EFFECTS OF SMALL LOGGED OPENINGS ON SNOW ABLATION DURING A HIGH SNOW YEAR

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ABSTRACT

The effects of small logged openings on snow ablation rate were studied from 1994 through 1998 at a sub-alpine silvicultural systems research site in the Quesnel Highland of B.C. Six snow plots were in north-facing treatment units from which 21 to 34 percent of the forest had been previously harvested and one was installed in an unharvested control. One purpose was to determine the potential effects of group selection on peak streamflows in the event that this silvicultural system is applied over large areas. Average ablation rates in openings increased from 1.6 to 2.2 $cm*day^{-1}$ as opening diameters increased from 1 to 5 tree heights (1H to 5H). There was no significant effect of small openings on ablation rates in the adjacent trees. The net effect of harvesting 30 percent of the area in the form of 3H and 5H openings was that ablation rates increased by 5 and 13 percent respectively in a year with above-average snowmelt-generated peak streamflows.

INTRODUCTION

In the Interior of British Columbia, the ESSF biogeoclimatic zone is the highest elevation productive forest land for timber and is also one of the wettest environments. Most precipitation in this zone falls as snow which melts in about one month during the spring. Therefore, snowmelt from this zone is a major contributor to the annual peak flows of local streams.

The effect of small openings on snow has been studied by several researchers. Golding and Swanson (1978) found that the size of small openings affected both snow accumulation and ablation rate on flat ground in Alberta. They found that the lowest ablation rates occurred in 3/4H to 1H diameter openings and that ablation rates were 31 to 38 percent higher in the uncut forest in 3H to 6H diameter openings. They explained this as the combined effect of decreasing net longwave radiation and increasing shortwave radiation as the forest canopy is removed. This is consistent with Adams, et al. (1998) who found that most energy for snowmelt in a clearcut came from shortwave radiation while that in a mature forest came from longwave radiation.

Most previous studies of the effects of harvesting on snow have reported differences between openings and forest because this is appropriate for traditional-sized clearcuts. Winkler (2001) summarized 8 studies of this type, done between 1912 and 1994. However, those results are not easily applied to small openings or thinning because as opening dimensions decrease from many tree heights to several tree heights or less, categorizing the landscape simply as openings and forest becomes inadequate. It raises the question of how best to explain snow ablation rate as a function of harvesting treatments where spatial variability is high. This paper uses ablation rates during an above-average snow year to try to address this question.

DESCRIPTION OF THE AREA

Field work for snow research was done 10 km east of Likely, B.C. in the ESSFwc3 biogeoclimatic zone (Steen and Coupé, 1997) at an elevation of 1500 to 1600 metres. Old forests at this site consist mostly of subalpine fir (Abies lasiocarpa) and Englemann spruce (Picea englemannii) with white-flowered rhododendron (Rhododendron albiflorum) being the dominant understory species. The stand has a wide distribution of stem ages and heights, up to about 290 years and 25 metres. Slopes range from 15 to 45 percent and aspects range from NW to NNE. The site is characterized by cold, wet winters and cool, wet summers. Virtually all snow that reaches the forest floor in the winter remains until spring and most melt occurs during May. Precipitation is low in May and tends to occur as snow.

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Stathers et al. (2001) reported mean summer rainfall to be 24 cm at this site from 1994 to 1998. During the same period, the mean water equivalent of snowfall above and below the undisturbed forest canopy was estimated to be 58 and 41 cm respectively (Teti, 2003). This indicates that 71 percent of precipitation was in the form of snow and that average snow interception loss was 29 percent in the undisturbed forest.

Group selection logging was done in the summer of 1992 and winter/spring 1993 as part of an interdisciplinary study of mountain caribou habitat, small mammals, birds, and silviculture involving a team of Ministry of Forests researchers. Within each treatment unit, logging consisted of regularly repeated patterns of circular openings making up 30 percent of the area. Opening size was varied across three treatment types while maintaining approximately 30 percent of area harvested. Treatments are referred to as small, medium, and large openings. A map of the site is shown in Figure 1 and opening dimensions are shown in Figure 2.

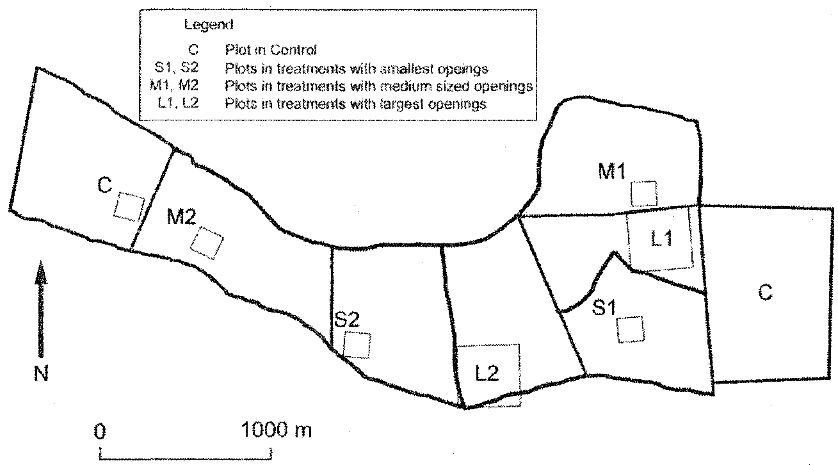

Figure 1. Map showing treatment unit boundaries and snow plot locations. 30 percent of each treatment unit was harvested.

FIELD METHODS

Two snow survey plots were installed in each of the three treatment types after logging and one was installed in an unlogged control. Figure 2 shows the layout of snow stakes within plots. Plots were sized so that that they would

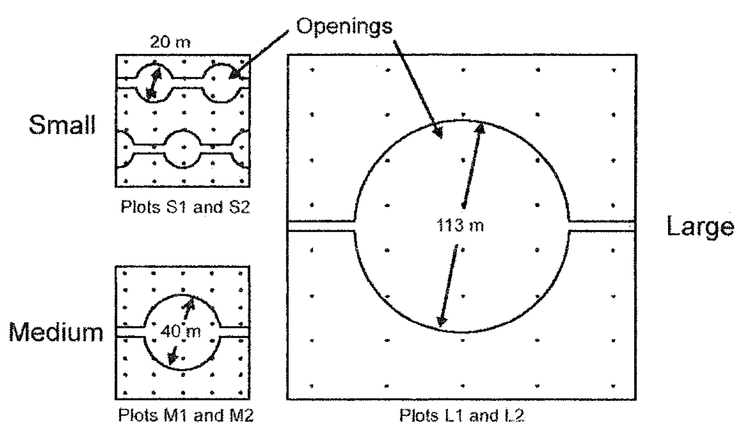

Figure 2. Plot dimensions, opening dimensions, and layout of stakes within plots

have the same 30 percent ratio of logged area as the overall treatment. Each plot consisted of 40 sampling points arranged in a grid of 5 columns and 8 rows. Points were marked with bamboo poles attached to 5/8 inch diameter rebar. It was not always possible to install stakes at the exact location specified by the grid due to the presence of trees and boulders. We were usually able to install them within a half-metre of the planned location and we compensated for this bias at the time of snow sampling by the method described below.

Snow water equivalents (SWE) and depths were measured with a Federal Snow Sampler 6 or 7 times each year at intervals of 9 to 12 days from 1994 through 1998. Snow sampling in a forest is prone to errors due to a combination of high spatial variability of snow and the difficulty of making spatially unbiased observations. Snow measurements were therefore made not at the stakes themselves but 70 cm from the stakes in a random direction each time. This sampling method reduced the bias associated with stake placement. For example, it was possible for the sampling location to fall inside the bole of a tree, on a log, or on a boulder. If the sampling location fell inside the bole of a tree, zero snow depth was recorded. This procedure also reduced the problem of snow disturbance between consecutive surveys because snow cores were taken at different places along the circumference of a circle instead of at the same point. The surveyor always approached the measurement location from outside the sampling circle to avoid disturbing the snow.

We mapped snow stake locations by differentially-corrected GPS and drew opening boundaries using the midpoint between stumps and the nearest standing trees. We estimated basal area by counting stems with a 6M prism at each point. Standing dead trees were included because many of them still retained small branches. For canopy density measurements, we took fisheye photos between 2000 and 2003 with a Nikon Coolpix 990 or Nikon Coolpix 4500 digital camera with fisheye adapter (FC-E8) mounted on a Manfrotto tripod with grip-action ball head having a built-in level. Exposures were made with center-weighted metering using a correction of +0.7 Exposure Value and the sharpness option off. Azimuth was indicated on photos in the field by holding a yellow field book north of the camera. We were not able to restrict our photography to overcast days so when the camera lens was in the sun, we shaded it with a paddle on the end of a pole and retouched the images before analysis.

We calibrated both cameras on their tripods by photographing the walls and ceiling of a room in which we had marked the vertices of polygons representing altitude-azimuth coordinates and sun positions. We defined 65 polygons in equal increments of altitude and azimuth and 4 polygons representing sun positions in hourly increments from 10 AM to 2 PM local solar time during May. We measured canopy density with Adobe Photoshop and Scion Image software. Scion Image is a public domain program which allows customized regions of interest to be defined and has a macro programming language for automating image analysis. It allows a color image to be separated into red, green, and blue monochrome images. We did our analysis in the blue color channel, which we found provided good discrimination between canopy and sky pixels. Four parameters were calculated at each snow measurement point. We calculated canopy cover as canopy density within 10 degrees of the zenith. Shade was the portion of sky occupied by canopy along sun paths in May from 10AM to 2PM. Canopy view factor was canopy density in the full hemisphere in 10 degree altitude increments weighted by the cosine of the zenith angle. Like shade and canopy cover, this parameter also has a value from zero to 1 and is a factor in the transfer of longwave radiation (Steyn, 1980).

Air temperatures were recorded in Stevenson screens in the centers of a medium opening, a large opening, and the unlogged forest.

RESULTS

Figure 3 is an overview of the five years of snow surveys showing average SWE's for each year. Each point is average SWE at all 280 points in the study area (7 plots of 40 points each). The highest and lowest snow years (1997 and 1998) had average peak SWE's of 59 and 35 cm respectively. Maximum observed SWE's occurred between late-March and mid-April. The relatively small changes in snow storage during the first surveys each year suggest that our maximum observed SWE's were close to the actual maximum SWE's. Most ablation occurred during the month of May and average SWE is inferred to have gone to zero by about June 10th each year.

Annual maximum ablation rates between consecutive surveys ranged from 1.04 cm*day^{-1} in 1994 to 2.05 cm*day^{-1} in 1998. In this paper, we focus on ablation rates in 1997 because that was the year with the highest peak SWE and the highest peak discharge in local streams. Plot average SWE decreased by 51.9 cm between May 6th

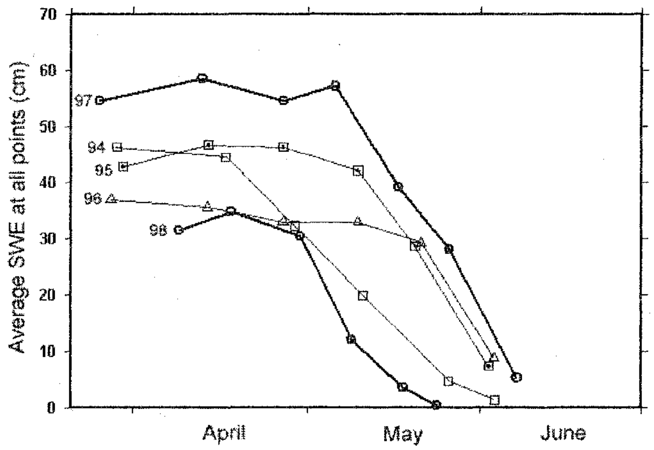

Figure 3. Average water equivalents at the time of each survey in each of the five years. Each point represents the average at all 280 points.

and June 7th, 1997 corresponding with an average ablation rate of 1.6 cm*day^{-1}. Also in 1997, the Horsefly River (785 sq. km. watershed draining the west side of the Cariboo Mountains 40 km southeast of the study area) had its largest peak flow of the study period. Its peak discharge was 151 m^{3}sec^{-1}, corresponding with 1.7 cm*day^{-1} of runoff, and occurred on June 1st.

Figure 4 shows average 1997 SWE versus time in the Control and each of the three treatment types. Average snow storage was always higher in openings than in the adjacent forest and plot average SWE was always closer to

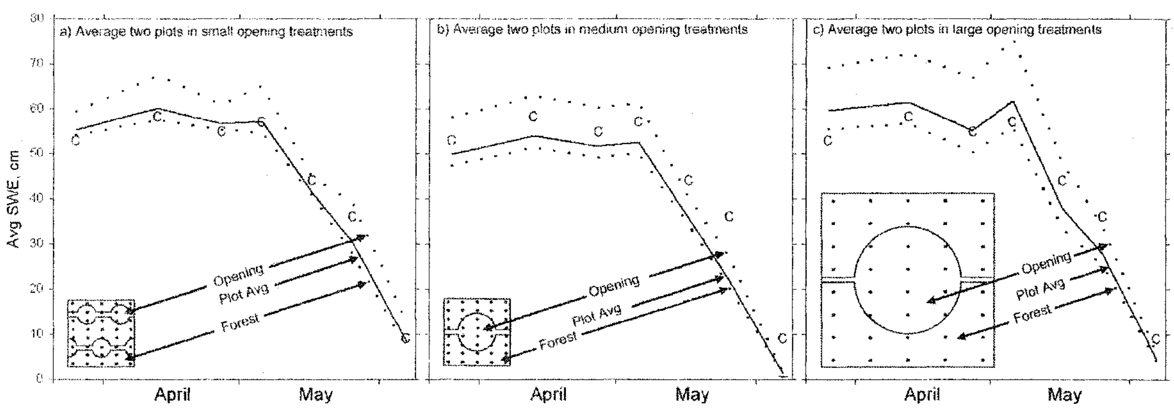

Figure 4. Average SWE versus time in 1997 for plots in each of the three treatment types (solid line) and the Control ("C"). The upper and lower dotted lines are average SWE in the logged and unlogged portions of each treatment type.

the forest average than the opening average, reflecting the proportion of area harvested in all treatments. Ablation from the plot in the unlogged Control averaged 1.51 cm*day^{-1} over 32 days while ablation rates from the small, medium, and large opening treatments averaged 1.52, 1.60, and 1.79 cm*day^{-1} respectively.

Ablation rates and plot characteristics are summarized in Table 1. The actual area harvested in snow plots ranged from 21 to 34 percent. The forest in plot L2 was found to be thinner than that in the other plots as reflected in all four forest measurements. Canopy and stand parameters differed between openings and the forest in ways that would be expected based on opening diameter and the nature of the measurement. For example, while basal area in openings is zero, the variable-radius estimation method is influenced by trees up to about 15 m away. Therefore, calculated basal areas in openings were greater than zero and were greatest in the smallest openings due to the greater influence of nearby trees. Cover was reduced in the small openings almost as much as in the large openings because cover was measured within 10 degrees of the zenith. However, shade in openings decreased as opening diameter increased because it was influence by canopy at angles of 30 to 45 degrees from the zenith. Canopy view factors in openings were even more influenced by opening diameter because this measurement encompasses the entire hemisphere and can therefore be affected by trees at greater distances.

	Plot						
	C	S1	S2	M1	M2	L1	L2
Elevation, m	1585	1540	1575	1510	1600	1540	1570
Slope, percent	13	15	13	15	16	16	13-26
Slope direction	N	NNE	NW	NNE	NW	N	NW
Opening diameter, tree heights	na	1	1	2	2	5	5
Portion of area harvested, percent	0	25	34	25	21	28	28
Measurements at points in forest							
Basal area, m^2*ha^{-1}	41	38.1	38.3	41.2	37.2	40.9	32.6
Canopy cover, percent	32	44	43	37	39	38	22
Shade, percent	62	74	64	63	63	64	55
Canopy view factor, percent	75	71	72	71	71	72	64
Ablation rate, $cm*day^{-1}$	1.51	1.50	1.47	1.62	1.43	1.52	1.73
Measurements at points in openings							
Basal area, m^2*ha^{-1}	na	10.9	12.0	10.7	12.7	2.0	2.5
Canopy cover, percent	na	10	2	4	3	0	1
Shade, percent	na	43	34	30	25	5	8
Canopy view factor, percent	na	55	52	43	42	21	19
Ablation rate, $cm*day^{-1}$	na	1.64	1.64	1.9	1.83	2.17	2.23
Plot Averages							
Basal area, m^2*ha^{-1}	41	31	33	34	32	29	24
Canopy cover, percent	32	35	35	30	31	27	16
Shade, percent	62	65	58	55	55	46	41
Canopy view factor, percent	75	67	68	65	65	57	50
Ablation rate, $cm*day^{-1}$	1.51	1.54	1.50	1.68	1.52	1.71	1.88

Table 1. Post-harvesting plot characteristics and ablation rates.

Daily minimum and maximum screen temperatures in the unlogged forest are plotted in Figure 5. Daily minima and maxima in the middle of a large opening were always within 2 degrees of minima and maxima in the Control.

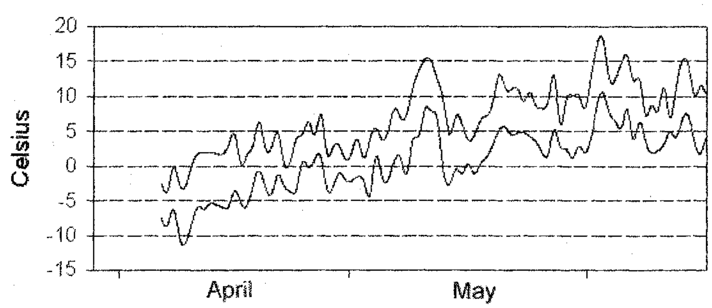

Figure 5. Daily minimum and maximum air temperatures in the unlogged Control.

ANALYSIS AND DISCUSSION

The power of this experiment is limited by the absence of pre-treatment stand and snow data. We had only two replicates per treatment and there were some differences in stand density and percent area harvested between plots. Therefore, the results must be interpreted with caution.

Figure 6a shows ablation rates versus opening diameters. Ablation rates in openings increased from 1.6 to 2.2 cm*day^{-1} as opening diameters increased from 1 to 5 tree heights. The linear relation was

$$\text{Opening Ablation Rate (cm*day}^{-1}\text{)} = 1.55 + 0.133 \times \text{Opening Diameter (Tree Heights)}$$

with $r^2 = 0.96$.

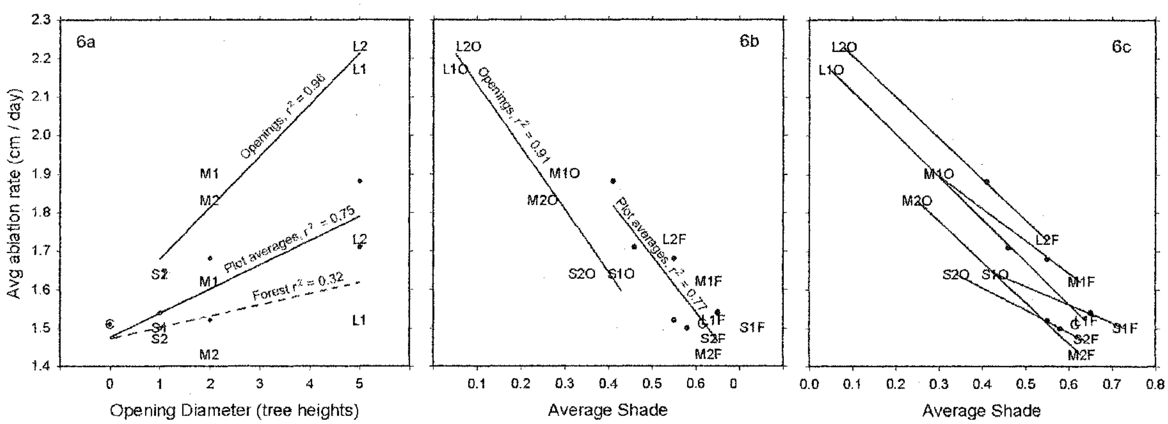

Figure 6. Ablation rates in openings, forest, and plot averages versus opening diameter and shade. Plot designations are the same as in Table 1. O = Openings, F = Forest, Dots = plot means.

This result differs from Berry and Rothwell (1992) who found that melt rates on a north-facing slope were increased by similar amounts (14 to 19 percent) in openings with diameters of 1H, 3H and 5H.

We found that openings had little effect on ablation rates in the adjacent forest. The only forested part of any plot that had an elevated ablation rate was that in L2 and it had the lowest basal area and canopy density of any residual stand (Table 1). The ablation rates in forested parts of other plots were similar to those in the Control and did not increase with the diameter of adjacent openings.

Storck et al. (1999) showed that during clear weather, net shortwave radiation to a snowpack in a thinned (shelterwood) forest was several times greater than net longwave radiation and that it was greater than short and longwave radiation combined in the uncut forest. Direct solar radiation was likely the major source of ablation energy in our small openings. We considered shade as a potential independent variable because we thought it might explain differences in ablations rates as a function of differences between stands. Figure 6b and 6c show ablation rates versus shade (10 AM to 2 PM in May) in the openings, forested portions of plots, and plot averages. These figures reveal several patterns:

1. Average shade in openings decreased from 39 to 7 percent as opening diameters increased from 1H to 5H due to the relation between opening geometry and solar angles. Ablation rates in openings were inversely-correlated with shade in openings ($r^2 = 0.91$, Figure 6b).

2. Average shade in the forested parts of treatments was similar between plots and did not explain a significant amount of the variability in ablation rates ($r^2 = 0.38$, regression line not shown in 6b).

3. Although statistically significant ($r^2 = 0.77$), the correlation between plot average ablation rates and plot average shade (solid dots and regression line in 6b) is an artifact of the very good correlation in the openings and the very poor correlation in the forest of each plot. The regression relations for openings and plot averages also had different Y-axis intercepts, possibly reflecting the fact that our shade parameter was not the only thing affecting ablation rates.

4. Figure 6c shows that the changes in ablation rates per unit change in shade were nearly identical in the medium and large opening treatments but that ablation rate increased more slowly with decreasing shade in the small opening treatments. This too suggests that factors other than shade contributed to differences in ablation rates.

We also considered canopy view factor as a potential independent variable due to the significance of longwave radiation as an energy source for ablation in forest environments (Adams et al., 1998; Storck et al., 1999). If longwave is the dominant source of energy and longwave from the canopy is greater than longwave from the sky, then ablation rate should be positively correlated with canopy view factor. Not surprisingly, average ablation rates decreased with average canopy view factors in openings ($r^2 = 0.98$) and in whole plots ($r^2 = 0.87$) because net shortwave radiation was likely much greater than net longwave. However, average ablation rates also decreased with average canopy view factors at our forest points ($r^2 = 0.57$). This is not easily explained and illustrates the risk of trying to represent the variability of energy budget components with simple canopy parameters.

CONCLUSION

Ablation rates in small openings during a high-snow year increased with increasing opening diameters from 1H to 5H. Opening diameter explained even more of the variance (96%) in ablation rate than did shade (91%). Since shade decreased with opening diameter ($r^2 = 0.90$), this may indicate that opening diameter conveys a good combination of information about both net shortwave radiation and sensible heat associated with wind-induced convective mixing. Ablation rates in the smallest openings (1H) and in the forests adjacent to openings were similar and the variability was not well-explained by any of the parameters investigated. This supports the idea that small openings have very little effect on ablation rates in adjacent stands. The overall variability of ablation rates in partially-harvested stands with small openings on a north-facing slope was best-understood by assuming that all differences were due to an increase in ablation rates in the openings, which in turn were a function of opening diameter.

Our results indicate that in stands with complex structure, such as that caused by partial harvesting in the form of group selection, ablation rates and canopy parameters should not be averaged over the whole stand or misleading relationships may result.

This project would have provided more conclusive results if several years of pre-treatment data had been collected. This is being addressed in the Mount Tom Adaptive Management Trial which was started in 2001. Several years of pre-treatment snow surveys are being conducted prior to partial harvesting. The new study also includes south-facing as well as north- facing plots. It will allow the hypotheses developed above to be tested and will allow better estimates to be made of the effects of group selection logging on ablation rates.

LITERATURE CITED

Adams, R.S., D.L. Spittlehouse, and R.D. Winkler. 1998. The snow melt energy balance of a clearcut, forest and juvenile stand. 23rd Conference on Agricultural and Forest Meteorology: Weather Data Requirements for Integrated Pest Management. American Meteorological Society, Albuquerque, NM. 54-57.

Berry, G.J. and R.L. Rothwell. 1992. Snow ablation in small forest openings in southwest Alberta. Can. J. For. Res. 22:1326-1331

Golding, D.L. and R.H. Swanson. 1978. Snow accumulation and melt in small forest openings in Alberta. Can. J. For. Res., 8: 380-388.

Stathers, R.J., T. Newsome, M.J. Waterhouse, and C. Sutherland. 2001. Microclimate Studies on a Group Selection Silvicultural System in a High-elevation ESSFwc3 Forest in the Cariboo Forest Region. For. Sci. Prog. B.C. Min. For., Victoria, B.C. Work. Pap. 58/2001. 29 p.

Steen, O.A. and R.A. Coupé. 1997. A field guide to forest site identification and interpretation for the Cariboo Forest Region. B.C. Min. For., Victoria, B.C. Land Management Handbook No. 39.

Steyn, D.G. 1980. The calculation of view factors from fisheye-lens photographs. Atmosphere-Ocean, 18:254(3)-258.

Storck, P., T. Kern and S. Bolton. 1999. Measurement of differences in snow accumulation, melt, and micrometeorology due to forest harvesting. Northwest Science, 73:87-101.

Teti, P. 2003. Relations between peak snow accumulation and canopy density. The Forestry Chronicle 79(2): 307-312.

Winkler, R.D. 2001. The Effects of Forest Structure on Snow Accumulation and Melt in South-Central British Columbia. PhD. Thesis, Faculty of Forestry, University of British Columbia, Vancouver, B.C. 151 p.

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