Snow accumulation and ablation under fire-altered lodgepole pine forest canopies
by Peter Brooks Skidmore

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University
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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 heights were measured during the 1992 summer season to assess the effects of forest cover on snow variables. Results suggest that burned forest canopy reduction results in a 9 percent increase in snow water equivalence accumulations as compared to mature forest stands; forest canopy reduction in burned forest stands produces ablation rates which are as much as 57 percent greater than in mature forest stands; and forest fire produces a forest structure which approximates the effects of clearcut openings on snow accumulation and ablation.

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APPROVAL

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Peter Brooks Skidmore

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date March 19, 1994

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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 heights were measured during the 1992 summer season to assess the effects of forest cover on snow variables. Results suggest that burned forest canopy reduction results in a 9 percent increase in snow water equivalence accumulations as compared to mature forest stands; forest canopy reduction in burned forest stands produces ablation rates which are as much as 57 percent greater than in mature forest stands; and forest fire produces a forest structure which approximates the effects of clearcut openings on snow accumulation and ablation.

INTRODUCTION

Snowpack accumulation and ablation rates in mountainous environments are influenced by many variables including annual weather, elevation, topography, and vegetative type and density. Variation in vegetation type and density affect accumulation and ablation rates by creating differences in interception of snowfall, alteration of wind velocities, and differences in the amount of scattering, absorption, and emission of radiation (Bohren, 1972). The changes that fire induces in vegetation should also effect accumulation and ablation of snow as compared to pre-fire conditions. The objective of this study was to measure those precise changes. Potts, Peterson, and Zuuring (1985) and Farnes and Hartman (1989) produced models for watershed runoff following forest fire which showed increased water yields from burned areas. These models are, however, largely theoretical and based on hydrologic records and minimal field data. Fire-altered canopies are a common forest type in the Rocky Mountain region and yet few field studies have addressed the effects of fire-altered canopies on snow accumulation and ablation.

There is a strong correlation 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 represent one extreme with minimal snow accumulation and maximum snow retention during the ablation season. Openings within the forest represent the other extreme with greater snow accumulation and high ablation rates except where wind scouring removes snow from the ground. Leafless deciduous canopies represent intermediate canopy coverage and subsequently accumulate more snow but exhibit greater ablation rates than coniferous canopies (McKay, 1968; Doty and Johnson, 1969; and Federer and Leonard, 1971). I expected fire-altered canopies, which consist of leafless branches and blackened trunks, to produce snow accumulation and ablation rates similar to deciduous canopies or clearcut openings.

Objective of Study

The objective of this research was to determine the effect of a fire-altered forest on snow accumulation and ablation. In order to accomplish this, I addressed the following hypotheses: 1. There is a measurable increase in the snow water equivalence (SWE) within a fire-altered coniferous forest canopy at peak accumulation as compared to an unburned coniferous canopy; and 2. Within fire-altered coniferous forest canopies, ablation rates are increased relative to unburned coniferous forest canopies. These hypotheses were tested by measuring the spatial and temporal variations in snow depth, density, SWE, and ablation rates in three areas: a burned lodgepole pine forest (*Pinus contorta* var. *latifolia*), an undisturbed lodgepole pine forest, and a clearcut opening.

Previous Studies

Most previous studies of snow distribution in forest environments have addressed those factors which influence the volume and timing of runoff (Hibbert, 1967; Troendle and King, 1985; and Gottfried, 1991). These previous studies have focused on variations in accumulation and ablation patterns among clearcut areas, undisturbed coniferous forests, and undisturbed deciduous forests. The studies have shown that snow accumulates more readily and ablates more rapidly in clearcuts than in undisturbed forests. Deciduous forests accumulate and ablate at intermediate rates when compared to clearcuts and undisturbed coniferous forests.

Greater snow accumulation in clearcuts as compared to surrounding forests has been well documented (Wilm and Dunford, 1948; Gary, 1980; Troendle and King, 1985; Golding and Swanson, 1986; Berris and Harr, 1987). The increase has been attributed to a decrease in the amount of snow intercepted by the forest canopy and subsequently lost by sublimation (Satterlund and Haupt, 1970; Kolesov, 1985; and Schmidt and Troendle, 1992), an increase in snow gained from wind redistribution processes (Gary, 1975; Troendle and Meiman, 1984; and Golding and Swanson, 1986), or a combination of interception and redistribution phenomena.

Studies which have focused on snow accumulation in clearings and adjacent forests have shown large variations in their results (Meiman, 1970). This variability prompted many subsequent studies which focused on the effect of the size and shape of clearings on snow capture. Snow transported by wind during storms is more likely to fall in clearings because of the eddy effect associated with the clearing (Gary, 1975). Circular and strip cut clearings have been examined to determine the optimal shape and size for maximizing SWE accumulation to augment water supply. The diameter or width of clearcut openings is generally expressed using the average tree height of the adjacent forest (H) as units of distance. Kattelman (1982) found that openings of 1H to 2H (i.e., between one and two tree heights in width) produce the greatest snow water equivalent (SWE). Accumulation was found to be further enhanced by orienting strip cuts perpendicular to the prevailing wind direction (McGurk and Berg, 1987). Larger strip cut clearings exhibited gains on the windward side of the clearing but losses due to wind scour on the leeward margins (Troendle and Meiman, 1984).

Greater snow accumulation in clearcuts has also been attributed to a decrease in the amount of snow lost by melt or sublimation from snow intercepted by the forest canopy. Tree crowns intercept and retain falling snow until it slides from the branches, melts and drips off, or is sublimated to the atmosphere. Golding and Swanson (1986) compared two adjacent sub-basins and found decreased interception to be the dominant factor resulting in increased SWE in one sub-basin and redistribution in the other. Haupt (1979) studied the effects of clearcutting on snow water storage in northern Idaho and found a 56 percent increase in peak accumulation, most of which resulted from a decrease in interception losses. Between 5 and 60 percent of snow intercepted by conifer crowns may be sublimated rather than accumulated below the canopy at forest sites (Satterlund and Haupt, 1970; Kolesov, 1985; Wheeler, 1987; and Schmidt and Troendle, 1992). Troendle and King (1985) found that two thirds of the snow water equivalent gains in clearcuts is due to decreases in sublimation from intercepted snow and one third is due to increased deposition generated by clearcuts.

Other studies have compared the effects of varying forest densities on accumulation to determine the importance of interception losses. Potts (1984) concluded that snow accumulation is inversely proportional to canopy density as determined by forest thinning practices. Gary and Troendle (1982), Troendle and Meiman (1984), and Hardy and Hansen-Bristow (1990) also found an inverse relationship between canopy and snow accumulation and argued that, in their studies, interception is the primary factor controlling variability of snow accumulation.

Canopy density can be altered by the seasonal loss of leaves in deciduous forests or by forest fire which removes needles and twigs in coniferous forests. Deciduous forest canopies, without leaves during the snow season, may simulate the effects of fire on SWE accumulation in a coniferous forest. Jeffrey (1968) noted that snow accumulation is greater and more uniform under leafless deciduous canopies than coniferous canopies. McKay (1968) concluded that snow accumulation in deciduous forests is greater than in coniferous forests, but less than in openings within the forest. Small openings within a leafless canopy were found to accumulate as much as 30 percent more snow than accumulated under a similar forest with leaves (Swanson and Stevenson, 1971).

The rate at which snow ablates is also significantly affected by forest canopy. Forest canopy reduces the net shortwave radiation incident upon the snowpack and increases the amount of reradiated longwave radiation (LaFluer and Adams, 1985). Trees also influence advection through changes in wind speed and turbulent flux which, in turn, affect the energy balance (Bernier, 1989). The radiation balance at the snow surface has been documented to be the most important factor determining heat exchange at the snow surface (Obled and Harder, 1978; Male and Granger, 1981) and explains 40 to 90 percent of variation in daytime snowmelt (Zuzel and Cox, 1975 and Price, 1988). These factors contribute to an inverse relationship between snow ablation rates and canopy cover for both coniferous and leafless deciduous forests (Anderson, 1956; Hendrie and Price, 1978; Bernier, 1989).

Variations in snow ablation have been further explained using vapor pressure and wind velocity. Higher wind velocities generate accelerated turbulent energy exchange and increased evaporative rates (Kaser, 1982). Bernier (1989) found that evaporative rates in openings were 3 times greater than those in the forest. Male and Granger (1981) further determined that evaporative rates in a leafless deciduous forest and a coniferous forest were only 70 and 47 percent, respectively, of the rates in an open site. Wind speed is reduced by 50 to 67 percent by leafless canopies and therefore significantly reduces the turbulent energy exchange which, in turn, diminishes snow ablation and evaporation (Federer and Leonard, 1971).

Studies conducted in clearcuts have consistently shown increased ablation rates relative to forested areas. Haupt (1979) and Hardy and Hansen-Bristow (1990) reported maximum ablation rates in clearcut areas, moderate rates in intermediate growth forests, and the lowest ablation rates in mature forests. Gary and Troendle (1982) found that ablation rates in low density, thinned forests and in small clearcut patches were increased by 20 to 60 percent. Deciduous forest canopies exhibit lower ablation rates than forest openings but greater rates than coniferous forests (Federer and Leonard, 1971). The difference in ablation rates between leafless canopies and open areas has been attributed to radiation shading and reduced wind velocity. Leafless canopies reduce solar radiation incident upon the snowpack by as much as 50 percent (Jeffrey, 1968) thereby altering the energy balance at the snow surface.

Study Area and Plots

The study site is adjacent to Hebgen Lake on the Gallatin National Forest in southwestern Montana, 7 km west of Yellowstone National Park (Figure 1). The Hebgen Lake watershed includes an important source of water for much of the region's municipal, agricultural, and hydroelectric needs. This watershed also provides ecological, recreational, and timber resources. Land ownership in the watershed is shared by the U.S. Forest Service, the National Park Service, and private landowners and, therefore, incorporates a variety of management considerations.

The study area is located within 30 km of two USDA Soil Conservation Service (SCS) SNOTEL and two National Oceanic and Atmospheric Administration (NOAA) climatological data collection sites (Figure 1). All stations record daily maximum and minimum temperatures, total precipitation, total snowfall, and snow depth on the ground. The SCS SNOTEL sites (Whiskey Creek (2070 m) and Beaver Creek (2390 m)) also record daily snow water equivalence. The elevations of the Hebgen Dam (2000 m) and West Yellowstone (2040 m) NOAA sites are approximately the same as the study area (2003 m). The study area includes clearcut openings, mature lodgepole pine 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

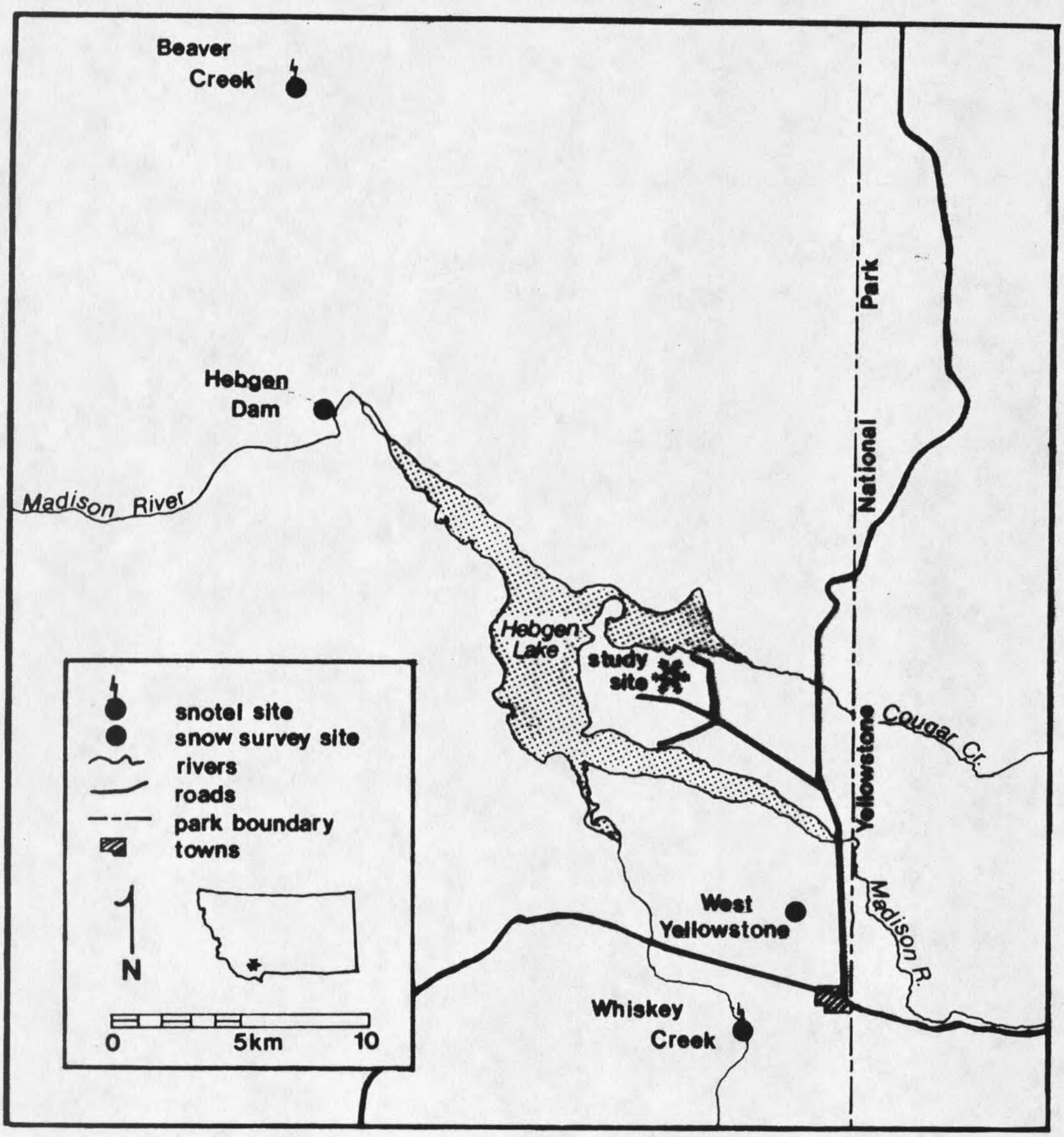

Figure 1. The study site, adjacent to Hebgen Lake, is located within the Madison River watershed, 7 km from Yellowstone National Park in Southwestern Montana. (After USGS, 1972) Blank areas represent clearcuts.

between plots. Consequently, elevation, aspect, and slope are not important as variables affecting the snowpack. The soil consists of highly porous obsidian-sand alluvial outwash (Pfister, et al., 1977). Due to high porosity and permeability, snowmelt and rain typically percolate into the sand rather than running off.

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

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 (Romey, 1992), and 3) a clearcut surrounded by unburned, mature forest (Figure 2). These plots were chosen to measure the effects of fire-altered canopy on SWE accumulation and ablation rates compared to those in unburned and clearcut openings. The clearcut plot was included for comparison of results to similar studies which examined the difference between clearcut openings and undisturbed forests.

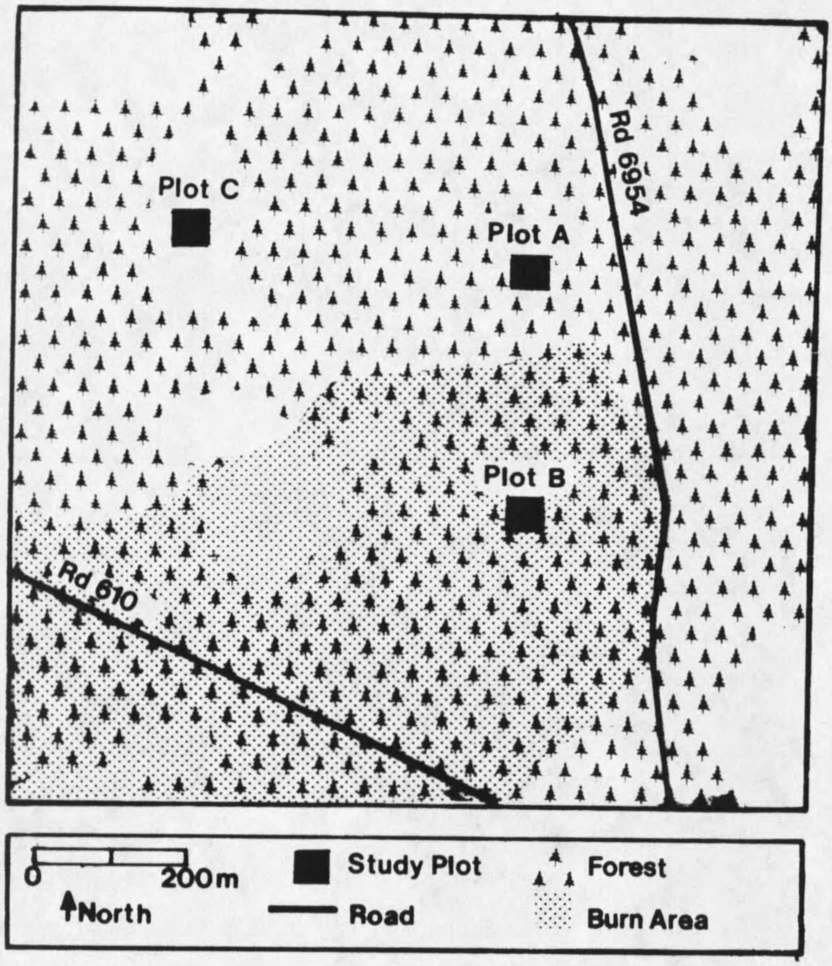

Figure 2. The location of study plots (A, B, and C) within the study area. (Sketch drawn from U.S. Forest Service air photograph, 1990).

Plot A (forested) is located within a mature lodgepole pine stand. The stand is representative of the Pinus contorta/Purshia tridentata (PICO/PUTR) habitat type (Pfister, et al., 1977) which encompasses a 260 km2 area surrounding the town of West Yellowstone. Ground cover consists of widely scattered small shrubs, primarily bitterbrush (Purshia tridentata), and barren soil.

Plot B (burned) is 300 m south of Plot A (forested) in the burned portion of the study area. The plot is centered in a burned forest 180 m from the nearest clearcut or unburned forest. Trees in Plot B were killed by fire 5 years prior to the study and consist of charred stems and leafless branches. Ground cover consists of burned stumps, prostrate and leaning trunks, and scattered annual flowering plants.

Plot C (clearcut) is 350 m west of Plot A (forested) and is centered in an irregular shaped 4 ha clearcut opening, 2H from the forest margin. Trees were removed from this site in 1982 (Romey, pers. comm., 1992). Ground cover consists of numerous stumps, prostrate trunks, and a few small trees less than 2m in height.

METHODS

Study Plot Design

A grid system was established at each of the three study plots. Grid lines were oriented north-south and east-west. The grid orientation allowed analysis of the effects of prevailing wind on snow accumulation across the plots. Plots A (forest) and B (burned) were located on a north-south line 120 m and 180 m, respectively, from the boundary between the unburned and burned tree stands (Figure 2). These locations were selected to maximize the degree of similarity in pre-fire forest structure between the forested plots. Plot C was centered in a clearcut with a 2H (30 to 45 m) buffer zone separating it from the adjacent forest to minimize forest margin effects (Gary, 1980) which could cause non-representative snow accumulation as a result of wind redistribution from the adjacent forest.

Sixteen sample points within each plot were spaced at 10 m intervals and arranged on a square grid (Figure 3). The number, spacing, and arrangement of sample points in each plot was based on similar studies by Steppuhn and Dyck (1974), Dickison and Daugharty (1978), Rawls, et al. (1980), Toews and Gluns (1986), and Dozier and Melack (1987).