EFFECTS OF TREE HEIGHT ON SNOWPACK INSTABILITY IN THE NORTH SHORE MOUNTAINS OF VANCOUVER, BC CANADA

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ABSTRACT: This study aims to understand if there is a relationship with an easily measurable variable, tree height, and snowpack instability; such that instability assessment can be determined at the micro-scale and interpolated over a large spatial scale. Seven sample sites were chosen north of Mount Seymour ski area in the North Shore Mountains of Vancouver, BC that had trees of various heights: low (1.5-5m), medium (5-15m) and high (>15m). These sites were sampled at a 2-meter and 4-meter downslope distance from the tree base for various snowpack instability score data; including class I, II, and III categories of data. There was no significant effect of tree height on snowpack instability. However, there was a significant difference between the low and medium tree height classes on total instability, class II data instability, and average wind speed. These results were surprising, as it was predicted that with greater tree height, there'd be less instability. However, canopy-effects that begin at the medium tree height class seem to diminish the number of instabilities present, especially focused on the snowpack stratigraphy (class II) characteristics. These results suggest there may be a relationship that begins at the medium tree height class, though future research is required to define a specific threshold in which tree height contributes to less instability. Research regarding maritime snowpack climates is rare, and as such, understanding the influence of vegetation on snow metamorphism in a maritime snowpack can provide useful information for decision-making tools within these regions.

KEYWORDS: spatial variability, vegetation effects, snow metamorphism, PWLs, maritime snowpack climate, start zone characteristics

1. INTRODUCTION

Vegetation effects play a critical role in managing avalanche risk in North America. Compared to other regions where avalanches occur in the world, the US and Canada have much more forested terrain (Weir 2002). Historically, most research has focused on the effect tree density has on providing areas of less instability (McClung 2001). However, the effects that vegetation has on the snowpack are many, and a large contributor to the remaining effects includes crown canopy-induced effects (McClung and Schaerer 2006). Because tree height is directly proportional to crown canopy extent (Brett 1997), there may be a relationship between tree height and snowpack instability.

While there are many studies observing the influence of tree density on snowpack instabilities (Stethem et al. 2003), few studies correlate the influence of other vegetation factors on the snowpack. Vegetation effects included here are twofold: 1) the influence of the crown on atmospheric and snow surface conditions and 2) canopy-induced microclimatic effects that may affect snow metamorphism (McClung and Schaerer 2006).

There exists amble evidence that crown closure has a role in influencing many micro-climatic and class III variables that ultimately influence instability, including: radiative heat transport and loss, dampening wind effects, interception of recent snowfall within the canopy, etc (McClung and Schaerer 2006). In addition, there is plenty of evidence correlating the direct relationship of tree height to crown closure (Brett 1997). However, few studies observe a relationship between tree height and its impact on snowpack instability.

This study aims to understand micro-scale factors (factors with a spatial resolution within 2 meters) that lead to changes in instability and how they are influenced by an easily measurable terrain feature, tree height. Implications of this research could better understand how to map micro-scale variability on a larger landscape scale (whole drainages, an entire highway corridor, etc), and better understand start-zone characteristics that influence instability in maritime snowpack climates.

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2. METHODS

2.1 *Instability Analysis*

Instability is evaluated by analyzing a number of factors when making avalanche-forecasting decisions (McClung and Schaerer 2006). For the purpose of this study, instability is defined as the elements contributing to an unstable snow condition primed for avalanche release; which is a combination of two factors: where and how the stress is applied (stress distribution), ultimately causing shear-fracture failure of a weak layer in the substratum below the slab (shear fracture toughness; Schweizer et al. 2003). Stress distribution relates to where and how much force is applied to a specific snowpack (McClung 2008). Generally, when shear stress exceeds shear strength, there is a condition primed for avalanche initiation (McClung 2008). Shear-fracture toughness is the amount of force required to cause shear deformation of crystals in the weak layer such that propagation will occur (McClung 2008).

Due to the high degree of uncertainty each data type provides on influencing the final instability score, multiple types of data are required to determine instability (McClung 1995). Instability can be quantified based on three major categories of data: direct avalanche instability data (class I), snowpack stratigraphy data (class II) and meteorological data (class III). Elements of direct avalanche and instability data (class I), combined with snowpack stratigraphy components (class II) are weighted to produce a final instability score. Micro-scale meteorological factors (class III) data are then compared to the instability score to observe the effect that they have on producing an unstable snow condition.

In this study, a system to assess instability quantitatively between samples was developed, and is described in Table 1 below. Overall instability scores are a sum of total class I and II data types.

2.2 *Study Area*

Observations on instability were collected in the field at sample sites immediately north of Mount Seymour Ski Area (UTM Zone 10U, 504221.37 m E, 5469631.09 m N; Fig. 1). This region is classified as a maritime snowpack climate. Therefore, avalanche problem types associated with this snowpack climate generally are associated with specific storm events (storm and wind slab) or moisture and radiation effects later in the season (wet slab, loose wet, etc; Haegeli et al. 2010). These problem types are vastly different from problems generally encountered in a more continental snowpack climate, where avalanche problems are predominately developed by constructive metamorphism in persistent weak layer forms (Haegeli et al. 2010).

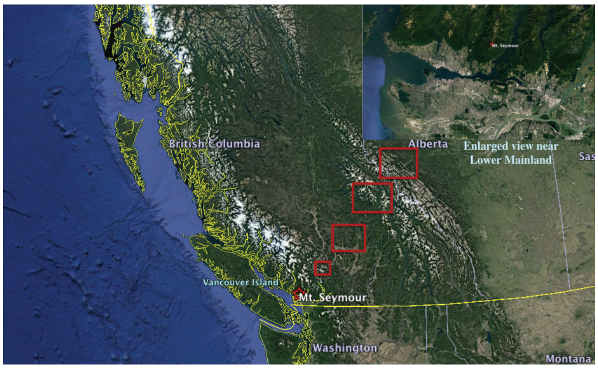

Fig. 1: Location of Mt. Seymour and study sites.

All sites were chosen based on the criteria of 1) being accessible to reach via hiking, 2) low probability of hiker or skier compaction at each sampling site and 3) isolated spatially by a tree of each height class. In addition, site characteristics such as slope angle, position on slope, aspect, and elevation were controlled for to minimize the effect of these factors on collected data. I used the tangential method to determine the height of each tree measured within a sample (Larjavaara and Muller-Landau 2013).

Table 1: Summary of weights for Class I and Class II data classes for determination of total instability score. Extended column test (ECT) codes are described in ORGS 2014.

Data Class	Type of Data	Qualitative Stability Rating	Data Value	Class Weight
Class I	ECTX	Very Good (VG)	1	2x
	ECTN21-30	Good (G)	2	2x
	ECTN11-20	Fair (F)	3	2x
	ECTN1-10	Poor (P)	4	2x
	ECTV	Very Poor (VP)	5	2x
Propagation	Presence or absence	-		1.5x presence, 1x absence
Overall I	Total Class I Score = (Data Value*propagation score)*class weight			
Class II	Yellow Flags Data		Sum of interface & layers	1x
Overall II	Total sum of yellow flag data		Total II = (Sum of interface and layers for yellow flag data)*class weight	

2.3 *Data Collection*

In order to collect instability score data, full snow profiles adjacent to each sample site were dug in accordance to CAA Observational Guidelines and Recording Standards for Weather, Snowpack, and Avalanches, (OGRS 2014). Direct evidence of instability (class I) data were evaluated by conducting an extended column test (ECT) in the test wall of each pit prior to evaluating each for snowpack stratigraphy (class II) data. Class II data was quantified using Jamieson and Schweizer's (2005) Yellow Flags criteria to assess snow profiles. Micro scale meteorological (class III) data were measured via kestrel instruments throughout the sampling day at two hour intervals to 1) measure any temporal variability throughout each sampling day and 2) determine how vegetation affected the micro scale climatology within each sample, which may effect the snowpack structure indirectly.

Sampling occurred in periods of calm weather immediately after storm events. The aim with this study design was to reduce temporal variability during each sampling day, while ensuring signs of instability were present.

Temporal variability was designed to be minimized, but unfortunately was not eliminated from this study due to limited resources available when collecting data. All pits were dug to an equal depth on all three-tree height classes for each sample before conducting tests to minimize the effects of temporal variability.

3. RESULTS AND DISCUSSION

Tree height has no significant effect on snowpack instability overall, when looking at the effects among all three tree height classes. However, significant variability exists between the low and medium tree height class, especially when observing the total instability score, snowpack stratigraphy factors, and average wind speed.

These results are surprising, as tree canopies associated with taller trees have been shown to dampen wind effects at the snow surface, intercept snow, and cause much more mild temperatures overall. However, there is a significant difference between low and medium tree heights, and very little difference between medium and high tree height classes (regarding instability), suggesting that canopy influences may not be present for low tree heights, but the canopy becomes significant enough in size to influence instability factors at the medium tree height class (Davis et al. 1997).

Because the factors that were most affected between the low and medium tree height classes were total instability, snowpack stratigraphy factors, and average wind speed, it may be true that high canopy extent is influencing

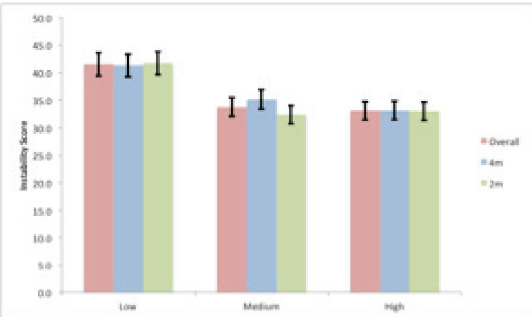

Fig. 2: Mean instability scores for each tree height class.

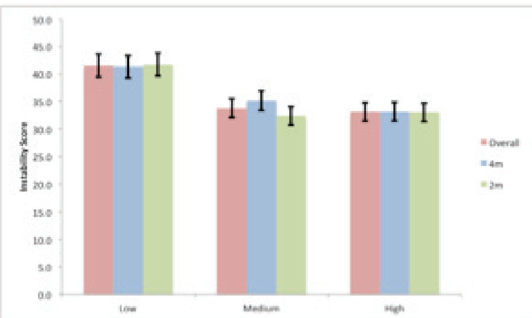

Fig. 3: Mean yellow flag scores for each tree height class.

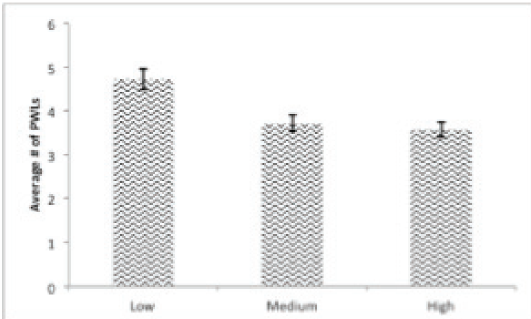

Fig. 4: Average number of persistent weak layer (PWL) forms in snowpack for each height.

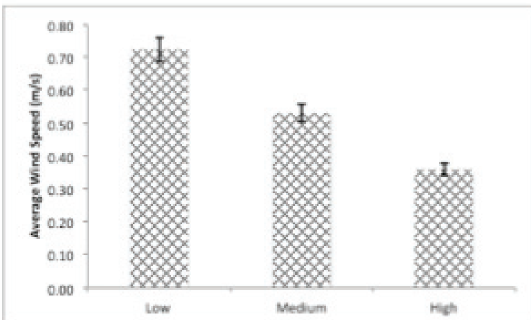

Fig. 5: Overall average wind speed for each tree height class.

metamorphism in addition to providing the wind dampening effects as predicted.

Looking at snowpack stratigraphy first, there was a significant difference between the number of yellow flags associated with low and medium tree height classes for both the 4m and 2m downslope samples (Fig. 3), with snowpacks associated with low tree heights having significantly higher numbers of yellow flags. As a reminder, the Yellow Flags criteria assigns values to layers and interfaces present in a snowpack that are most likely to be a concern for avalanche initiation (Jamieson and Schweizer 2005). The criteria associated with higher yellow flags primarily consist of large changes in grain size, hardness, depth of the interface, and presence/absence of PWLs (Jamieson and Schweizer 2005). Observing these data, significantly fewer PWLs were present for snowpits in the medium and high tree height classes when compared to the low tree height class (Fig. 4). This implies that canopy effects may play a role in destructive snow metamorphism, and limit the development of persistent weak layer forms.

Average wind speed was significantly different among all tree height classes, with an indirect relationship between tree height and wind speed (higher tree height, lower wind speed, Fig. 5). These results explain that the canopy is affecting wind dampening as stated previously; however, this effect is not limiting the development of wind slab formation as there is no trend between a lower frequency of wind-packed particles for snowpacks near trees of higher heights. Further studies focusing on the effects of canopies in relation to wind slab development would be useful to understand if there is a relationship existing here.

4. CONCLUSIONS

With the results discussed above, there is a clear relationship at the medium tree height class where instability is lessened. Crown canopy effects likely play the most significant role in influencing this relationship. How the canopy influences the processes that affect instability however is yet to be determined.

Implications of determining a quantitative relationship between tree height and instability scores in a maritime snowpack climate are massive. Using remote sensing technologies, as well as geospatial data, we could map and understand snowpack spatial variability at very small (within 2m) scales, yet be able to interpret these relationships over large spatial scales. Few studies observe this relationship in maritime snowpack climates, therefore understanding how vegetation influences snowpack structure and instability in these climates can help us manage avalanche risk in these snowpack climates.

5. FUTURE STUDIES

As this study is one of the first of its kind measuring crown canopy effects on a maritime snowpack, many future studies would be useful to understand the effects and implications of vegetation on the snowpack.

As mentioned above, understanding the effects that wind dampening have on limiting wind slab development would be useful, especially given that there is such a direct relationship between tree height and average wind speed.

In addition, since fewer PWLs exist for snowpits in the medium and high tree height classes, it would be valuable to understand if vegetation plays a role in either 1) promoting destructive metamorphism, or the sintering process and/or 2) limiting the development of persistent weak layer forms.

Also, it would be useful to understand where at the medium tree height class there is more or less instability. This class was the most diverse of all the classes described (ranging from 5-15m tall trees), and hence understanding what the threshold in tree height is that contributes to more or less instability can be determined by breaking down this class further.

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REFERENCES

Brett, R. B. (1997). Regeneration patterns on some old-growth and clearcut sites in the Mountain Hemlock zone of southern British Columbia (Doctoral dissertation, University of British Columbia).

Canadian Avalanche Association. (2014). Observation guidelines and recording standards for weather, snowpack, and avalanches. pp. 1-91.

Davis, R. E., Hardy, J. P., Ni, W., Woodcock, C., McKenzie, J. C., Jordan, R., & Li, X. (1997). Variation of snow cover ablation in the boreal forest: A sensitivity study on the effects of conifer canopy. *Journal of Geophysical Research. D. Atmospheres, 102,* 29.

Haegeli, P., Atkins, R., and Klassen, K. (2010) Auxiliary material for Decision making in avalanche terrain: a field book for winter backcountry users. Avalanche Canada, Revelstoke, B.C. Accessed at www.avalanche.ca.

Jamieson, B. and Schweizer, J. (2005). Using a checklist to assess manual snow profiles. *Avalanche News,* pp: 1-6.

Larjavaara, M. and Muller-Landau, H.C. (2013). Measuring tree height: a quantitative comparison of two common field methods in a moist tropical forest. *Methods in Ecology and Evolution, 4(9)*: pp: 793-801.

McClung, D.M. (1995). Use of expert knowledge in avalanche forecasting. *Defense Science Journal, 45(2):* pp. 117-123.

McClung, D.M. (2001). Characteristics of terrain, snow supply and forest cover for avalanche initiation caused by logging. *Annals of Glaciology, 32:* pp. 223-229.

McClung, D.M. and Schaerer, P. (2006). The avalanche handbook: 3rd edition. The Mountaineers Books, 1001 SW Klickitat Way, Suite 201, Seattle, WA 98134.

Stethem, C., Jamieson, B., Schaerer, P., Liverman, D., Germain, D., Walker, S. (2003). Snow avalanche hazard in Canada – a review. *Natural Hazards, 28*: pp. 487-515.

Schweizer, J., Jamieson, B.J., and Schneebeli, M. (2003). Snow avalanche formation. *Reviews of Geophysics, 41(4):* pp. 2-1-2-25.

Weir, Peter. (2002). Snow avalanche management in forested terrain. *Res. Br., B.C. Min.For., Victoria, B.C. Land Manage. Handb. No. 55.*