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SNOW COVER DISTRIBUTION IN FORESTED AND DEFORESTED LANDSCAPES IN NEW BRUNSWICK, CANADA

By

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INTRODUCTION

The Nashwaak Experimental Watershed Project was initiated in central New Brunswick, Canada to study the effects of some common forestry practices on selected environmental parameters. The principal forestry practice to be evaluated was commercial clearcutting. Following eight years of calibration, the harvesting operation was carried out in 1978-79. This study reports on the effects of this treatment on snow cover distribution in the subsequent three years.

In this region, which is 86% forested land, a knowledge of the snow cover/forest cover relationships, and the extent to which they are altered by forest management (especially forest removal), are vital to overall resource management. Floods involving snowmelt contribution are a continual threat (Inland Waters Directorate, 1974), and the general public frequently accuse the forest industry of aggravating these events by harvesting practices. In addition, changes in snow cover distribution are of interest from a wildlife management point of view. New Brunswick is on the northern fringe of the range of the white-tailed deer (<u>Odocoileus virginianus</u>). Populations in such areas appear to be controlled by winter severity (Verme and Ozoga, 1971), which is strongly related to snow depth; therefore, any change in snow depth distribution after clearcutting that would tend to increase winter mortality rates could influence management strategies.

Analyses of snow-cover/forest cover relationships during pre-treatment years have been reported elsewhere (Dickison 1979; Dickison and Daugharty, 1978: 1979: 1980). By incorporating elevation, forest cover type, and depth measurement at a single index station, it was possible to explain 74.8% of the variance in snow depth within the study area prior to clearcutting (Dickison and Daugharty, 1978). In this paper we will examine the change in these relationships brought about by the treatment. The experiment has used the paired-watershed method (Hewlett and Nutter, 1969), thus we are able to use time-independent methods of comparison in addition to before-treatment/after-treatment relationships.

PROJECT AREA

The experimental watersheds are located in central New Brunswick (Figure 1) and drain into the Nashwaak River, one of the Province's major salmon fishing streams, at a point about 50 km northwest of Fredericton. Physical characteristics of the two basins are given in Table 1.

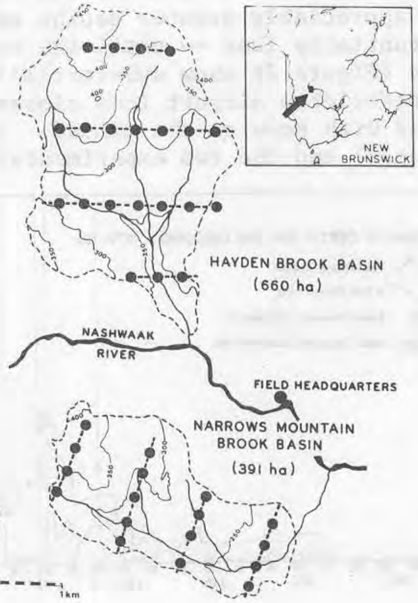

Figure 1

Location of Nashwaak Experimental Watershed Project and Snow Survey Transects

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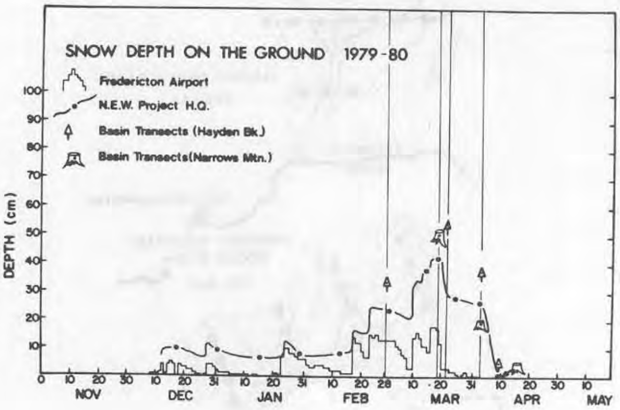
Table 1

Physical Characteristics of Control and Treatment Basins

	Hayden Brook Basin (Control)	Narrows Mountain Brook Basin (Treatment)
ELEVATION - Range - Mean	197 - 478 m 317 m	224 - 418 m 296 m
ASPECT - Mean	156°	128°
SLOPE - Range - Mean	0 - 46% 7.6%	0 - 27% 11.4%
DRAINAGE AREA	660 ha	391 ha

Both basins were covered with maple (<u>Acer sacharrum</u>), beech (<u>Fagus grandifolia</u>), balsam fir (<u>Abies balsamea</u>) and red spruce (<u>Picea rubens</u>), with the hardwood and softwood species covering about equal areas but ranging from pure hardwood on the ridge tops to pure softwood on the lower slopes. Approximately 94% of the original basal area on Narrows Mountain Basin was removed by the clearcut, leaving only protective strips along the main stream channels and scattered unmerchantable residuals.

Annual precipitation averages 1280 mm, about one-third of which is snow, with a permanent snow pack usually lasting from late November to early May. Prior to the clearcut (Dickison and Daugharty, 1980) it was estimated that snow cover, measured at the Project headquarters at an elevation of 185 m, normally reached a maximum depth of about 93 cm, with a water equivalent of about 235 mm. Periodic basin surveys (Dickison and Daugharty, 1980) show appreciably greater depths at higher elevations. Since treatment, snow cover has been substantially less -- until the current year. Comparative snow depths for the past three years (Figure 2) show substantially greater depths at the project headquarters station than at Fredericton airport (the closest site of daily snow depth measurements) and a longer period with snow on the ground. Differences between the headquarters measurement site (in the open) and the two experimental basins are also indicated.



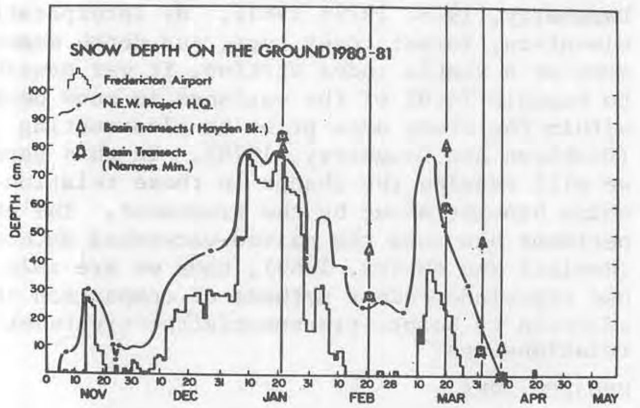
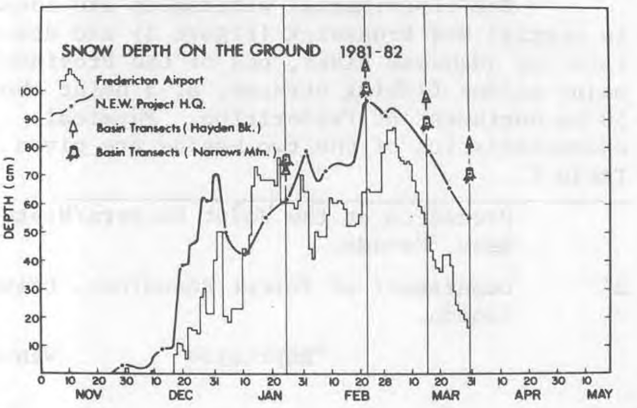


Figure 2

Comparative Snow Depths on the Ground at the Fredericton Airport, N.E.W. Project Headquarters and Clearcut and Control Basins



Mid-winter rainstorms and periods of above-freezing temperatures are not uncommon characteristics of our Maritime winters. But such a substantial thaw as occurred in February, 1981, practically removing the entire snowpack even in this densley forested region, is a rare event. Mid-winter thaws characteristically do not remove the snowpack, but result in the formation of ice lenses which complicate the determination of snow water equivalent.

METHODS OF DATA COLLECTION

Periodic two-day surveys are carried out according to a schedule set out by the Eastern Snow Conference. Surveys begin in late January and proceed at about one-month intervals with the intervals decreasing to two weeks as the melt season approaches. In the three seasons since treatment 12 surveys are available for analysis, although two of these (February 28, 1980 and April 23, 1981) were not carried out in the clearcut basin because it contained almost no snow.

Sampling is carried out at intervals of 100 m along four transect lines of each basin (Figure 1), with five measurements of snow depth (SD) at each site. Five measurements of snow water equivalent (SWE) are taken at every third sampling site (300 m intervals), corresponding to a network of forest growth and composition study plots. The value used for analysis is the mean of these five. All measurements are taken with Mount Rose-type samplers read to the nearest half-inch. Two of the depth measurement sites were within the protective strip left along the stream following the clearcutting. The snow collected at these sites remains within the watershed and would need to be taken into account when computing water balances. For the purpose of this paper, however, the data collected from these sites has been excluded.

METHODS OF ANALYSIS

The objective of this analysis is to determine relationships between snow depths and water equivalents and topographic and forest cover factors in order to describe differences between forested and de-forested areas. The snow depth and water equivalent measurements obtained from the transect surveys in the forested basin were related to the independent variables using a correlation matrix and multiple linear regression. These relationships were then used to determine predicted values for the clearcut area, based on the pretreatment forest cover. (It had previously been determined (Dickison, 1979) that these estimates did not differ significantly from measured values during the pre-treatment condition.) The difference between those predicted values and the measured values following de-forestation may then be used as a measure of the treatment effect.

It was also desired to describe the spatial distribution of the differences in snow cover within the de-forested watershed. This was accomplished with a square-grid model (Dickison and Daugharty, 1978). The basin was divided into 1-ha units, and topographic variables (elevation, slope, aspect) were determined from 5-m contours on a 1:10 000 topographic map. Within the sampling plots several measurements of stand density and canopy coverage were available, of which percent basal area in hardwoods consistently provided the best correlation with snow cover variables (Patch, 1980). In order to extend this relationship to the grid squares, however, it was found that the descrimination on aerial photographs permitted the determination of cover type classes only within 20% ranges of percent basal area in hardwoods (Dickison and Daugharty, 1978).

RESULTS OF ANALYSES

The snow cover data are summarized by survey date in Table 2. Some of the problems with the data set are evident. In 1980 conditions in February mitigated against a snow survey in the cleared watershed, and the mid-March snow survey was interrupted by a major rainstorm making basin comparisons questionable. There is also considerable doubt about the comparative snow water equivalents in the January survey in 1981. On January 27th, when Narrows Mountain Brook basin was surveyed, the weather was very mild (maximum temperature = 5°C) and the observer noted that "the upper layers of the snowpack contain liquid water which freezes inside the sampler when it penetrates the colder pack below." On the following day, when Hayden Brook basin was surveyed, temperatures were colder and sampling conditions were excellent; snow depths were found to be about 6 cm less than in the clearcut on the previous day, but the water equivalent 67 mm <u>greater</u>.

Table 2

Summary of Comparative Snow Survey Data from Control and Treatment Basins following Forest Removal

Date of Beginning of Survey	Hayden Brook Basin			Narrows Mountain Brook Basin		
	Number of Sites	Depth (cm)	Water Equivalent (mm)	Number of Sites	Depth (cm)	Water Equivalent (mm)
28 Feb 80						
Plot Data	18	36.4	68	No Survey -- patches of snow on shallow ice layer.		
All Data	49	35.1				
17 & 20 Mar 80[1]						
Plot Data	18	54.9	160	15	51.1	101
All Data	51	52.2		40	52.5	
01 Apr 80						
Plot Data	18	38.1	117	15	18.5	66
All Data	51	36.5		40	20.2	
27 Jan 81						
Plot Data	12	79.6	189	11	85.4	122[2]
All Data	32	80.9		28	88.4	
25 Feb 81						
Plot Data	18	49.0	173	15	27.7	78
All Data	49	46.4			30.6	
24 Mar 81						
Plot Data	18	83.9	247	15	60.5	147
All Data	49	80.3			61.7	
06 Apr 81						
Plot Data	18	49.1	186	15	10.5	36
All Data	49	47.6		39	9.6	
23 Apr 81						
Plot Data	18	11.4	47	N/A	0	0
All Data	51	9.6				
26 Jan 82						
Plot Data	11	72.3	147	11	74.2	132
All Data	31	72.5		31	78.4	
23 Feb 82						
Plot Data	15	108.2	253	15	102.2	243
All Data	40	107.6		40	103.2	
16 Mar 82						
Plot Data	15	96.7	263	15	88.1	236
All Data	40	96.4		40	88.9	
30 Mar 82						
Plot Data	16	81.0	253	15	70.6	229
All Data	43	80.5		40	71.1	

[1] March surveys in 1980 were carried out on the 17th in Narrows Mountain Brook basin and on the 20th in Hayden Brook basin. A rainfall of 55 mm occurred between the two survey dates.

[2] The measured water equivalent on the sampling date is considered to be erroneous as a result of adverse sampling conditions (see text).

There is reason to believe, from the survey observations, that snowpack densities were somewhat lower amid the residual logging slash in the clearcut area -- but not nearly of this magnitude. Yet another source of difference is that of a real difference in precipitation between the two basins. Accumulated December and January precipitation, measured with unshielded standpipe gauges, was 31 mm less in Narrows Mountain Brook basin than in the control. There is eveidence that reduced catch efficiency of gauges no longer protected by surrounding forest accounts for some of this difference, but part of the difference -- especially for the rainfall contributions to the snow water equivalent -- is probably due to spatial variation in precipitation.

For the reasons discussed above, and because of abnormal seasonal distribution of snow cover in 1980 and 1981 as shown in Figure 2, our analysis of comparative forested and de-forested conditions is mostly limited to the 1982 season.

Basin-wide Effects.

Prediction equations using multiple linear regressions developed from the control watershed data have been used to determine predicted snow cover values for the treated watershed. Calculated differences for the de-forested condition may be discerned from Table 3 for snow depth and snow water equivalent respectively. Differences between the forested and de-forested conditions are at a minimum early in the snow-cover season and increasing deficits are exhibited as the season progresses.

Table 3

Measured Versus Predicted Snow Depth and Snow Water Equivalent
in Narrows Mountain Brook Basin Following Clearcutting

Date of Beginning of Survey	Snow Depth (cm)			Snow Water Equivalent (mm)		
	Predicted	Measured	Difference	Predicted	Measured	Difference
01 Apr 80	37	21	-16	128	66	-62
27 Jan 81	76	87	+11	184	122	-62
25 Feb 81	52	31	-21	150	78	-72
24 Mar 81	81	62	-19	232	147	-85
6 Apr 81	50	11	-39	181	36	-145
26 Jan 82	74	78	+ 4	144	132	-12
23 Feb 82	106	103	- 3	262	243	-19
16 Mar 82	96	89	- 7	251	236	-15
30 Mar 82	82	71	-11	238	229	- 9

The distribution of snow cover differences may be displayed by the grid-square mapping program. We have used the 1982 data to illustrate the pattern of differences early and late in the snow-cover season (Figure 3). The prediction equations, incorporating elevation, aspect, slope and pre-treatment cover type, explain 48.2% (SE=10.9 cm) and 30.3% (SE=10.8 cm) of the variance for the early season and late season conditions respectively. It is clearly evident that the differences are systematically distributed within the basin. Deficits are found at higher elevations in the areas previously covered predominantly with hardwoods, and excesses at lower elevations previously covered with softwoods. Before discussing this distribution pattern we will examine the independent contributions of several factors.

Elevation.

During the calibration period, elevation had consistently provided the best correlation with snow cover of any of the topographic parameters -- until very late in the snow cover season. Over the entire Project area elevation/snow depth relationships at the time of maximum snow depth were significant in every pre-treatment season, with gradients ranging from +6.5 to +13.6 cm/100 m; when standardized against the snow depth at 300 m (the approximate mean elevation of the watershed area) these produced gradients of +5.9% to +14.3%/100 m -- within the range found by most other studies (Dickison and Daugharty, 1980).

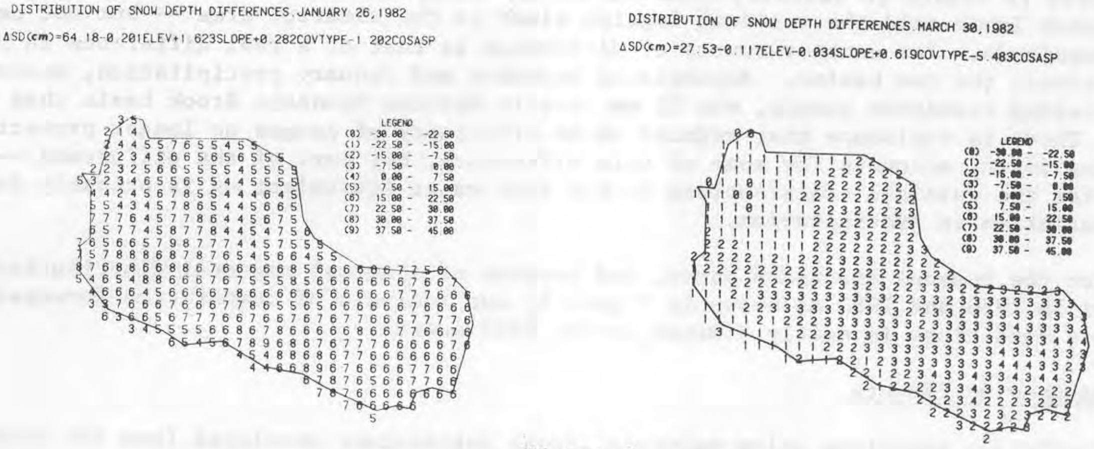


Figure 3

Differences in Snowpack Depth (Observed—Predicted) Early and Late in the Season After Forest Removal

Following clearcutting, the abnormality of the 1980 and 1981 seasons confounds the relationships somewhat, and even in 1982 the maximum-pack gradient of snow depths within the forested basin is below the range of those found during the calibration period (Table 4). However, within the clearcut area a drastic reversal of the relationships is evident, with snowdepth/elevation gradients at maximum pack of -6.1, -10.7 and -10.3 cm/100 m in the past three years. Snow water equivalent gradients can be compared only for the 1982 season: these were calculated at the time of maximum pack to be +36.6 mm/100 m in the forested watershed and -16.7 mm/100 m in the clearcut area. The forested value is very close to that determined for the "normal" seasons during the calibration period (Dickison and Daugharty, 1980).

Table 4

Statistics from Linear Regression of Snow Depth Against Elevation at the Time of Maximum Snow Cover

Date of Beginning of Survey	Number of Observations	Mean Depth (cm)	Regression Statistics			
			r^2	a (cm)	b (cm/100m)	b/SD_{300} (%/100m)
--- Hayden Brook Basin ---						
20 Mar 80	51	52.2	.254***	23.7	9.4	18.1
24 Mar 81	49	80.3	.001	78.0	0.7	0.9
23 Feb 82	40	107.6	.126**	89.8	5.8	5.4
--- Narrows Mountain Brook Basin ---						
17 Mar 80	40	52.5	.086*	70.7	-6.1	-11.6
24 Mar 81	40	61.7	.076	93.8	-10.3	-17.3
23 Feb 82	40	103.2	.101**	134.2	-10.3	-10.0

* Significant at the 0.10 level
** Significant at the 0.05 level
*** Significant at the 0.01 level

The trend of the standardized snow depth/elevation gradients during the snow cover season is shown in Figure 4 for the calibration period, and for the post-treatment period separately for each basin. No clear elevation relationship seems evident for the pattern of snow disappearance from the de-forested area.

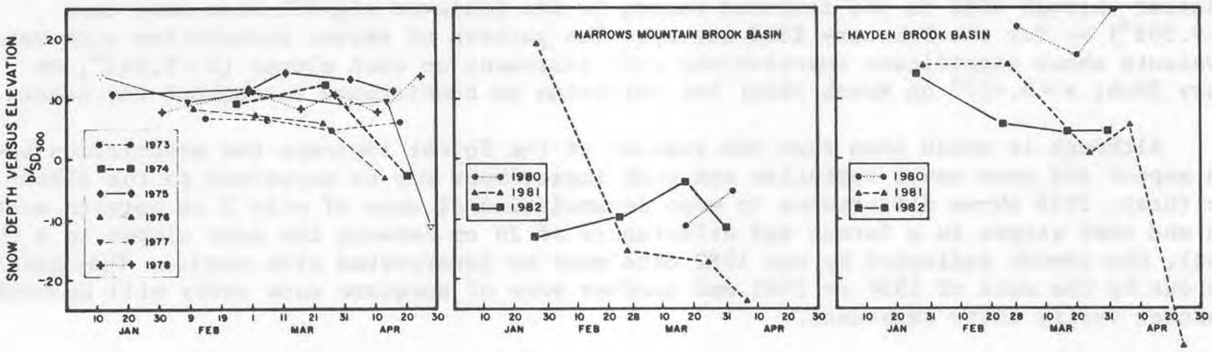


Figure 4

Time Variation of the Standardized Gradient of Snow Depth With Elevation, Before and After Forest Removal

Slope/Aspect

The effect of slope during the calibration period was found to be occasionally significant -- and generally a positive correlation at the time of maximum snow depth, reversing to a negative correlation by the end of the season due to more exposure to melt forces on steeper slopes within these generally southeast-facing basins. Following forest removal the difference in slope effects between northern (± 45°) and southern aspects became distinct and exhibited a clear seasonal trend (Figure 5), although the sample sizes for these cases are small and significant only for the north-facing slope on the March 30th survey.

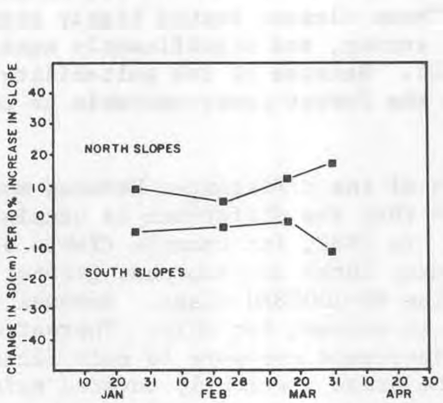


Figure 5

Time Variation of the Gradient of Snow Depth with Slope on North-facing and South-facing Slopes Within the Clearcut Area

Aspect has been incorporated into the analyses as a cosine function, a model which assumes snow cover shallower on south-facing than on north-facing slopes. By successive displacements of 45°, 90° and 135° it is possible to test various axes of symmetry. Prior to calibration it was found (Dickison and Daugharty, 1977) that aspect was generally non-significant until late in the melt season when north-south differences became significant.

In 1982, the aspect code favouring greater accumulations on southwest slopes showed consistently better associations with snow depth than any of the other codings and maintains significance in both March 16th ($r = -0.573^{**}$) and March 30th ($r = -0.623^{**}$) surveys. Water equivalent also maintains a consistent relationship with this aspect code throughout 1982 which is significant for the last three surveys -- February 23rd ($r = -0.536^{**}$), March 16th ($r = -0.682^{**}$) and March 30th ($r = -0.637^{**}$).

Although the aspect code favouring increased snow depths on north slopes has been consistent through 1982 in the forested basin, it has achieved significance only once ($r = -0.508^*$) — for the February 23rd survey. The pattern of aspect association with water equivalents shows significant correlations with increases on east slopes ($r = 0.541^*$, on January 26th; $r = 0.497^*$ on March 16th) but maintains no consistency throughout the season.

Although it would seem that the removal of the forest improves the association between aspect and snow cover variation and such improvement may be supported in the literature (Gray, 1978 shows differences in mean accumulation of snow of only 2 cm between north, south and east slopes in a forest and differences of 20 cm between the same slopes in a cut forest), the trends indicated by our 1982 data must be interpreted with caution. They aren't borne out by the data of 1980 or 1981 and another year of adequate snow cover will be needed to further verify their existence.

Forest Cover

Several measures of forest cover have been tested as estimators of snow cover variability (Patch, 1980). The percent of basal area of hardwoods (%BAH) consistently emerged as the best forest cover variable, independently explaining up to 64.7% of the variance of snow depth and 35.5% of the variance of snow water equivalent at the time of maximum snow depth.

The gradients of snow cover with %BAH are positive throughout most of the season, indicating deeper snow cover within hardwood stands, consistent with the findings of other investigators (Dickison and Daugharty, 1977). Toward the end of the melt season, however, these relationships reverse as a result of the lesser exposure to melt factors within softwood stands.

In order to extend the determination of predicted snow cover to each of the 1-ha units of the square grid model it was necessary to group %BAH into categories which could be descriminated on aerial photographs. Five classes were established, where cover type 1 = 80 - 100%BAH and 5 = 0 - 20%BAH. These classes tested highly significantly against snow depth in nearly every maximum-pack survey, and significantly against snow water equivalent on half of all surveys (Patch, 1980). Because of its suitability for use with the spatial model we have chosen cover type as the forest cover variable to be used for the post-treatment period.

Our post-treatment analysis of the differences between measured and predicted snow cover within the clearcut area show that the difference is consistently and significantly related to the cover type removed. In 1982, for example (Table 5), it may be seen that snow depths early in the year (January 26th) are somewhat greater than predicted for the forested condition for all except the 80-100%BAH class. Removal of the interception loss component for softwoods would seem to account for this. Thereafter, snow cover differences increase as a result of continual increased exposure to melt factors -- exhibiting by March 30th the greatest differences in the areas previously covered mainly by hardwoods, although the range of differences between hardwoods and softwoods has been lessened.

Table 5

Variation of the Standardized Gradient of Snow Depth with Cover Type

Date		Cover Type					$\overline{SD}$
	r^2	1	2	3	4	5	(cm)
26 Jan 82	$.267^{***}$	0.034	-0.019	-0.072	-0.125	-0.178	77.9
23 Feb 82	$.129^{**}$	0.095	0.062	0.034	0.030	-0.035	107.6
16 Mar 82	$.124^{**}$	0.152	0.118	0.083	0.049	0.014	88.9
30 Mar 82	$.159^{**}$	0.228	0.188	0.148	0.107	0.068	71.0
		(80-100% basal area hardwood)				(0-20% Basal Area Hardwood)	

DISCUSSION OF RESULTS

The removal of forest cover from the large (391 ha) area under study in central New Brunswick has resulted in changes in snow cover which are mainly summarized as follows:

a) small differences in snow cover early in the season;

b) increasingly reduced snow cover as the season progresses;

c) redistributed snow cover throughout the season, with less snow cover at higher elevations and increased snow cover at lower elevations.

It is difficult to separate the effects of elevation from those of cover type, because of the strong relationship between elevation and %BAH ($r^2 = 0.268$) at the rate of increase of 35% per 100 m. We had previously suggested (Dickison and Daugharty, 1980) from an examination of the survey on March 1, 1977 that the apparent gradient between snow water equivalent with elevation would be reduced to about two-thirds of that determined from considering elevation alone. This, however, is not sufficient to explain the actual reversal of gradients following forest removal, i.e. resulting in a decrease of snow cover with elevation. The most logical explanation is a redistribution due to drifting. Wind directions during snowstorms in this region tend to be northeasterly at the beginning of the storm, backing gradually toward the northwest which is the prevailing direction following storms. Given the northwest-southeast orientation of Narrows Mountain Brook basin this would cause snow to be drifted toward lower elevations. The comparative snow cover relationships between forested and de-forested landscapes, as evidenced by this study, have been greatly confounded for much of the post-treatment period by occurrences of heavy rainstorms and extended periods with little or no snow cover. The current season is providing more nearly "normal" conditions for analysis. The apparent basin-wide effects should be reasonably applicable within the climatic region. Many of the physiographic relationships, however, appear to be considerably affected by redistribution of the fallen snow and therefore determined largely by orientation with respect to prevailing winds. The results should be interpreted accordingly.

ACKNOWLEDGEMENTS

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