Clearcutting Impacts on Snow Accumulation and Melt in a Northern Hardwood Forest

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ABSTRACT

Snow accumulation and melt on north- and south-facing slopes in the Turkey Lakes Watershed (TLW) in central Ontario were compared for a mature hardwood maple stand and an adjacent clearcut. Snow accumulation in the clearcut exceeded that in the forest. Melt was significantly larger in the south-facing clearcut and forest relative to corresponding north-facing sites. Daily melt in the clearcut on the north-facing slope was slightly greater and more spatially variable than in the adjacent forest. Nevertheless, the control of aspect on the spatial variations in melt was larger than that due to clearcutting. Micro-scale variations in canopy density did not explain inter-point differences in daily melt within either the clearcut or the forest. The hydrological consequences of greater pre-melt snow water equivalent and larger daily melt in clearcuts include quicker delivery of meltwater to the soil surface and promotion of rapid near-surface runoff to receiving waters relative to undisturbed forest stands at TLW.

Key words: Clearcut, snow accumulation, snowmelt, hardwood forest, Turkey Lakes Watershed.

INTRODUCTION

Snowmelt is the most significant component of the annual water balance of tolerant hardwood forests on the Canadian Shield. These ecosystems are becoming increasingly stressed by land use changes, particularly in the form of disturbances imposed by forest harvesting. However, little research has concentrated on the impacts of forest harvesting on snow accumulation and melt in hardwood forests. Numerous studies have suggested that forest harvesting can have a major impact on snow accumulation and melt in coniferous forests (e.g. Bhatti *et al.* 2000, Storck *et al.* 1999, Marks *et al.* 1998, Pomeroy *et al.* 1997). Interception and subsequent sublimation of snow mean that pre-melt snowcover under coniferous stands is often significantly less than in clearcuts (Storck *et al.* 1999, Pomeroy *et al.* 1997). Snowfall may also be redistributed to clearcuts, which further contributes to differences in pre-melt snowpack between these land cover types (Stegman 1996). Harvested areas exhibit increased exposure to incoming short-wave radiation and turbulent fluxes, resulting in enhanced rates of snowmelt in clearcuts compared to adjacent forested stands (Metcalfe and Buttle 1995, Pomeroy and Granger 1997). The purpose of this study is to determine if these differences in snow accumulation and melt also occur when clearcuts are compared with northern hardwood forest stands, and how these differences (if any) vary with slope aspect and degree of canopy closure.

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STUDY AREA AND METHODS

This study was conducted on an east-west oriented ridge on the northern boundary of the Turkey Lakes Watershed (TLW), approximately 60 km north of Sault Ste Marie, in the Algoma District of central Ontario (47°03'N, 84°25'W) (Figure 1). The elevation range of the ridge site is ~ 44 m. The mean gradients on the north- and south-facing slopes are 0.29 and 0.30, respectively, while the ridge crest is relatively flat. The ridge is typical of slope morphologies within the TLW. Total annual precipitation in the TLW since 1980 ranges from 892 mm (1997) to 1535 mm (1988), with a mean of 1224 mm. Snow accounts for as little as 22% or as much as 47% of this precipitation, with a mean of 35% (Jeffries 1999). Vegetation consists primarily of uneven-aged old-growth tolerant hardwood forest. Sugar Maple (*Acer saccharum* Marsh.) accounts for ~ 90% of the total phytomass, Yellow Birch (*Betula lutea* Michx. f.) and other hardwoods ~ 9%, and White Spruce (*Picea glauca* Moench Voss.), White Pine (*Pinus strobes* L.) and other conifers account for the remaining ~ 1% (Jeffries *et al.* 1988).

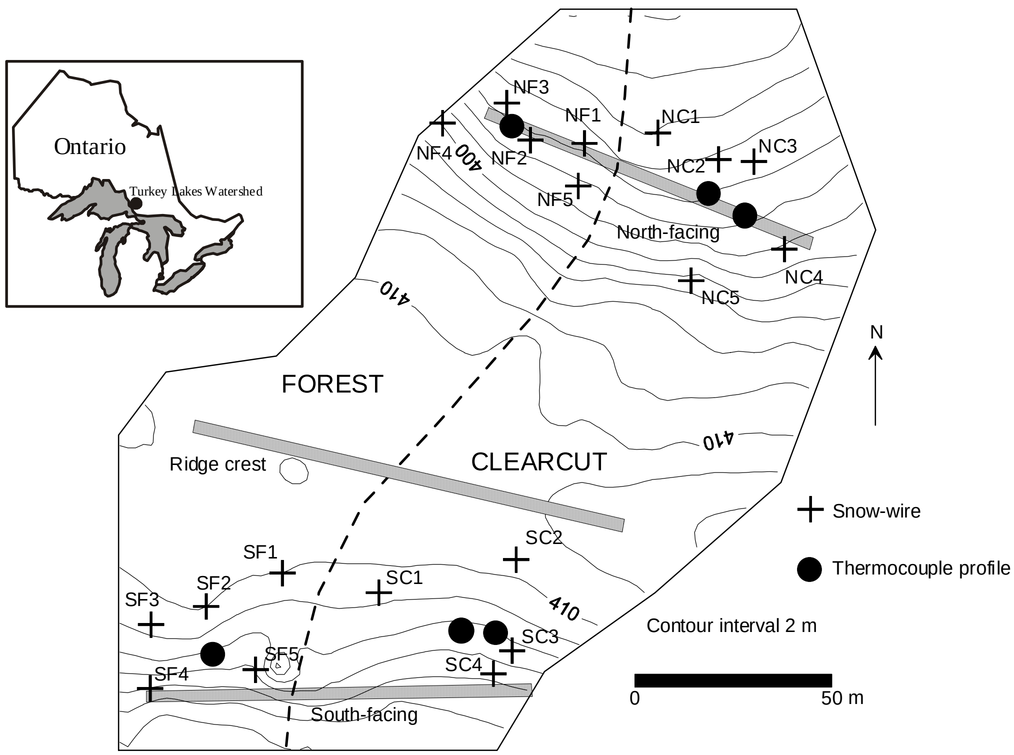

Figure 1: Study site location, instrumentation and snow survey transects.

In the fall of 1997 several areas, including half of the ridge site, were harvested as part of the Turkey Lakes Forest Harvesting Impacts Project. This project was initiated to evaluate the effects of forestry practices on the hydrology of tolerant hardwood forests. Trees with a diameter at breast height (dbh) > 20 cm were harvested and removed from the site, trees between 10 and 20 cm dbh were cut and left on the site as they were too small to mill, and trees < 10 cm dbh were left standing. Clearcutting is not a commercially acceptable harvesting practice in tolerant hardwood forests in Ontario. The experimental harvest was undertaken to produce maximum hydrological disruptions rather than to simulate an actual commercial harvest.

The spatial distribution of snow water equivalent (SWE) was determined by snow surveys conducted on March 13 2000 (Day of Year [DOY] 73), following a mid-February melt, and on February 16, 2001 (DOY 47), prior to the principal melt period. The surveys were conducted along 3 transects: one across each of the north- and south-facing slopes and one along the ridge crest (Figure 1). Each transect ran from the harvested zone, through the forest boundary, into the mature forest. Snow density and snow water equivalent (SWE) were determined using an

Atmospheric Environment Service snow tube. Measurements of snowpack depth were taken every 5 m along the transect, and density measurements were taken at 15 m intervals. The mean snowpack density in 2000 was 378.8 kg m^{-3}, and was found to be relatively uniform within both the forest and clearcut along each transect (coefficient of variation ≤ 0.34). There was no correlation between snowpack depth and density. Therefore SWE was estimated at sites in the forest or clearcut zone on a given transect at which only a depth measurement was taken using the average snowpack density in that zone.

Nineteen snow-wires were set up at the site in the fall of 1999. Ten were located on the north-facing slope (five in the forest and five in the clearcut) and nine were on the south-facing slope (five in the forest and four in the clearcut). The snow-wires were used to estimate daily melt using the methods of Heron and Woo (1978) (Figure 2). A taut wire 5 m in length was suspended horizontally over the snowpack surface between two aluminum poles. Prior to the daily melt cycle the distance from the wire to the snowpack surface (z) was measured at 11 points at 0.3 m intervals over a distance of 3 m along the central portion of the wire. Mean density of the surface snow layer ($\bar{\rho}_s$) was estimated from three 100 cm^3 snow cores extracted parallel to the snowpack surface. Melt was determined from (Equation 1):

$$M = \overline{\Delta z} \times \frac{\bar{\rho}_s}{\rho_w} \qquad (1)$$

where M = daily melt (mm)

$\overline{\Delta z}$ = mean change in the distance from the wire to the snowpack surface between times t and $t+\Delta t$ (mm)

$\bar{\rho}_s$ = mean density of surface snow layer at time t (kg m^{-3})

ρ_w = density of water (kg m^{-3}).

The standard error associated with the mean melt depth was determined as:

$$s.e._M = \sqrt{s.e._{\Delta z}^2 \times \left(\frac{\bar{\rho}_s}{\rho_w}\right)^2 + \left(\frac{s.e._{\rho_s}}{\rho_w}\right)^2 \times \overline{\Delta z}^2} \qquad (2)$$

where $s.e._M$ = standard error of the mean melt depth (mm)

$s.e._{\rho s}$ = standard error of the mean density of the surface snow layer (kg m^{-3})

$s.e._{\Delta z}$ = standard error of Δz (mm).

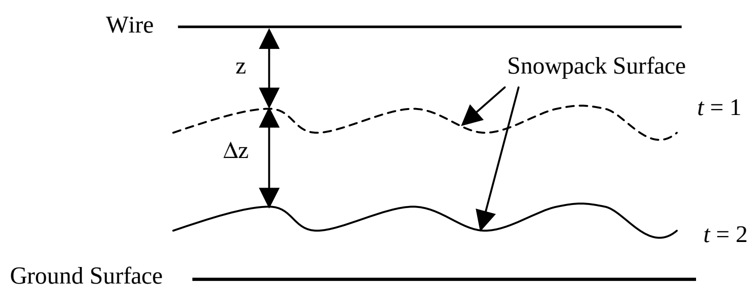

Figure 2: The snow-wire method of estimating melt.

Canopy coverage was assessed at each snow-wire using a LAI-2000 plant canopy analyzer (Li-Cor Inc.) on November 20, 2000. Measurements were taken under a leafless canopy to represent conditions during snowmelt. The LAI-2000 provides an indirect measure of the canopy structure based upon light interception. Measurements are presented as gap fractions (GF), which range between 0 and 100%. A GF of 0% indicates that no sky is visible to the sensor, whereas a GF of 100% implies that no canopy is visible to the sensor. All measurements were taken before sunrise or after sunset to ensure uniform sky conditions. This minimized potential errors caused by differing sky conditions, and direct beam or diffuse radiation (from a sunlit canopy) striking the LAI sensor (Welles and Norman 1991). A 180° view cap was used on the optical sensor to differentiate between north and south aspect influences. Therefore two LAI measurements were taken at each snow-wire, one with the sensor at a 360° (north) bearing, and the other at a 180° (south) bearing. Each LAI measurement consisted of 2 above-canopy readings taken in a clearing and 11 below-canopy readings. Below-canopy measurements were taken at each of the 11 points used to estimate $\overline{\Delta z}$ (Figure 2). GF was calculated as the ratio of below-canopy to above-canopy readings.

Snowpack temperatures were monitored at six locations on the ridge (Figure 1), in order to determine when the snowpack became isothermal. This information was used to distinguish periods of melting from changes in the distance from the wire to the snowpack surface due to settling of the snowpack. White wooden posts were erected at each of the monitoring sites the previous autumn. Holes were drilled into the post at 0.05 m, 0.1 m, 0.2 m, 0.3 m, 0.4 m, 0.5 m and 0.6 m above the ground surface. Thermocouple wire was wrapped around a 0.3 m length of wooden dowel, and inserted horizontally through the holes into the snowpack. Temperatures were monitored at 5 minute intervals and hourly averages were recorded, using Campbell CR-10 (with AM416 relay multiplexers) or CR-21X dataloggers.

RESULTS AND DISCUSSION

Pre-melt snowpack conditions

The snow survey on March 13 2000 (Table 1, Figure 3) was conducted after a substantial amount of SWE was lost during a mid-February thaw. The results show similar mean SWE in the clearcut and forest on a given sampling transect; however, SWE was more variable in the clearcut than in the forest. Given that the clearcut experienced greater melt rates than the forest (see below), this suggests that snow accumulation was greater in the clearcut than in the adjacent forest prior to the mid-February melt. This is supported by the results of snow surveys conducted on February 16 2001 (Table 1, Figure 3). The mean SWE in the clearcut on the south-facing slope and along the ridge crest was significantly greater than that in the adjacent forest stand. As in 2000, the SWE was more variable in the clearcut than in the forest. However, the mean SWE in the forest and clearcut on the north-facing slope was not significantly different. This may reflect the prevailing northerly winds during the winter months at TLW, which would redistribute snow from the north-facing clearcut into the clearcut on the ridge crest and the south-facing slope, thus accentuating the difference between clearcut and forest SWE along these transects. The greater overall variability in SWE in 2000 relative to 2001 likely reflects substantial snowmelt prior to the 2000 survey. This would enhance the spatial variations in SWE along the transects, given the inverse relationship between pre-melt SWE and melt rate observed elsewhere (e.g. Faria *et al*., 2000).

Mean SWE in the clearcut exceeded that in the forest by 13% on the south-facing slope, and 18% on the ridge crest. These differences are comparable to the results of Sartz and Trimble's (1956) study that found a peak SWE in a clearcut that was 4-10% greater than in an adjacent hardwood forest. They are also comparable with Sartz's (1957) observations of peak SWE in an open area that was 17% greater than that in an adjacent hardwood forest. Both of these studies were conducted at Hubbard Brook, New Hampshire. Our results are consistent with predicted minor increase in peak SWE following clearcutting in a largely hardwood basin in central New Brunswick (Meng *et al*. 1995). Conversely, our values are smaller than Bhatti *et al.* (2000) observations in a jack pine stand in north eastern Ontario, where clearcut SWE exceeded that in the forest by ~33-75%. This greater difference between clearcut and forest SWE likely reflects larger interception and sublimation of snowfall in coniferous compared to hardwood forests.

Table 1: Summary statistics from 2000 and 2001 snow surveys along sampling transects, TLW.

	South-facing slope		Ridge crest		North-facing slope	
2000	Forest	Clearcut	Forest	Clearcut	Forest	Clearcut
Mean SWE (mm)	41	85	89	88	173	176
Standard deviation SWE (mm)	35	95	28	55	40	50
Coefficient of Variation	0.854	1.118	0.315	0.625	0.231	0.284
n†	11	11	15	13	13	15
2001						
Mean SWE (mm)	161*	182	194*	228	181	183
Standard deviation SWE (mm)	12	22	11	27	11	15
Coefficient of Variation	0.075	0.121	0.057	0.118	0.061	0.082
n	10	10	14	12	10	9

† Number of observations.

* Significantly less than mean clearcut SWE at $p = 0.05$ level.

Daily melt

Limited data were available from the snow-wires on the south-facing slope due to the loss of SWE during the mid-February melt in 2000. Nevertheless, melt was significantly greater in the south-facing clearcut and forest relative to corresponding north-facing sites (Figure 4). There was no significant difference between cumulative melt at forest and clearcut snow-wires on the south-facing slope. The south-facing forest sites lost all snowcover before sites in the north-facing clearcut had lost 25% of their total melt during the spring. This suggests that aspect exerts greater control on spatial variations in melt than that due to clearcutting.

There was substantial overlap in cumulative melt at the clearcut and forest snow-wires on the north-facing slope. This is likely a result of the large variability in SWE in both the clearcut and forest before melt (Figure 3). Several studies have suggested a relationship whereby melt rates decrease with increasing SWE (Buttle and McDonnell 1987, Faria *et al.* 2000). Therefore sites with relatively small pre-melt SWE should experience large daily melts, with reduced melt at sites with relatively large pre-melt SWE. Thus, mean daily melt was 13±9 mm in the clearcut and 10±6 mm in the forest. Although these means were not significantly different, daily melt tended to be greater in the clearcut relative to the adjacent forest. The difference was not as pronounced as has been observed under coniferous forest cover (e.g. Pomeroy and Granger 1997), due to the more open canopy in the hardwood forest. The overlap may also reflect the presence of trees with < 10 cm bhd providing shading at some harvested sites similar to that experienced in the forest. This enhanced melt in the north-facing clearcut resulted in greater wetting-up of near-surface soil compared to the forest (Buttle *et al.* submitted). This in turn resulted in lateral downslope transfer of melt inputs through the more conductive upper soil horizons and reduced opportunity for mixing between meltwater and pre-event soil water and groundwater in the clearcut relative to the forest.

Canopy Coverage

The range in GF values measured on a north bearing was ~10% within both the clearcut and forest, while the range in GF values was smaller when measured on a south bearing (Figure 5). The number of days required to melt a given depth of SWE (DSWE) was plotted against GF at each snow-wire site (Figure 5), following the approach of Metcalfe and Buttle (1995). DSWE was relatively constant in the forest for both north and south bearing GF values, with the exception of the number of days required to melt 50 mm SWE. Conversely, DSWE was more variable in the clearcut, which is consistent with the greater range in cumulative melt in the north-facing clearcut

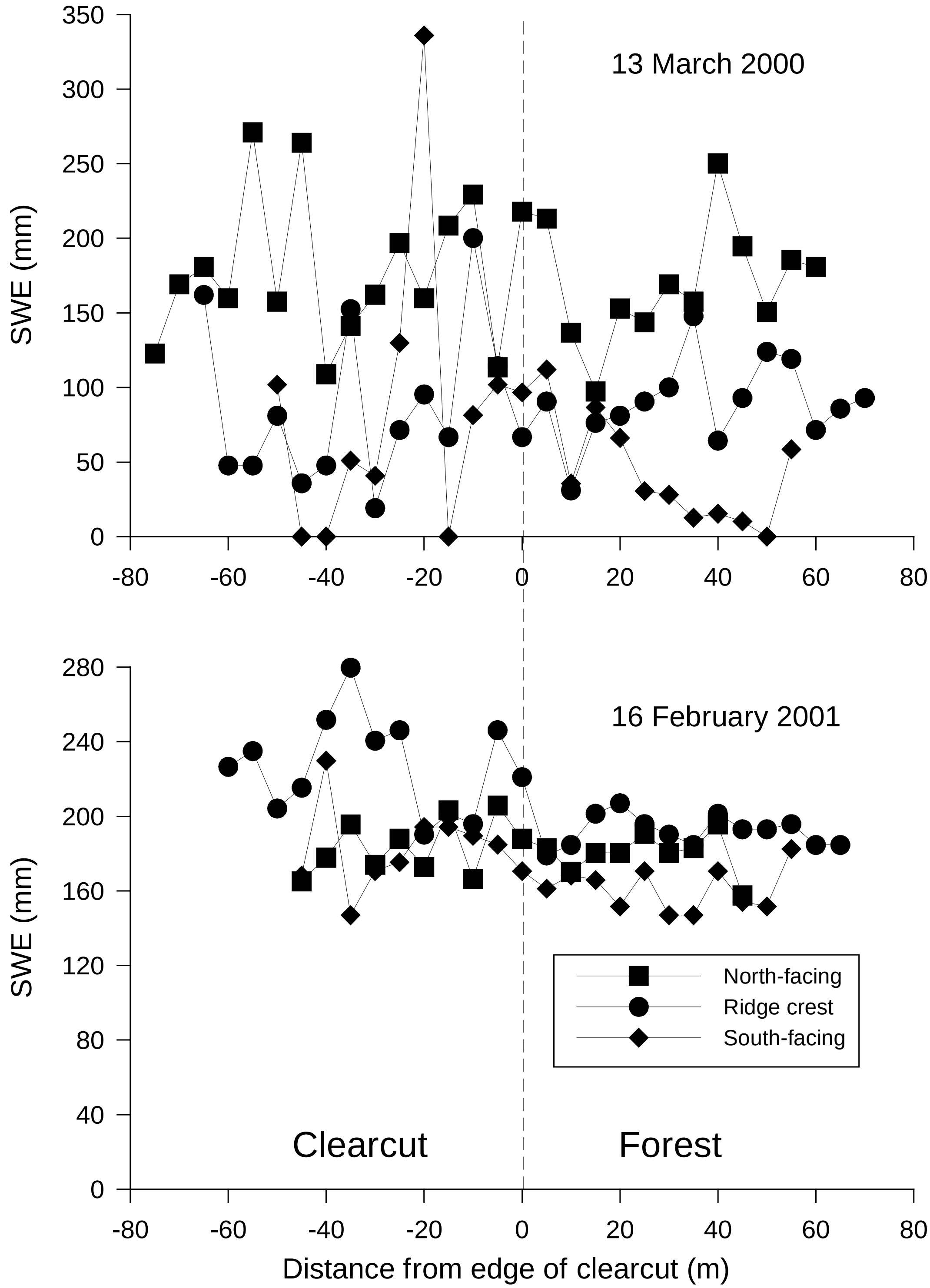

Figure 3: Change in snow water equivalent (SWE) along sampling transects midway through the 2000 spring snowmelt and prior to the 2001 snowmelt.

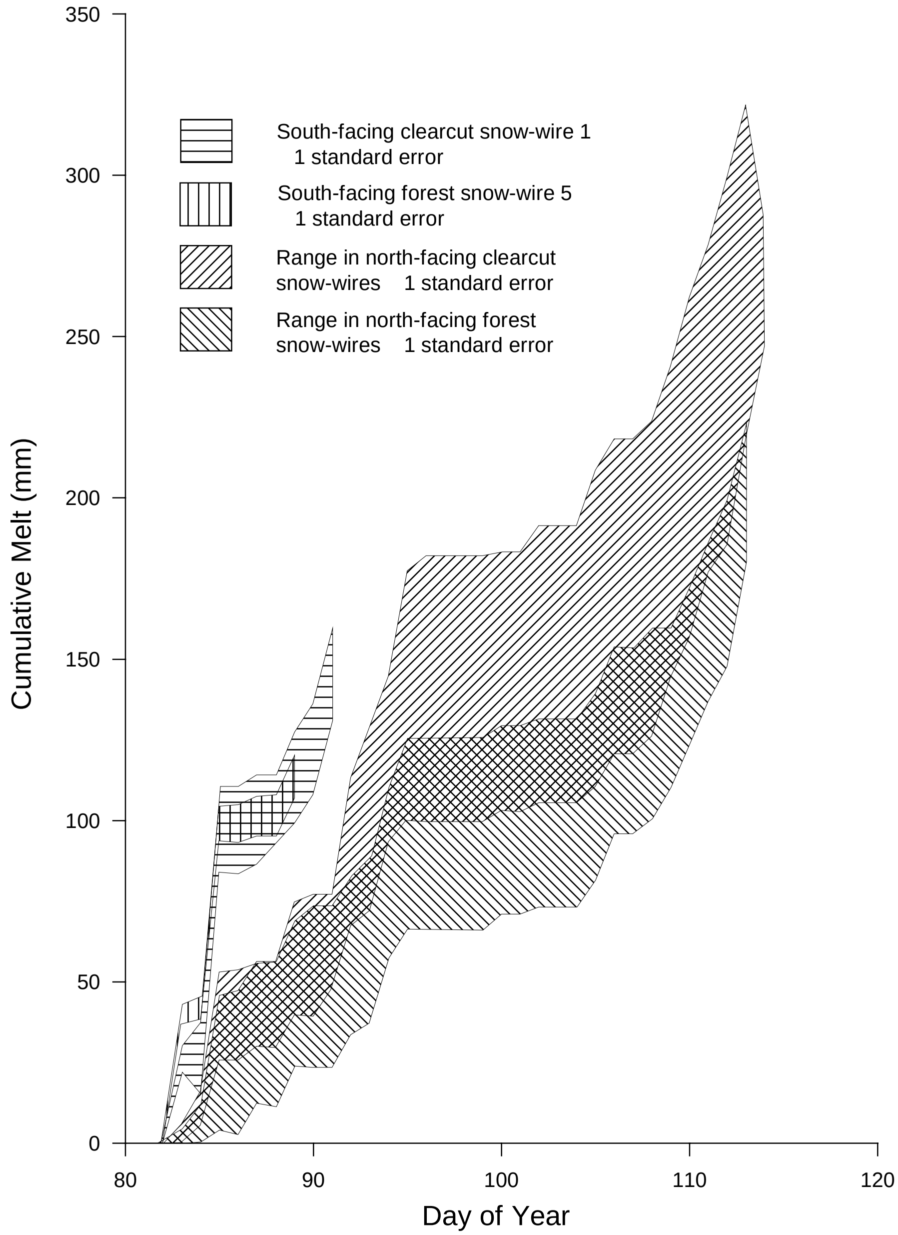

Figure 4: Cumulative melt ± 1 standard error on north- and south-facing slopes during the second half of the 2000 spring snowmelt.

relative to the adjacent forest (Figure 4). On the north-facing slope DSWE decreased with an increase in GF moving from the forest to the clearcut by an average of 7, 7 and 13 days for 25, 50 and 100 mm SWE, respectively. A similar decrease in DSWE was noted for an increase in GF when stands of differing canopy densities were compared in the boreal forest of northern Manitoba (Metcalfe and Buttle 1995). However, GF does not appear to explain variations in daily melt between snow-wires in either the clearcut or forest. This variation may be attributed to inter-site differences in microtopography and proximity to trees and slash that could not be discerned using GF measurements.

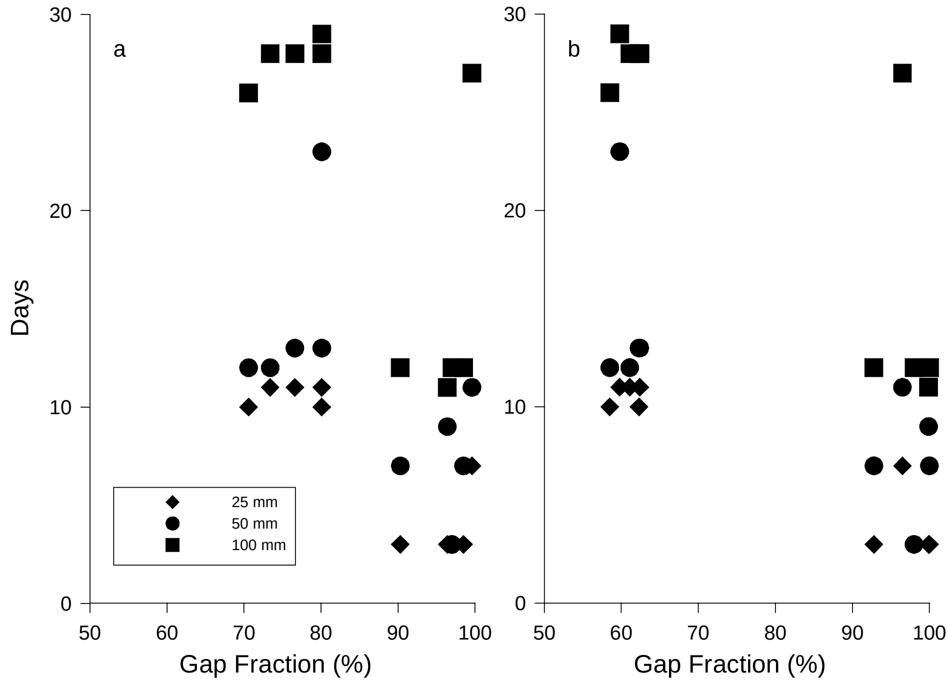

Figure 5: Number of days required to melt a given depth of snow water equivalent vs. gap fraction measured on north (a) and south (b) bearings at each snow-wire site on the north-facing slope.

SUMMARY

Snow accumulation was greater in a clearcut relative to a mature hardwood forest stand on an east-west oriented ridge at TLW. Differences in accumulation were greatest on the ridge crest and south-facing slope, likely due to the prevailing northerly winter winds that redistributed snow from the north-facing clearcut. Aspect exerted greater control on spatial variations in melt than clearcutting did. Nevertheless, daily melt rates tended to be greater in the clearcut relative to the adjacent forest. Canopy gap fraction did not appear to explain variations in daily melt between snow-wires in either the clearcut or forest. This variation may be attributed to inter-site differences in microtopography and proximity to trees and slash that could not be discerned using gap fraction measurements. The differences in accumulation and melt rates between clearcut and forest were not as pronounced as has been observed under coniferous forest cover, likely due to the more open canopy in this hardwood forest. Nevertheless, these differences in pre-melt SWE and melt rate have important implications for spatial and temporal patterns of meltwater delivery to the soil surface at TLW, and subsequent hydrological and hydrochemical fluxes at the point, slope and basin scales.

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