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Areal differentiation of snow accumulation and melt between peatland types in the James Bay Lowland

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Abstract:

Snow accumulation and melt between various peatland types in the James Bay Lowlands is poorly understood despite being a significant source of fresh water to the saline James Bay. Many topographical factors that control snow accumulation and melt (e.g. slope, aspect) are not relevant in the James Bay Lowlands because of the extremely low relief. Thus, vegetation characteristics (e.g. winter leaf area index, tree density), which are strongly linked to peatland type, may dictate spatial patterns of snow accumulation and melt across the landscape. A 1.5-km long transect that bisected five peatland types representative of the local area was used to determine average snow depth, density and water equivalence for each of the landscape units. The peatland types were classified, in part, because of the density of treed vegetation and were named open bog, open shrub fen, low-density treed fen, medium density treed bog and high-density treed fen. Those with medium or high-density treed vegetation accumulated significantly more snow than those with low or open densities. Snow density, however, showed no correlation with landscape unit, and snowmelt proceeded at similar rates between all landscape units because of the relatively open canopy typical of this environment. A randomization test showed that the areally weighted basin average snow depth estimates varied by less than 10 cm as a result of the small but statistically significant differences in snow accumulation among landscape units. These differences are therefore relatively unimportant for accurately quantifying basin-wide snow depth in this landscape.

KEY WORDS peatlands; James Bay Lowlands; snow accumulation; snow melt; landscape units; vegetation density

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INTRODUCTION

The James Bay Lowlands (JBL) represent a significant contribution of the fresh water runoff to the saline James Bay (Rouse *et al*., 1992), yet there is a dearth of information on how different types of wetlands behave hydrologically in terms of snow accumulation and melt. Determining the average snow depth, density and water equivalent for large basins can be critical for an accurate understanding of the hydrological processes (e.g. runoff) in these basins (Pietroniro *et al*., 1996; Hamlin *et al*., 1998; Woo, 1998; Pomeroy *et al*., 2002), yet doing so can be expensive and labour intensive. However, landscape units within the same climatic region tend to accumulate snow with repeatable patterns (Steppuhn and Dyck, 1974; Woo and Marsh, 1978), and thus targeted surveying in easily identifiable landscape units can improve our regional generalizations from a few measurements (Adams and Roulet, 1982) in targeted terrain types (Woo and Marsh, 1978) *versus* a simple random sample (Elder *et al*., 1991).

At the regional (Steppuhn and Dyck, 1974) or macroscale (Pomeroy *et al*., 2002) (10–1000 km) snow accumulation is controlled by latitude, elevation, orographic influences, atmospheric circulation and large water bodies; at the local or mesoscale (100–1000 m), it can be controlled by terrain variables such as elevation, slope and aspect and vegetation variables such as vegetation type, canopy and tree density; and at the microscale (10–100 m) by interception, surface roughness and redistribution along airflow patterns. Despite differences in snow accumulation at the microscale, Pomeroy and Gray (1995) note that snow accumulation patterns are still evident at the stand (meso) scale. These accumulation patterns typically vary with the effective winter leaf area index (LAI; total horizontal area of stems, needles and leaves per unit area of ground) (Pomeroy *et al*., 2002) and the impact of wind redistribution of snow (Benson and Sturm, 1993), both of which should be affected by differences in the relative tree density between different landscape units in the JBL.

Snow interception in forested canopies is impacted in part by the leaf area and tree species (Hedstrom and Pomeroy, 1998), and in combination with sublimation, losses directly from the canopy can greatly reduce snow accumulation in forested sites (Koivusalo and Kokkonen, 2002). In areas where the LAI is low, snow accumulation patterns are similar to those in open areas (Pomeroy *et al*., 2002). Further, wind-blown snow from adjacent open areas will accumulate in stands of more dense vegetation where surface wind speeds are reduced (Benson and Sturm, 1993). The JBL is dominated by low LAI landscape units (e.g. sparse trees in bogs) that have yet

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to be suitably characterized but will likely result in much subtler differences in snow accumulation patterns compared with forested watersheds with higher average LAI and also higher spatial variability in LAI

Relatively little research on snow accumulation and melt processes has been conducted in low relief and sparsely vegetated landscapes typical of Canada's northern lowland regions. Adams and Roulet (1982) studied snow accumulation in a small sub-arctic drainage basin and found that average snow depth was greatest in areas with the closest spacing of trees (e.g. 146 cm with 2–6 m spacing and 126 cm with 7–12 m spacing) and shallowest in open tundra environments (e.g. 77 cm with shrub covered tundra). Sturm *et al.* (2001) found that the deepest snow packs were found in areas with the tallest, densest shrubs in a tundra site in arctic Alaska. Additional research is required to accurately characterize spatial variability of snow accumulation in JBL sub-arctic lowland environment.

The rate of snowmelt at the microscale and macroscale is controlled and also strongly influenced by the vegetation canopy LAI, hence tree density, and its effect on the energy available for snow ablation (Boon, 2009). A forest canopy will reduce the net radiation and turbulent transfer contributions to snow ablation. Similar to accumulation processes mentioned earlier, the relatively open canopies in the JBL may not be notably different than open areas resulting in similar snow melt rates across landscape units.

Many studies have used the landscape unit approach in their snow studies; however, these have largely been used in the Western boreal forest (e.g. Pomeroy *et al.*, 2002), Southern Ontario forest (Adams, 1976), Sierra Nevada alpine (Elder *et al.*, 1991), disturbed forest (Boon, 2011) and sub-Arctic (Adams and Roulet, 1982) and high-Arctic (Woo and Marsh, 1978; Woo and Young, 1997; Woo, 1998) systems. Few studies have employed the 'landscape unit' approach in wetland dominated basins, especially in the JBL where more than 60% of the landscape is covered by bogs and fens (Riley, 2011). Many of the terrain factors that can affect snow accumulation at the mesoscale are irrelevant in extremely low relief areas such as the JBL. Vegetation factors, however, vary with peatland type and are likely to influence snow accumulation and ablation patterns. Different peatland types are, in part, a function of vegetation structure, and unambiguously classifying them is difficult (Di Febo, 2011). While the Canadian Wetland Classification System (NWWG, 1997) categorizes wetlands with a three-level hierarchical system on the basis of (1) class (e.g. bog or fen), (2) form (e.g. peat plateau bog or channel fen) and (3) type (e.g. treed bog or graminoid fen), these hierarchical structures, especially form, are often difficult to identify. Riley (2011) offers an alternative system that ignores form and focuses mostly on class and type, where type is predominantly vegetation based. Therefore, using Riley's (2011) classification scheme would conveniently divide the landscape into relatively homogenous 'landscape units'.

Considering the limited understanding of snow dynamics between and within different 'landscape units' in peatland dominated basins, the objective of this paper is to determine the snow pack and melt regime characteristics of various peatland types in the JBL.

STUDY SITE

The study site is located 500 km north–north–west of Timmins, Ontario, and 90 km west of Attawapiskat, Ontario, in the Hudson–JBL (lat. 52.8349, long. −83.9290). The study area comprises part of the North Granny Creek (NGC) watershed, which is a tributary of the Nayshkootayaow River and subsequently the Attawapiskat River (Figure 1). NGC splits into two distinct channels that we have labelled south-NGC (SNGC) and north-NGC (NNGC).

The snow survey transect was 1.5-km long and bisected five different peatland types common to the area (Figure 1). The start of the transect was a medium density treed lichen-rich bog, which led into areas of low-density treed fen and high-density treed fens in the riparian areas near the streams. The bog that separates SNGC and NNGC is similar to that at the southern end of the transect. At the north end of the transect is an open shrub fen water track classified as open shrub fen. Lastly, there is an open, lichen-rich low shrub bog at the northernmost end. Table I provides a key to the nomenclature (including transect locations).

The two closest stations with long-term meteorological records were Lansdowne House (inland 300 km west–south–west) and Moosonee (near the coast, 250 km south–east). The average annual January and July temperatures for Lansdowne House are −22.3 and 17.2 °C, respectively, and for Moosonee are −20.7 and 15.4 °C, respectively (Environment Canada, 2008). Annual precipitation for Lansdowne House is 700 mm with ~35% falling as snow; for Moosonee, precipitation is 682 mm with ~31% falling as snow.

The study site is located at the De Beers Victor Mine, and therefore the possibility of dust enhanced melt (from blasting in the open pit) must be addressed (Drake, 1981). Drake and Moore (1980) studied dust loading around a mine in Schefferville, Quebec, and noted that prevailing winds were a large control on dust fall and that within a distance of 1 km cross-wind from the disturbed area, dust fall returns to a '. . .presumably normal background level'. The normal background values by Drake and Moore (1980) are reported as 2 g/m^2 over the winter season (~6 months). The study area at the Victor Mine is located several (3–4) kilometres directly upwind of the mine, and thus dust fall is likely not an issue. In addition, as part of De Beers' monitoring requirements, dust fall is collected at four orthogonal locations around the mine. At the location nearest the transect, dust falls for 2008, 2009 and 2010 for May were 0.8, 1.8 and 1.2 g/m^2/30 days (Steinback (De Beers Canada, Victor Diamond Mine), pers. comm.; 2011 data were not ready for release, but

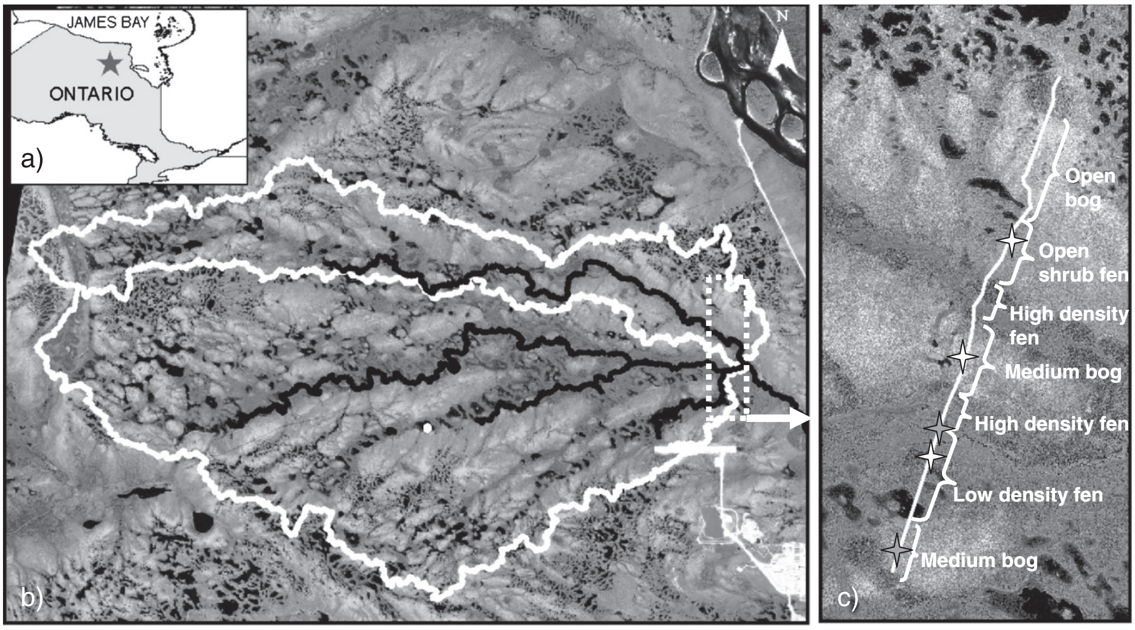

Figure 1. Site map. (a) Location of study area within Ontario. (b) IKONOS image showing part of the NGC watershed divided into the NNGC and SNGC subwatersheds (white lines) and the streams (black lines). The De Beers Victor mine camp is visible in the lower right hand corner; the pit is located ~1 km further to the right. The image is approximately 9 km across. (c) IKONOS image of the snow survey transect (solid white line), ablation lines and snow pits (all stars 2009, grey stars 2011) and landscape types along the transect. The transect is 1500 m long. Note: Some high vegetation density fen sites do exist in the low-density fen areas but have been omitted in Figure 1 and Table I for simplification. They were classified correctly for all analyses

Table I. Landscape classification class and type

Distance along transect (m)	Classification (Riley, 2011)	Official	This paper	Tree properties		
				Height (m)	Distance (m)	% treed
0 to 145; 615 to 810	Medium density treed lichen-rich bog	T(md)lrB	Medium bog	3.3	16	50
145 to 580	Open treed or low-density treed fen	T^5F-T(ld)F	Low-density fen	3.9	17	18
580 to 615; 810 to 866	High-density treed fen	T(hd)F	High-density fen	3.9	4	63
886 to 1200	Open shrub fen	OsF	Open shrub fen	3.0	29	6
1200 to 1500	Open, lichen-rich low shrub bog	OlrlsB	Open bog	3.7	35	12

The superscript T^5 is a quantification of how open the area is, e.g. <5% tree cover. The letters can be deduced from the classification column. Tree distance was determined from the manual tree density survey. Height was determined as the average of non-zero returns from the canopy height model. % treed was calculated as the number of non-zero returns for that landscape type/total returns (zero and non-zero) for that landscape type × 100.

as the pit continues to get deeper, the risk of dust contamination diminishes), which, although slightly higher, are in-line with those reported by Drake and Moore (1980).

METHODS

Meteorological

A weather station was erected ~1 km south of the Victor Mine in March 2000; this weather station was decommissioned when a new weather station was erected ~2 km north of the Victor Mine near the study area in April 2008. Both weather stations measured precipitation, temperature, relative humidity, net radiation, wind speed and direction.

Snow surveys and ablation lines

Snow surveys were conducted every 4–5 days from April to May in 2009 and 2011 along the research transect. In 2010, there was an abnormally low snowfall and early melt and is not considered in this paper. Depth measurements using a metal ruler were taken every 15 paces (~10 m) with depth and snow water equivalent (SWE) every 30 paces using an ESC-30 (Eastern Snow Conference) plastic snow tube (1.2 m by 0.07 m i.d.) and hanging mass scale. SWE was calculated on the basis of the mass of the snow in the tube and water density of 1 g/cm^3; snow density was calculated using the volume (depth of the sample and tube dimension). At each SWE measurement location, a GPS reading (±4 m) was taken to locate the landscape type sampled (a separate ground truthing survey for landscape classification was completed in November 2009). To measure the rate of snowmelt, measurements of the change in snow surface elevation were made at 0.5 m intervals along 6.5 to 10.5 m ablation wires. In 2009 (all stars, Figure 1), they were erected in medium bog (*x*2), low-density fen (*x*2) and open shrub fen (1) (Figure 1) and, in 2011 (grey stars only, Figure 1), in medium bog (1) and low-density treed fen (1). Snow pits were used to measure density and temperature profiles in the area near each ablation line in both years; however, they were only completed once in 2011. Density samples were taken using a fixed volume cutter ($6 \times 3 \times 5.5\,cm = 99\,cm^3$) centred at every 5 cm for the entire snow pit depth. Ablation lines and snow pits were measured when they were reached along the snow survey transect. Different snow pits in roughly the same area (within 5 m) were used each time.

Tree canopy properties

Starting at the southern end of the transect, the distance and the diameter at breast height (DBH) was measured for the closest tree in each quarter [following the point-quarter method (Cottam and Curtis, 1956)] at a point every 50 m along the transect. Because of the stunted growth of trees in the JBL, the definition of tree was extended to those with a DBH of 6 cm rather than 10 cm. Where canopy cover was very open (e.g. north end of the transect) and trees would be double counted (i.e. the same tree would be the closest for the subsequent quarter), the spacing was increased or the survey stopped.

To create the canopy height model, a 5-m resolution digital surface model (DSM) was first interpolated using the maximum elevation of all LiDAR returns using a 5 by 5 m moving window that followed the snow survey transect. The ground surface elevation was subtracted from this DSM using the 5-m resolution bare earth digital elevation model (DEM). Areas with no classified vegetation returns were assigned a height of 0 m.

Landscape classification

The watershed boundaries and landscape composition are based on classification of LiDAR and IKONOS remote sensing imagery (Di Febo, 2011). Briefly, a maximum likelihood classification was conducted on the IKONOS red, green, blue and near-infrared bands as well as several topographic derivatives computed from a 2.5-m resolution LiDAR derived DEM that were shown to improve the classification accuracy. The final cross-validated accuracy of the classification (using separate training and validation classes and excluding water, which is relatively easy to discriminate) was approximately 80%.

RESULTS

The average April temperature (when the majority of the melt occurs) based on the 8-year record located on site (2000–2007) fell between those at Lansdowne House and Moosonee, suggesting that those stations could be used for the long-term average. The average daily temperatures for April 2009 and 2011 and the 30-year Lansdowne House and Moosonee averages were, −2.9, −2.2, −2.4 and −1.6 °C, respectively, making 2009 slightly cooler than average and 2011 average. The first half of April 2009 averaged −6 °C, whereas for 2011, it was −3 °C, in part because of a warm period (average daily temperatures >0) for 4 out of 5 days (and the <0 day daily temperature was only −1.8 °C) from 8 April to 13 April 2011; the second half of April was similar for both years (Figure 2). In 2009, a 5-day warm period occurred from 13 April to 18 April, with 16 April 2009 having a daily average and max temperature of 7.4 and 15.3 °C, respectively. Wind speeds were higher for the start of melt in 2009 but were similar between years after ~18 April 18. For 2009 and 2011, snow accumulation at the end of March (i.e. near the start of melt) was 133% and 71%, respectively, of the normal values reported at Lansdowne House (inland station), although snow melt in 2011 had started prior to our arrival.

In 2009, snowmelt started on 9 April and continued until ~7 May. Average snow depth across the site was 75 cm at the onset of melt, ranging from 63 cm in the open shrub fen to 90 cm in the medium bog (Figure 3). In 2011, snow melt had started before we arrived on site and some ripening and settling of the snow pack had occurred; however, very few bare patches were present (the tops of a few hummocks at the northern end of the transect were visible). Average snow depth upon arrival in 2011 was 39 cm, ranging from 27 cm in the open bog to 47 cm in the high-density fen (Figure 4). The completion of melt was not well documented in 2011 because of limited field personnel but the site became snow free ~28 April. For both years, the medium bog and

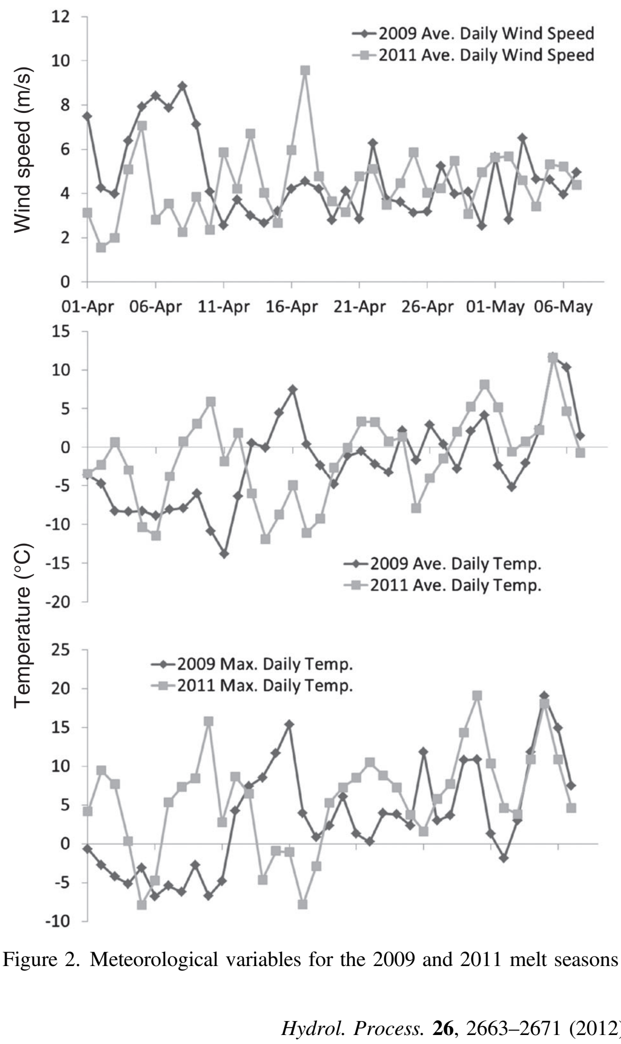

Figure 2. Meteorological variables for the 2009 and 2011 melt seasons

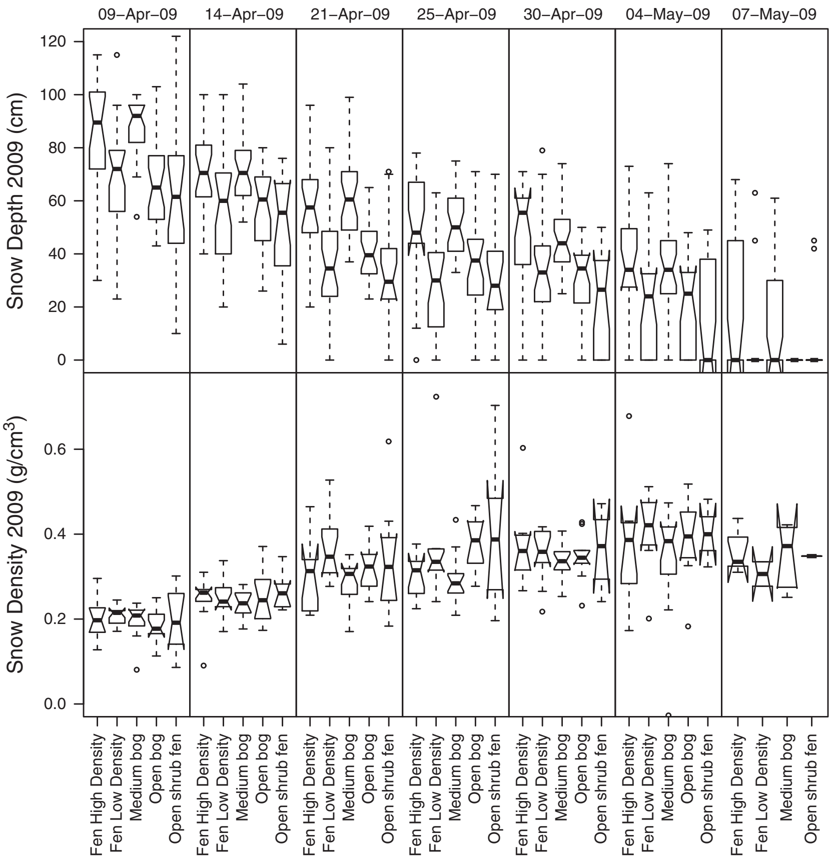

Figure 3. Box plots of snow depth (top) and density (bottom) through the melt period for 2009. The whiskers (upper and lower lines) show the 5% and 95% values, and open circles are outliers. The notches above and below the median can be used as a visual test of significance: where the notches do not overlap (e.g. low-density fen, medium bog), they are significantly different at 5%, but where they do overlap (e.g. open bog and open shrub fen), they are not significantly different (R Development Core Team, 2009)

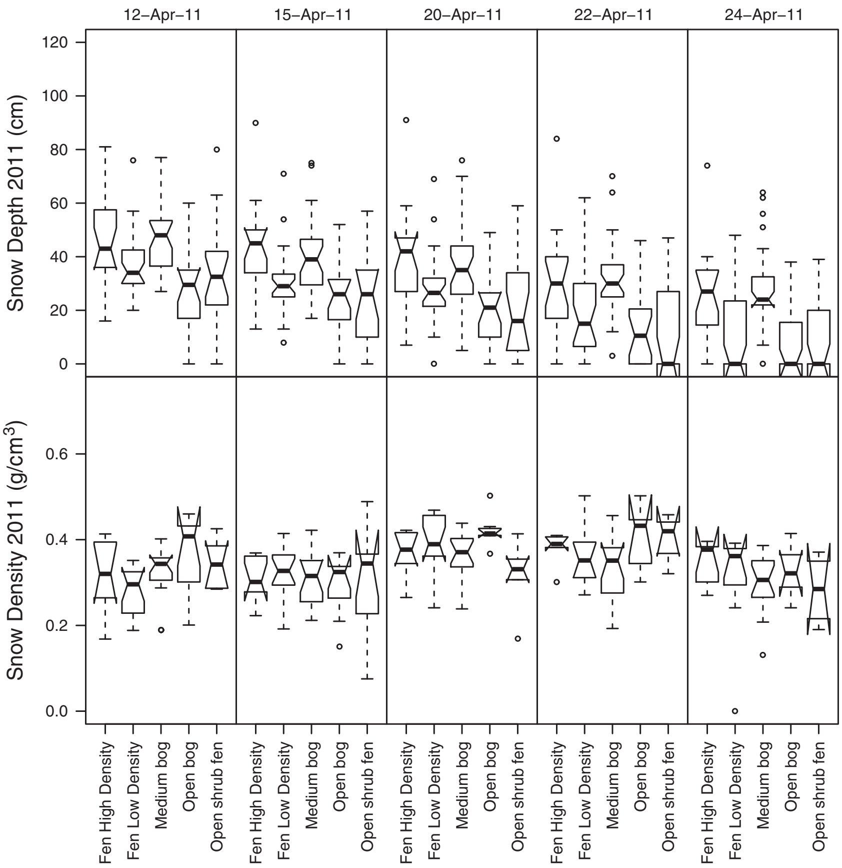

Figure 4. Snow depth (top) and density (bottom) through the melt period for 2011. See comment for Figure 3

Table II. *p*-values of Wilcoxon rank sum difference of means test for snow density (below diagonal) and snow depth (above diagonal) at onset of snowmelt (2009/2011)

	Fen high density	Fen low density	Medium bog	Open bog	Open shrub fen
Fen high density	—	**≤0.01/≤0.01**	0.95/0.90	**≤0.0001/≤0.0001**	**≤0.001/0.013**
Fen low density	0.90/0.43	—	**≤0.0001/≤0.0001**	0.45/0.24	0.29/0.32
Medium bog	0.73/0.79	0.76/**≤0.05**	—	**≤0.0001/≤0.01**	**≤0.0001/≤0.001**
Open bog	0.29/0.22	0.10/**≤0.05**	0.20/0.20	—	0.48/0.03
Open shrub fen	0.86/0.53	0.87/0.10	0.91/0.71	0.53/0.23	—

Bold entries significant at 95% or better.

high-density fen were above average in snow accumulation and were statistically significantly different than the open shrub fen, low-density fen and open bog, which were below average (Table II).

At the onset of melt in 2009, snow density ranged from 0.17 to 0.20 g/cm^3 in the open bog and low-density fen, respectively, but offered no real trend with landscape type (Figure 4). Snow water equivalence ranged from 12 cm in the open shrub fen to 18 cm in the medium bog. The site remained completely snow covered until 13 April and became functionally snow free ~7 May (some small, isolated drifts in heavily treed areas remained) (Figure 3). In 2011, snow density ranged from 0.28 g/cm^3 in the low-density fen to 0.36 g/cm^3 in the open bog on the first day of measurement (Figure 4). Again, no real trend with landscape type was observed. SWE was highest in the medium bog at 16 cm on the first day of measurements and was lowest in the low-density fen with 11 cm. In both years, the medium bog had the highest SWE followed by high-density fen. Open bog was the second lowest in both years.

The rate of snow surface lowering beneath the ablation lines in 2009 and 2011 were very similar between landscape types for the same period for both years and ranged between 0.5 and 10 cm/day (Figure 5a and b). The large increase in the second medium bog location was due to some small patches of relatively deep snow remaining that melted to nothing very quickly. For 2009, these corresponded to melt rates of between 2.3 and 0.24 cm/day (Figure 5c) and again were similar between all landscape types. The fewer points are a result of no snow pits being conducted on the last measurement days because of a very shallow snow pack.

Temperature profiles (not shown) in the snow pits in 2009 showed the snow profile in all five of the pits becoming isothermal and ripe (~0 °C) around 21 April shortly after the warm period noted previously (Figure 2). In 2011, the first (and only) snow pits (April 12) showed an already isothermal and ripe snow pack, again, corresponding with the end of the warm period (Figure 2).

The average distance to a tree (which is an inverse surrogate for tree density) is being used in this paper instead of tree density as it removes the need for dividing by an arbitrary area (e.g. hectares) to convert distance to a density. Snow depth at the onset of melt (or first survey for 2011) was inversely correlated to average distance to tree (Table I, Figure 6). The open bog point was artificially placed at 35-m distance as the tree density survey was stopped because of very low tree density (35 m was the furthest distance recorded in the open shrub fen before the survey was terminated). The R^2 values excluding the open bog point for 2009 and 2011 are 0.52 and 0.56, respectively. The open fen and open bog had 6% and 12% tree coverage on the basis of the canopy model created by the LiDAR, compared with 50% and 63% coverage for the medium bog and high-density fen locations, respectively (Table I). Shrub heights were not part of the original tree survey; however, personal observations show that in the medium bogs, shrubs were ~<60 cm tall and spaced similarly to the trees. In the open fen and open bog, shrubs were much more prevalent than trees however less frequent that in the medium bog locations and were smaller (~<45 cm).

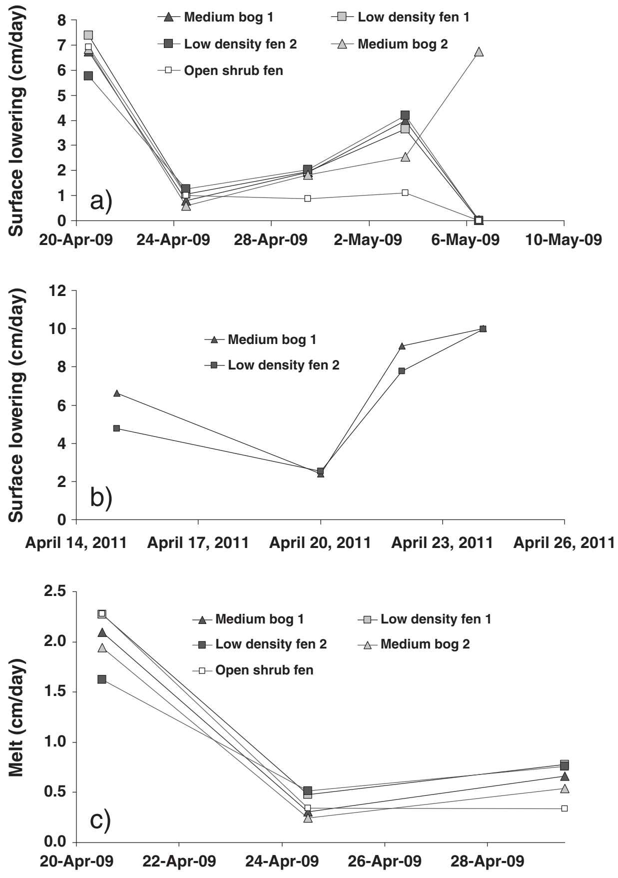

Figure 5. Snow surface lowering determined from ablation lines for 2009 (a) and 2011 (b) and the corresponding melt rates for 2009 (c). Snow pits were not completed on the last day

Figure 6. Average distance to tree *versus* snow depth for the different landscape types for 2009 (dark) and 2011 (white) initial snow survey. Recall tree being defined at a DBH > 6 cm

DISCUSSION

Classification of any landscape into 'landscape units' is difficult, especially low relief environments such as the JBL. Riley's (2011) system offers more flexibility over the NWWG (1997) as many of the types are scale dependant on the density of treed vegetation. Snow depth in this peatland complex varied by site (Figures 3 and 4) and was statistically significant between those with higher density and those with lower density (Table II). For instance, low-density and high-density fen were different; however, low-density fen and open bog or open shrub fen were not. This is also supported by the strong correlation between snow depth and tree distance (Figure 6). Sites with high or medium tree densities had snow depth above the overall average, and those with low tree densities were below; this trend was consistent for both years' data. Snow density, however, was similar among landscape types, and almost none were significantly different.

Melt rates were similar between landscape types, and most proceeded at very similar rates (Figure 5c), regardless of tree density. While the snow is deeper in areas with denser tree cover, shading by the canopy of these stunted, relatively well-spaced trees is minimal, and at almost all points along the transect, there is always a clear view of the sky. Reifsnyder and Lull (1965) showed that in forested environments (red pine), reducing canopy cover from 1.5 m average distance to tree to 7.7 m increased light intensity from 15 to 60%. As the tree distance is much larger in our study area (16 to >35 m) and the stunted black spruce typical of the JBL would have an already more open canopy than red pine, it is not surprising that melt rates proceeded similarly among landscape types. Exceptions to this are the very dense forested areas near the streams (average distance to tree of <4 m), but these represent a small proportion of the area [about 3% (Di Febo 2011)]. Therefore, the denser tree cover generally encourages snow deposition, likely due to lower wind speeds (Benson and Sturm, 1993; Ketcheson *et al.*, 2012), but is insufficient to markedly reduce the radiation budget and thus the rate of melt. While we do not have meteorological instruments in the forested sections to quantify the wind speed differences, field observations support lower wind speeds in the treed areas compared with the open fen and bog. Therefore, the duration of the snowmelt period in the JBL is ultimately dependant on how much snow was present at the start of the melt and the radiation balance.

Our results indicate small but statistically different snow depths between the majority of the landscape units at this JBL study site. In order to test whether these differences were *hydrologically* important at the scale of the entire drainage basin, a simple reallocation experiment was conducted. On the basis of the analysis of Di Febo (2011), we were able to relate our landscape units to Di

Table III. % area for each of the landscape units of the North Granny Creek basin and an example of the randomization for 9 April 2009

		Snow depths 9 April 2009			
			Areally weighed		
Landscape Unit	Area (%)	Survey	Correct	Max	Min
High-density fen	8	85.9	85.9	62.8	90.5
Open bog	17	65.4	65.4	65.4	85.9
Open shrub fen	19	62.8	62.8	67.7	67.7
Medium bog	26	90.5	90.5	85.9	65.4
Low-density fen	30	67.7	67.7	90.5	62.8
	Average	74.5	73.7	78.6	70.4

For example, the high-density fen occupied 8% of the area and contained 85.9 cm of snow on the basis of the field survey and therefore contributes $0.08 \times 85.9\,\mathrm{cm} = 6.9\,\mathrm{cm}$ of the 73.7-cm basin average for the 'correct' areally weighed allocation column.

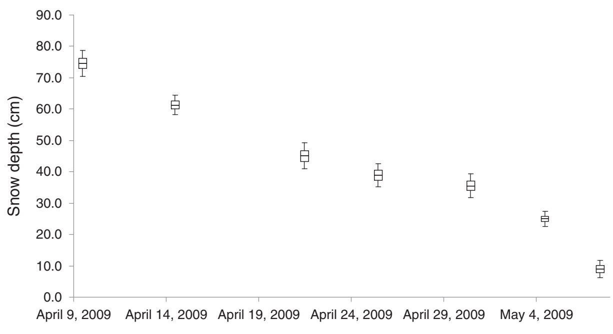

Figure 7. Randomized areally weighted average snow depths for the NGC basin. Whiskers in these box plots represent min and max

Febo's (2011) to areally weight the snow depths for the entire basin for the snow melt period. These areally weighted basin average snow depth values were always within 0.8 cm (Table III) of the field snow survey average, suggesting that the snow survey chosen was representative of the basin as a whole (Table III). To test the importance of the differences between landscape units, observed snow depths were re-assigned to different land cover types iteratively until all possible permutations of land cover type/snow depth observations were satisfied. The basin average snow depth was re-calculated each iteration and recorded. There are five landscape units, and therefore, there are 120 ($5! = 5 \times 4 \times 3 \times 2 \times 1 = 120$) ways (permutations) of reallocating the depths to the landscape unit areas. Table III shows an example for the first day of snow surveys in 2009. The snow survey average was 74.5 cm at the onset of melt, which compared well with the average of the 'correct' order of areally weighting the depths of 73.7 cm. The maximum (max column, Table III) would be one outcome (of the 120) where the depths arranged themselves ascending with ascending area (i.e. the shallowest snow depths with the smallest areas), whereas the minimum (min column, Table III) would occur when they were arranged in reverse. For example, the 62.8-cm average depth for open shrub fen was applied to the area for high-density fen (max) and then to low-density fen (min) (Table III). The outcomes of the other 117 (min, max, and correct) cases are summarized using box plots (Figure 7). The range (max–min) varied between 5.2 and 8.3 cm, with an average range of 6.9 cm. The inter-quartile range (upper–lower quartile) where 50% of the outcomes would occur ranged from 2 to 3.6 cm, with an average of 2.8 cm. Given the large natural variability of snow depth within a landscape type (Figures 3 and 4), these ranges are well within the expected error of measurement, implying that while landscape types do, generally, have statistically significantly different snow packs than each other, this difference is not important to the basin's average snow depth.

CONCLUSION

In this area of the JBL, snow depth is controlled mostly by land cover type and its associated vegetation characteristics, as opposed other landscapes where topography, aspect and slope have a much stronger influence on snow depth. Despite differences in snow depth, melt rates were similar across all landscape types, in part because of the relatively open canopy cover throughout this sparsely vegetated landscape. Because of the similar proportions of open bog/fen and low/medium fen and bog, and small area of high-density fen, changing the distribution of snowfall by re-allocating it did not significantly affect the average basin snow depth. Our findings contrast those of many other studies that have shown that topography and vegetation strongly influence the spatial pattern of snow accumulation and melt and must be specifically addressed as part of any snow sampling strategy designed to estimate basin-wide snow depth. Here, we found that a simple snow survey that transects some open and treed areas is sufficient to estimate basin-wide snow depth.

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