were analyzed to determine the similarities between the 25-year average and the 1992 and 1993 snow year. Additionally, average historical weather and snow conditions were used to estimate the expected date of peak accumulation and the last date of snow on the ground at the study site.

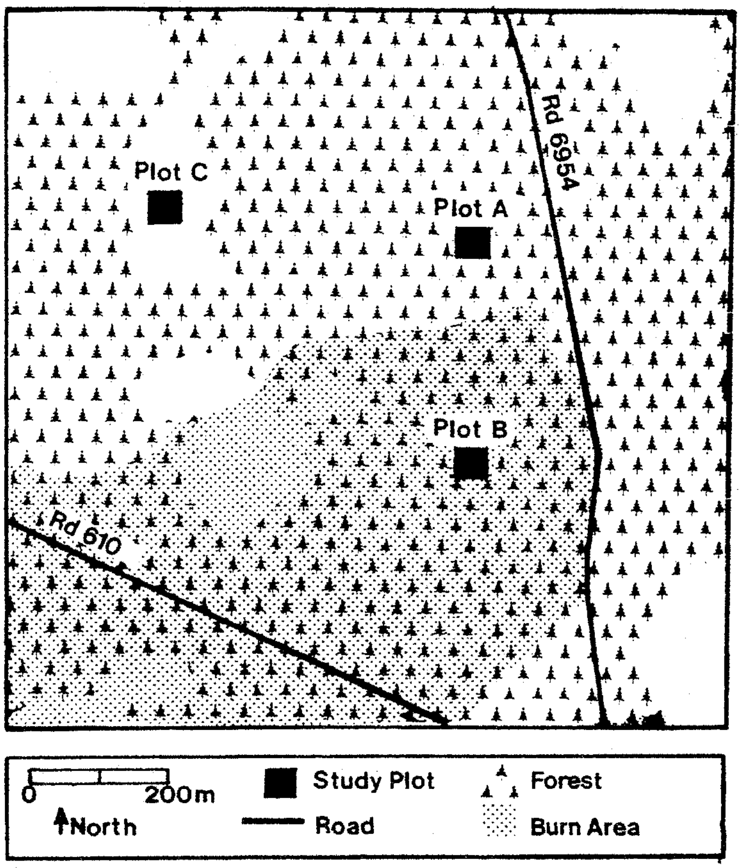

Figure 2. Study plots were located within three forest canopy categories (A = mature forest, B = burned forest, and C = clearcut forest) within the study area.

Forest studies were conducted during the summer of 1992 to measure the effect of forest fire on forest structure and to assess the degree of similarity between plots A (forest) and B (burned) prior to the 1987 fire. Tree measurements included canopy cover, basal area, and height. Canopy was measured using a photocanopyometer and a dot matrix overlay on the photo negatives as outlined by Codd (1959). Basal areas in Plots A (forest) and B (burned) incorporated both standing and fallen snags because numerous standing snags blew down in the burned forest plot during the sampling period. This measurement of basal areas permitted an interpretation of the forest structure prior to burning. Tree heights were determined using a Brunton compass and a measuring tape and averaged for 10 measurements within each plot.

RESULTS AND DISCUSSION

Based on basal area and tree height, we concluded that prior to burning, Plot B (burned) was statistically similar in forest structure to Plot A (mature forest). Fire resulted in a 90% reduction in mean canopy coverage in Plot B (Plot A = 42% cover; Plot B = 4% cover). We concluded that the snow sampling points at 10 m intervals were not spatially correlated. The weather conditions for the sampling period deviated only slightly from the regional norm.

Peak SWE accumulation at the study site occurred on or near March 1 for Plot B (burned) and Plot C (clearcut) and on March 15 for Plot A (forest).

A comparison of plot SWE means at the time of peak accumulation allowed an estimation the effects of canopy reduction on snow accumulation (Table 1). Plot B (burned) and Plot C (clearcut) had equal mean SWE values and were 9 percent greater than the mean for Plot A (mature forest). Results of the Tukey pairwise multiple comparison method used at the 95 percent confidence level to estimate differences in plot means indicated that Plots B and C were not significantly different. Plot A (forest), however, could be distinguished from both Plot B (burned) and Plot C (clearcut).

	Snow Water Equivalence (mean cm)			Snow Depth (mean m)		
Date	Plot A Forest	Plot B Burned	Plot C Clearcut	Plot A Forest	Plot B Burned	Plot C Clearcut
1-5	12.0	15.4	14.5	0.84	0.90	0.88
1-18	16.3	19.2	20.0	0.86	0.91	0.92
2-1	19.0	21.7	20.0	0.85	0.89	0.88
2-18	20.5	21.4	20.8	0.88	0.93	0.91
3-1	26.0	**28.3**	**28.3**	**1.02**	**1.08**	**1.09**
3-15	**26.4**	26.7	28.0	0.96	1.04	1.07

Table 1. Snow water equivalence and snow depth means for all plots during the accumulation period, 1993 (Peak accumulation values appear in **bold.**)

This relationship is again illustrated by regressing percent canopy and SWE for Plots A and B (Figure 3). The correlation coefficient for the relationship between canopy and SWE for Plot A (forest) and Plot B (burned) is -0.659 and linear regression produces an r2 of 0.43. Correlation of canopy and SWE is not as strong (correlation coefficient = -0.600, r2 = 0.36) if the values from the clearcut plot are considered in addition to both burned and unburned forested plots. The relationship between canopy and SWE is strongest (r2 = 0.47) in Plot A (forest) where canopy cover variation is greatest, as illustrated in Figure 3. In Plot B (burned), where canopy variation is small and in Plot C (clearcut) where canopy is absent, variation in SWE must be attributed to other factors. In both Plots B and C there was considerable ground litter, including fallen snags and stumps, which may be responsible for the variation in snow depths (i.e., snow cavities) and corresponding SWE. Ground litter was minimal in Plot A (forest) and apparently did not affect sample points.

A comparison of snow depth plot means at the time of peak accumulation produced similar results as the SWE comparisons (Table 1). Plots B (burned) and Plot C (clearcut) produced 6 and 7 percent greater mean snow depths than Plot A (forest) (significant at the p = .05 level). The relationship between snow depth and canopy cover was also consistent with the conclusions based on SWE measurements.

Ablation rates in all plots prior to April 19th, 1993 showed no significant differences between plots (Figure 4). Differences between plots after April 19th however, were significant. A linear regression analysis of the relationship between canopy coverage and ablation rates showed a poor correlation for the entire ablation season (correlation coefficient = -0.221, r2 = 0.05). Similar analyses of ablation rates calculated during the latter half of the ablation season (April 19 to May 2) showed a stronger relationship (correlation coefficient = -0.609, r2 = 0.37), suggesting that canopy cover was more important in influencing ablation rates when an increase in photoperiod and a higher sun angle occurs. The most significant divergence from parallel ablation rates between sites was initiated on April 19 (day 109). Plot B (burned) showed no loss of SWE from the previous date and Plot C (clearcut) showed an increase of SWE while Plot A (forest) continued to lose snow.

SNOTEL data from the Whiskey Creek and Beaver Creek SCS weather stations showed an increase in SWE and near 0° temperatures during the week prior to April 19 (day 109) (U.S. Soil Conservation Service, 1993) which might explain the minimal net change in Plot B (burned) and Plot C (clearcut). Ablation in these plots may have been balanced by precipitation gains resulting in no net loss of SWE. The continued decrease in SWE in Plot A (forest) may have resulted from a combination of snow interception by the forest canopy and potentially warmer temperatures in the forested plot. Warmer temperatures may occur as a result of longwave re-radiation of radiation absorbed by the trees (LaFluer and Adams, 1985).

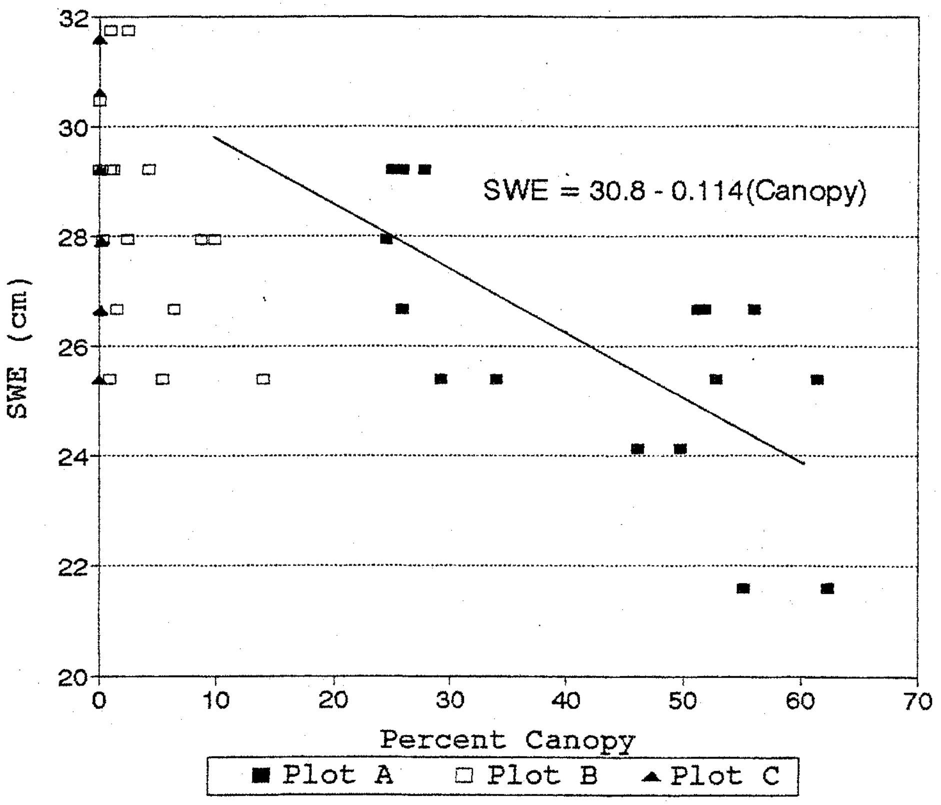

Figure 3. Scatter plot showing the relationship between percent canopy cover and SWE at the time of peak accumulation (March 1, 1993). The regression line and equation were calculated using all points in Plot A (forest), Plot B (burned) and Plot C (clearcut).

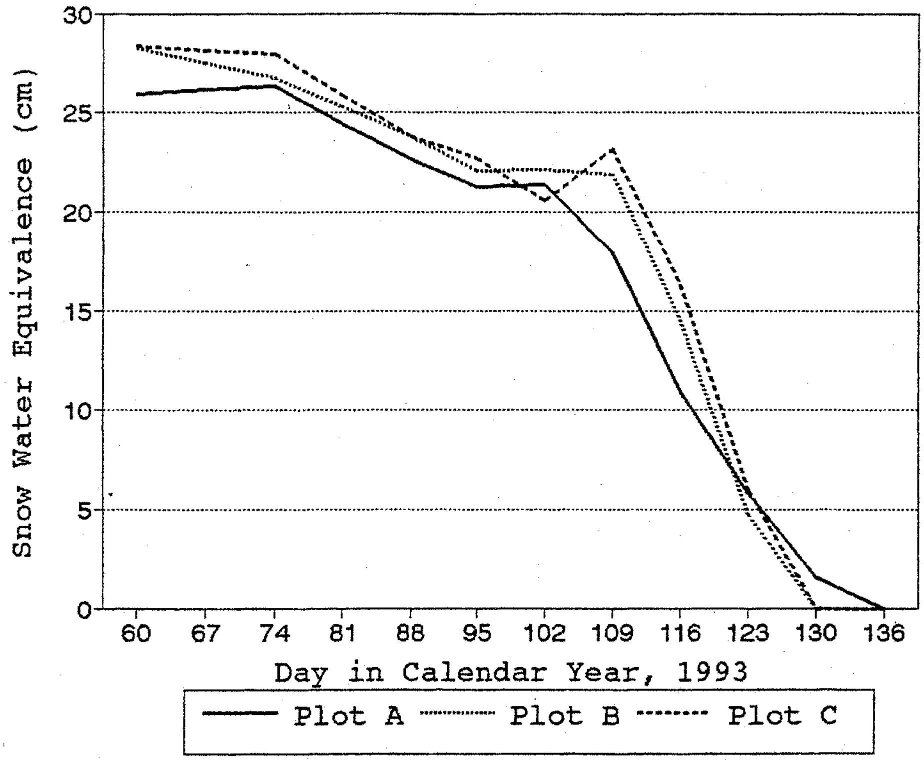

Figure 4. Snow water equivalence means for plots A (mature forest), B (burned forest), and C (clearcut) during the 1993 ablation season.

Snow depth was also used to evaluate ablation patterns and variation between plots. Changes in snow depth closely paralleled changes in SWE and supported previous conclusions based on SWE ablation analyses. Ablation rate variation among plots was not apparent before mid-April, at which time there was a significant change in the ablation rates in Plot B (burned) and Plot C (clearcut).

CONCLUSIONS

This study was unique in that it controlled terrain variables of elevation, slope and aspect, focusing entirely on the influence of forest canopy on snow accumulation and ablation. The study occurred during weather conditions that deviated only slightly from the regional norm. This allows for future application of the results to the majority of years which fall within the range of normal conditions.

Results of this study indicate that a fire-altered canopy (reduced by 90 percent) can affect both the accumulation patterns and ablation rates of snow. In this study, the snow water equivalent accumulation in both the burned and clearcut plots exceeded that in the mature forest plot by 9 percent, indicating that burned forest canopies simulate the effects of clearcut openings on snow accumulation. The 9 percent difference between the forested plot and both the burned and clearcut plots may not represent a substantial gain in accumulated snow, but this increase was for a forest with a canopy cover of only 42%. A larger canopy cover should intercept more snowfall and therefore produce greater differences between forested and burned or clearcut areas. Regression analysis of the effect of canopy on snow accumulation explained only 43 percent of the variation in snow accumulation, when comparing the burned and unburned plots, suggesting that other variables, such as ground cover and microclimate variability, are also important in determining snow accumulation. Snow ablation rates also differed between plots, further supporting the conclusion that burning of the forest canopy simulates the effects of clearcutting on snow processes. These differences were only significant, however, during the latter half of the ablation period. Both the burned and clearcut plot ablation rates were 57 percent greater than that of the unburned forest. The deviation between ablation rates early in the ablation season as compared to late in the ablation season, as well as those between other related studies, suggests that snow ablation rates are subject to additional variables such as weather conditions, photoperiod and solar angle, ground cover, and microclimate.

Throughout arid western North America snow is of critical importance to the water supply of both mountainous and non-mountainous environments. Melted snow represents more than 50 percent of water resources available in these areas (Haupt, 1979). The fires of 1988 burned more than one third of the forests in Yellowstone National Park, having a significant effect on the forest structure of the region (U.S. Department of the Interior, 1992). Future studies of the effects of forest fire on snow accumulation and ablation should be conducted in a variety of geographic locations, in forests exhibiting various degrees of recovery from fire, and over a long period of time. Such studies should ideally be corroborated with hydrograph data from burned and unburned watersheds in order to determine the net effects of canopy alterations on spring runoff. Large scale burning of forested watersheds may produce greater snow accumulation, thereby enhancing the available water supply. These gains may be offset, however, by the increased ablation rates and the resultant decreased water storage associated with forest canopy reduction. Increased ablation rates may also affect the length of the growing season and soil moisture available for plants. This study should add to our understanding of the potential effects of regional climate change on forest structure and thus on hydrologic systems.

ACKNOWLEDGEMENTS

This study was partially funded by the Jim Edie Scholarship Fund, the Department of Earth Sciences, the Yellowstone Center for Mountain Environments at Montana State University, the National Science Foundation (Grant #DMS-9115754), and Sigmati. Special thanks go to Dr. Stephan Custer, Dr. Andrew Marcus, and Phil Farnes for their advice and to the numerous field assistants who helped collect the data.

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