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# Snow damage in lodgepole pine stands brought into thinning and fertilization regimes

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ABSTRACT

Several heavy wet snowfalls occurred during 2007–2009 across a broad-scale thinning and fertilization experiment to bring overstocked juvenile lodgepole pine (*Pinus contorta* var. *latifolia*) in the foothills of Alberta, Canada into an intensive management regime. We examined the bending and breakage of trees in relation to thinning and fertilization and used a multimodel information-theoretic approach to model stand and tree level predictors of snow damage. Fertilized stands suffered the greatest amount of snow damage, and this was most noteworthy when stands were also thinned; here 22% (17% broken stems) of trees were damaged compared to 8% (4% broken stems) in the thinned and unfertilized stands. At the stand level, needle weight and crown cover were reliable predictors of snow damage. At the tree level, separate models were developed for each combination of thinning and fertilization. All models used total tree volume; usually the smaller trees in the stands were more susceptible to damage but in the thinned and fertilized stands larger but slender trees with large asymmetrical crowns tended to be damaged. Also, trees with lower total stem volume were more susceptible to damage. Only in the thinned and fertilized stands were variables related to crown shape and asymmetry important predictors of snow damage. We conclude that snow damage is an important agent for self-thinning in unthinned stands and fertilization tends to exacerbate damage because of increase in foliage size. In areas with regular occurrence of heavy snow, we do not recommend fertilization at the same time as thinning, as the larger and more economically important trees in the stand are at risk.



## 1. Introduction

In montane and boreal forests heavy loading of wet snow can seriously damage or kill trees thereby reducing stand productivity, wood quality, and make them vulnerable to insect attack (Nykänen et al., 1997). *Pinus* spp. are especially vulnerable to snow damage because their more horizontal branches are not well-adapted to shed snow compared to the more flexible branches of *Picea* spp. (Elfving et al., 2001; Quine and Gardiner, 2007). There are many interacting tree- and stand-level factors responsible for the occurrence of snow damage. Notable, abiotic factors relate to the amount of snow (thresholds are species dependent) and the moisture content and temperature of snow (how well it attaches to the foliage) and the interaction of this load with wind (Nykänen et al., 1997). Stem breakage from snow loading has been related to size and asymmetry of crowns, tree slenderness, stand densities (mutual support), and wood quality (related to previous damage from snow, wind, or insects) (Valinger and Fridman, 1999).

In lodgepole pine (*Pinus contorta* var. *latifolia* [Engl.] Critch.) forests of the montane and boreal regions of Canada, snow damage has never been reported as a serious agent of disturbance. However, this region has heavy snow fall events in the spring and fall when temperatures are at or slightly below freezing, thereby allowing snow to accumulate on the crowns of conifers (Vyse et al., 2008). Stem are often broken or permanently bent under heavy snow load (Nykänen et al., 1997; Päätalo et al., 1999).

Most lodgepole pine forests are regenerated naturally either following fire or from natural seeding following drag scarification and establishment densities are often high (Landhäusser, 2009). In this region there is increasing interest in intensive management of these forests by thinning and/or fertilization and our study of snow damage is linked to an Alberta-scale study of how to bring overstocked stands of lodgepole pine into a thinning and fertilization regime. Most of the current knowledge of snow breakage is from carefully managed conifer forests of northern Europe (e.g., Valinger and Fridman, 1999; Gregow et al., 2008), yet we do not fully understand the role of snow damage in 'wild' unmanaged stands of western North America. The stands considered below have stem densities nearly 10 times higher than planted stands of northern Europe (see Table 1) and they also tend to have clumped distribution of

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**Table 1**
Characteristics of lodgepole pine stands that incurred snow damage (>10% trees damaged) between 2007 and 2009, in the upper and lower foothills of Alberta, Canada. Values are means (with standard deviations in parentheses) prior to thinning and fertilization. Crown radius is the mean of the four cardinal (N, S, W, E) measurements.

| Site number | Age (years) in 2009 | Minimum number of storm events[a] | Lodgepole pine (density %) | Density (trees ha$^{-1}$) | Height (m) | DBH (cm) | Crown radius (m) | Crown length (m) |
|---|---|---|---|---|---|---|---|---|
| 5 | 23 | 2 | 97 | 35,589 (5229) | 8.5 (1.7) | 7.2 (2.9) | 0.705 (0.314) | 3.36 (1.33) |
| 6 | 21 | 2 | 99 | 39,438 (4633) | 8.1 (1.6) | 6.9 (2.9) | 0.582 (0.324) | 3.11 (1.20) |
| 7 | 14 | 2 | 93 | 15,745 (5003) | 3.5 (1.1) | 4.6 (2.2) | 0.575 (0.246) | 3.14 (1.10) |
| 9 | 27 | 1 | 70 | 29,541 (2385) | 8.6 (2.8) | 7.6 (3.5) | 0.644 (0.269) | 3.65 (1.73) |
| 10 | 26 | 1 | 79 | 31,341 (7309) | 10.2 (2.0) | 9.4 (3.6) | 0.800 (0.350) | 4.05 (1.81) |
| 11[b] | 39 | 2 | 95 | 11,100 (3818) | 8.4 (1.8) | 6.0 (2.4) | 0.520 (0.246) | 2.90 (1.12) |
| 12 | 17 | 2 | 95 | 47,786 (8883) | 4.7 (1.5) | 4.8 (2.7) | 0.526 (0.296) | 3.18 (1.44) |
| 17 | 12 | 3 | 99 | 20,694 (4493) | 3.8 (1.1) | 5.1 (2.5) | 0.722 (0.283) | 3.35 (1.06) |
| 25 | 23 | 1 | 84 | 27,142 (8030) | 8.6 (1.5) | 7.6 (3.0) | 0.619 (0.290) | 3.10 (1.34) |
| 27 | 23 | 1 | 85 | 40,738 (8580) | 6.8 (2.0) | 6.8 (3.6) | 0.582 (0.325) | 3.20 (1.67) |

[a] Based on needle discolorations.
[b] Fire-origin site.

trees. Secondly, changing climatic conditions may result in greater snow damage in the future because longer periods of warm fall and spring temperatures make it more likely that heavy wet snow will accumulate on conifer needles (Nykänen et al., 1997).

According to the information from the managed stands of Europe, snow damage is affected by tree height, diameter, and crown attributes (Nykänen et al., 1997). Thinning can increase wind and snow load on crowns of remaining trees and thinning removes the potential support from a neighboring tree, possibly making thinned stands more susceptible to snow damage (Valinger and Pettersson, 1996). In some cases, however, dense unthinned stands harbor trees with slender stems that are more at risk to snow damage compared to the stouter trees in thinned stands (Valinger et al., 1994; Päätalo, 2000). As fertilization of lodgepole pine results in larger needles (Brockley, 1990) fertilized trees should accumulate more snow and be prone to greater damage. For the unmanaged and high density juvenile lodgepole pine stands of Alberta, however, it is unclear how thinning and/or fertilization will affect damage from snow loading.

In our work to develop more integrated models of stand and tree characteristics related to snow damage we used information-theoretic (IT) methods; these are well suited for determining the best model(s) for prediction when there are many possible predictor variables. Model selection and multimodel analyses (IT methods) have been well developed (Burnham and Anderson, 2002; Lukacs et al., 2007) and used in various areas of the natural sciences (Johnson and Omland, 2004) but are rarely used in forestry-related research. Multimodel inferences allow for stable inferences about a natural process as a set of models with prior weight of evidence are used for predictions (Richards, 2005).

Our objective was to understand the tree and stand level characteristics affecting snow damage in juvenile, unmanaged lodgepole pine stands as they are moved into thinning and fertilization regimes. To this purpose, we conducted a multimodel analysis by deriving variables deemed important for a tree's resistance to snow damage based on previous research and logic of the factors involved in mechanical stability, snow loading and crown asymmetry.

## 2. Materials and methods

### 2.1. Study location and characteristics

This study took advantage of an intensive management experiment in the foothills of Alberta, Canada, established in the winter of 2005 and spring of 2006 (Fig. 1). Thirty (we only used ten for the statistical analyses, see below) relatively even-aged stands dominated by lodgepole pine were fertilized and/or thinned; thus there were four treatment plots per stand. There were 15 young (10–30 years old) stands of harvest-origin and 15 older stands (35–103 years old)

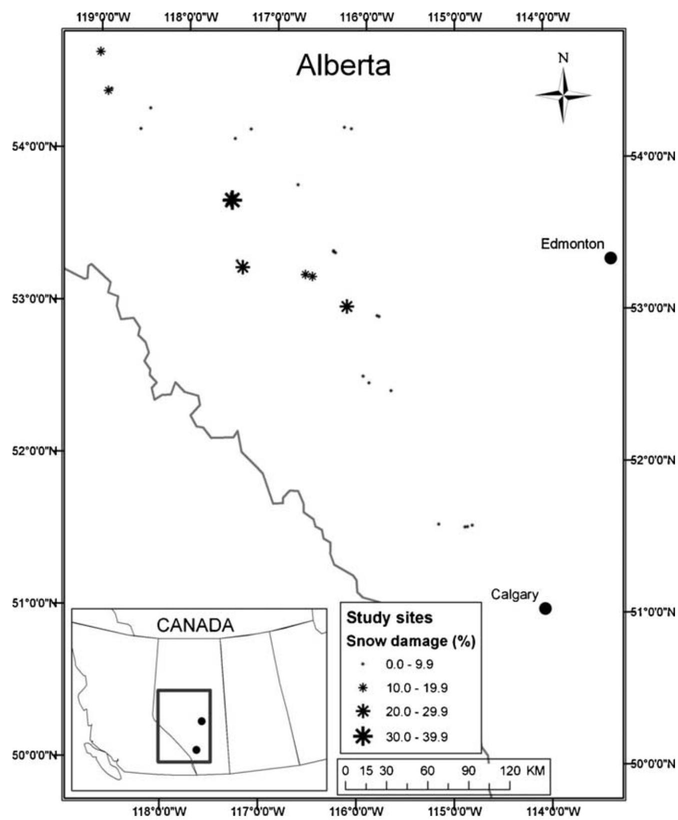


**Fig. 1.** Experimental sites with snow damage along the foothills of Alberta, Canada.

of fire-origin. In spring of 2008, we found evidence of snow damage on 11 of the 15 harvest-origin sites and 5 of the 15 fire-origin sites in the central and northern part of the range of study sites. In the summer of 2009, we sampled 10 of the younger sites which had at least 10% of the trees damaged by snow (Table 1, Fig. 1). Snow storms responsible for the damage occurred at least one year after the installation of the treatments.

### 2.2. Experimental design

The study was completely established in May of 2006 and laid out as a split-plot design where sites were considered blocks (random effect), the thinning treatment (two levels; thinned or not thinned) as the whole-plot fixed effect, and the fertilization treatment (two levels; fertilized or not fertilized) as the split-plot fixed effect. This design yielded 4 treatment combinations hereafter referred to as 'not thinned and not fertilized' (nTnF), 'not