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ORIGINAL ARTICLE

Influence of *Populus tremuloides* density on air and soil temperature

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Abstract
Density manipulation of overstory aspen provides increased light levels to promote growth of understory spruce, while it may also impact the air and soil temperature. We monitored temperature for three growing seasons in young mixedwood stands of variable density at two boreal locations in Alberta, Canada. Results indicate that partial aspen cover provides frost protection that may be location specific. Mean air temperature was similar or increased slightly across aspen densities during the growing season, while mean soil temperature significantly increased with decreasing overstory cover. The amount of accumulated air and soil heat over the growing season was inversely related to aspen density. The differential impact of density on temperature contributes to variation in growth relationships and may explain regional differences in competition effects.

Keywords: *Aspen, boreal mixedwoods, frost, temperature, white spruce.*

Introduction

Temperature is an important factor that regulates several physiological processes, such as the photosynthesis and respiration of plants (Kimmins, 1997). Plants have evolved to function optimally within certain ranges of temperature and have developed morphological and physiological adaptations to environment stress (Gillies & Vidaver, 1990; Larcher, 2003). These adaptations become increasingly important in the boreal climate where the growing season is short and freezing temperatures may occur at any time of the year. Frost has the most impact during the early stages of stand establishment and is a major cause of poor performance and mortality in young forest plantations (Stathers, 1989). Risk of frost occurrence is highest at the beginning and end of the growing season owing to lower air temperature and longer nights (Grossnickle & Major, 1994).

Frost damage to young conifer seedlings occurs when the air temperature drops below $-2°C$ to $-5°C$ during the growing season. However, frost damage is thought to be more strongly influenced by the duration of frost rather than the actual minimum temperature (Spittlehouse & Stathers, 1990). Freezing tolerance depends on the type of tissue being affected, as buds and emerging shoots are usually more susceptible to damage than mature shoots (Bigras & Hébert, 1996). Following frost, the leader could be lost and may be replaced by one or more lateral branches, resulting in a forked top or other stem and crown deformations (Langvall et al., 2001).

In addition to visible damage, frost may cause invisible damage to young seedlings. Reduced photosynthesis rates have been reported for conifer species following frost exposure (Dang et al., 1992; DeLucia & Smith, 1987; Ryyppö et al., 1997). Moreover, frost events are usually associated with clear sky conditions, and intense light the following morning may lead to additional damage to the photosynthetical apparatus through photoinhibition (Gillies & Binder, 1996; Örlander, 1993).

In northern climates, low temperature may be a serious limitation during the growing season (Grossnickle, 2000). Moreover, temperature fluctuations may impact growth further, as air temperature extremes (maxima and minima) in boreal forests typically increase with overstory reduction (Kubin & Kemppainen, 1991; Langvall & Ottosson Löfvenius, 2002). Cold soil temperature during

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spring, especially when complemented by flooded conditions, may lead to significant reduction in photosynthesis and growth of seedlings (DeLucia, 1986; Grossnickle, 1987). In addition to impacting growth through access to resources, temperature may affect the seasonal development of seedlings and phenological interactions with insects (van Asch & Visser, 2007).

Over the past two decades, there has been increasing public and industry interest in managing boreal mixedwood stands composed of trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* [Moench] Voss). While aspen regenerates more abundantly and grows faster initially, density manipulation of the aspen overstory to promote spruce growth and survival is considered a viable option (Comeau et al., 2005). Reducing aspen cover improves growth conditions (i.e. light availability) for understory spruce (Filipescu & Comeau, 2007), but at the same time may lead to increased likelihood of frost occurrence (Groot & Carlson, 1996; Pritchard & Comeau, 2004).

This study examined the influence of aspen cover on temperature in boreal mixedwood stands of variable density. The objectives were to evaluate the incidence of frost across a gradient of aspen densities following spacing treatments at two boreal locations, and to characterize the air and soil temperature regimes in the different densities during the growing season. We hypothesize that the reduction in aspen cover will increase frost occurrence, as well as mean air and soil temperature.

Materials and methods

The study used two field installations established by the Western Boreal Growth and Yield Association (WESBOGY), as part of a long-term study of growth and development of tended mixtures of aspen and white spruce. Experimental blocks consist of permanent plots of variable aspen density with understory of planted white spruce; each plot is 20 m × 20 m with a 5-m treated buffer. In this study, we used field installations near Peace River (56°55′N and 118°30′W) and Grande Prairie (54°55′N and 118°30′W) in Alberta, Canada. Basic climate data for the region are provided in Table I.

Table I. Climate data for study locations (mean values for 1971–2000, National Climate Data, Environment Canada)

	Temperature (°C)			Precipitation (mm)		
Location	Annual	January	July	Annual	January	July
Grande Prairie	1.9	−15.0	15.9	447	30.7	70.4
Peace River	1.2	−16.6	16.0	402	21.3	66.6

Sites were generally flat, with slopes less than 5%, and soil drainage ranging from moderate to well drained. All sites were characterized as low-bush cranberry ecosites, with mesic moisture regime and medium nutrient regime (Beckingham & Archibald, 1996). Soil parent materials were morainal, glaciolacustrine and glaciofluvial, with medium to moderately fine texture and less than 10% coarse fragments. Ground vegetation consisted of grasses and short shrubs, mainly willow (*Salix* spp.).

Aspen regenerated naturally after harvesting, while spruce seedlings were planted the following year using 1-0 containerized stock. No site preparation treatments were applied before planting. Competing vegetation was mechanically or manually removed within a 0.5 m radius around each spruce seedling until age 5. Plots were spaced to target densities at 5 years. When this study was initiated in 2002, stands were 11 years old, with individual tree heights ranging between 3.2 and 6.4 m for aspen and 0.7 and 2.6 m for spruce. There were no differences in dominant aspen height between plots. At each of the two locations, one plot was selected for each of four aspen densities (0, 500 and 1500 stems/ha and natural untreated). In the natural untreated plots, density at age 11 ranged between 6000 and 9000 stems/ha.

To measure air temperature, three custom-built chromel-constantan (fine wire Ø 0.0255 mm, wires welded together at 5 mm) thermocouples were installed at 1 m height near the center of each plot. Measurements of air temperature intended to include the effect of aspen independent of ground vegetation, and the height of 1 m above ground was also considered relevant for the current spruce size. Thermocouples were arranged in a triangle around the plot center at a distance of 3.5–4 m. Sensors were not shielded to increase the detection sensitivity to radiative cooling; as a result, measurements could be inflated when sensors are in direct sunlight; however, errors were considered minimal given the fine wire used for thermocouples. Soil temperature at two soil depths, 5 cm and 20 cm, was measured using custom-built chromel-constantan thermocouples (wire Ø 2.5 mm) at the same three clustered locations in each selected plot. These sensors were connected to CR-10X dataloggers through AM 16/32-XT multiplexers (Campbell Scientific Canada Corp., Edmonton, AB). Thermocouples were connected individually with measurements from each single thermocouple stored. These measurements were recorded every 10 minutes, with hourly averages and daily minima and maxima also stored. For both the Peace River and Grande Prairie locations, temperature was monitored continuously during the growing seasons of 2002, 2003 and 2004.

In this region, aspen leaf buds generally begin opening during mid to late May (Parry et al., 1997), while spruce budbreak and shoot development begin in early June (Volney & Cerezke, 1992). We intended to monitor temperature each year starting in early to mid May and continuing until mid to late September. However, in 2002, difficulties with equipment delayed the establishment of the study until late June, while in 2004 several dataloggers malfunctioned in September.

Leaf area index (LAI) at 1 m above ground was measured at each temperature sensor using LAI-2000 plant canopy analyzers (Li-COR Inc., Lincoln, NE) during the period of maximum leaf development in July of 2002 and 2003. The sensors were fitted with 180° view restrictors, with one reading taken facing west in the morning and a second reading taken facing east in the afternoon. These measurements were subsequently paired with a simultaneous measurement taken in an adjacent open area at the same height. The sky portion below 31.9° above the horizon was ignored, and values only from rings 1–4 of the LAI-2000 sensor were used, to avoid the influence of plot edges. In the zero aspen plots, LAI values reflected the presence of shrubs and spruce seedlings within the sensor view.

For statistical analysis of temperature differences between aspen densities, we applied paired *t*-tests in R (R Development Core Team, 2010). Significance level for differences between means was 0.05.

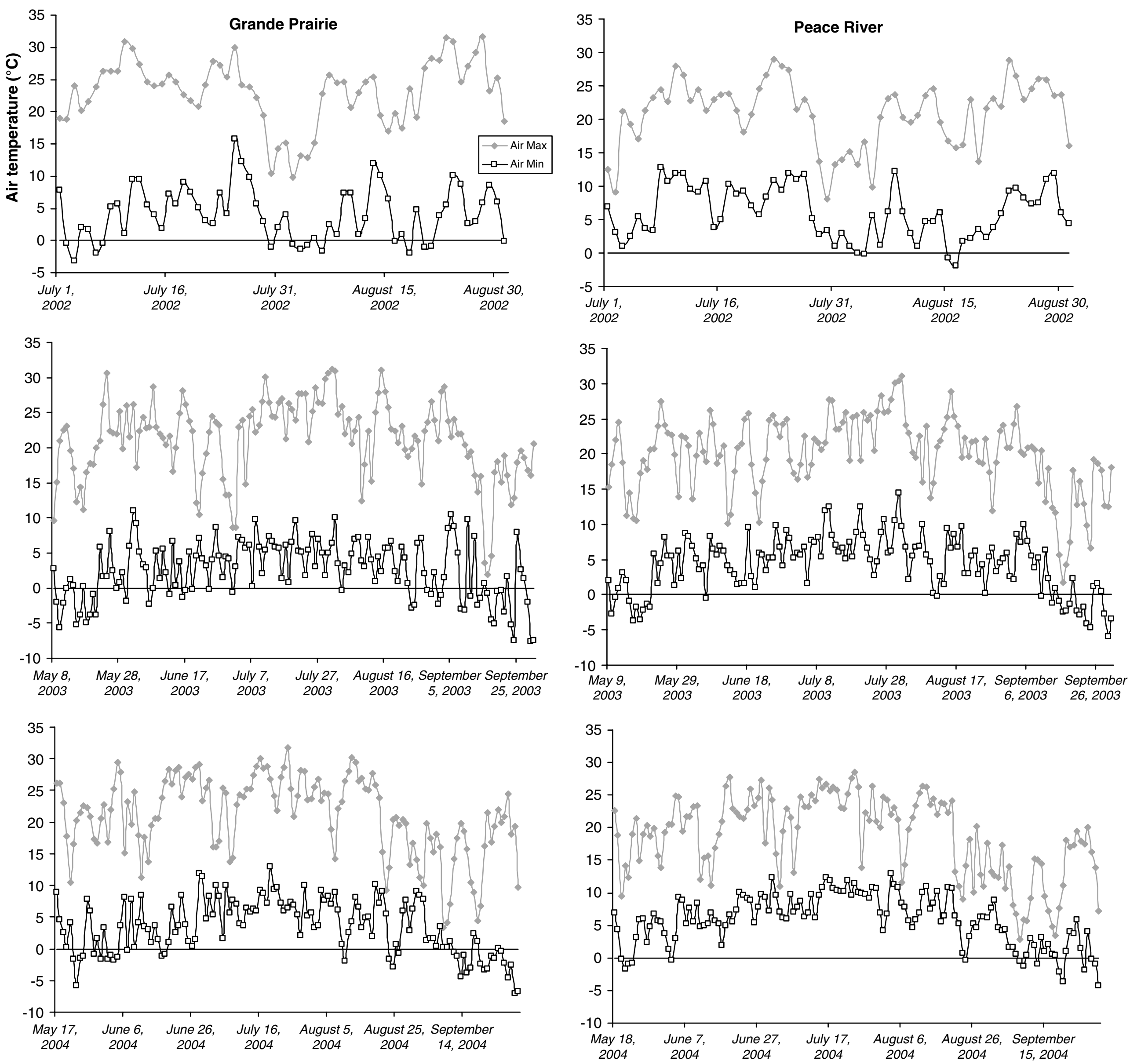

Figure 1. Daily minimum and maximum air temperature for the zero aspen plots at the two study sites (Grande Prairie and Peace River) during the growing seasons of 2002, 2003 and 2004.

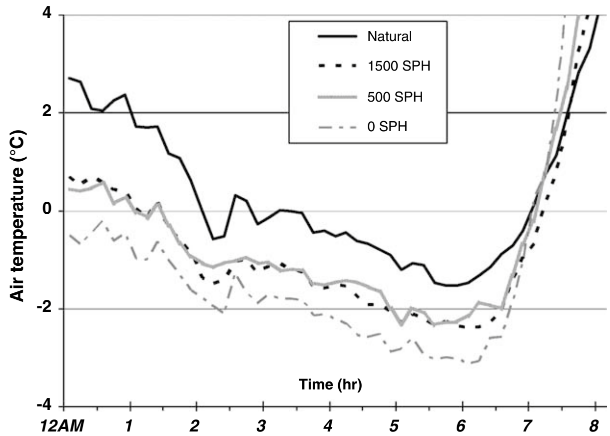

Figure 2. Frost event at Grande Prairie during the morning of 3 July 2002. SPH represents overstory density in stems per hectare.

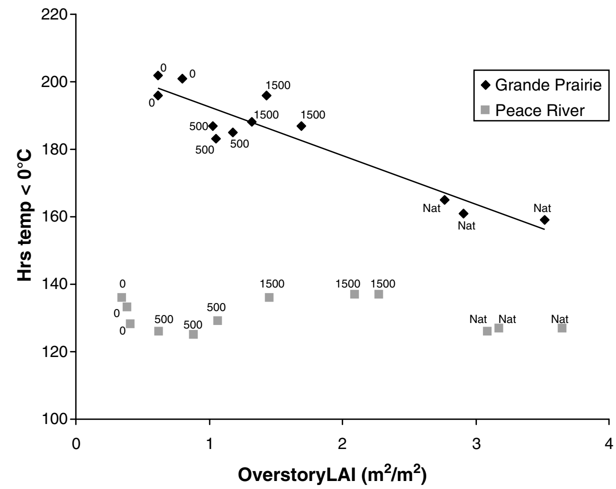

Figure 3. Relationships between overstory leaf area index (LAI) and frost occurrence (hours with temperature $<0°C$) at the two study locations (8 May–30 September 2003). The linear regression for Grande Prairie is hrs $= -14.42$ LAI $+ 206.93$ ($n = 12$, $R^2_{adj} = 0.86$, p-Value < 0.0001). For Peace River, the relationship was not significant. Labels for each data point represent overstory density in stems per hectare.

Results

Frost events were recorded during the three growing seasons for both sites (Figure 1). While air temperature dropped below freezing mostly during May and September, frosts were also recorded during June, July and August. Frosts occurred more often and were more intense at Grande Prairie compared with Peace River.

A typical frost event during the morning of 3 July 2002 is illustrated in Figure 2. Temperature dropped to lower levels and for a longer interval in the zero aspen plot compared with the intermediate densities and the natural untreated. The lowest temperatures were recorded in the early morning, a common characteristic of radiative frosts, at $-1.5°C$ for the natural plot, $-2.3°C$ for the 500 stems/ha plot, $-2.4°C$ for the 1500 stems/ha and $-3.1°C$ for the zero aspen plot.

Reduction in aspen density increased the frequency of hours with negative temperature (Figure 3). There was a clear distinction between the Grande Prairie site where the reduction in aspen cover was linearly associated with increased frost and the Peace River site where frost incidence was similar across the range of aspen LAI. At Grande Prairie, the natural plot was clearly differentiated from the zero aspen, while the 500 and 1500 plots were similar in regard to frost.

Comparison of mean hourly temperature referenced to frost events in the zero aspen plots indicated that at Grande Prairie the natural plot differed significantly from the 0, 500 and 1500 plots in 2003, while the natural plot differed only from the zero and 500 plots in 2004 (Table II). At Peace River, the zero and 500 plots differed significantly from the 1500 and natural plots for both 2003 and 2004.

Temperature trends across the density gradient for the summer months (June–August) were very similar for both 2003 and 2004 (results shown only for 2004). Mean hourly air temperature decreased with increasing aspen cover, although differences were not significant between all levels of density for both sites (Table III), with no significant differences detected between densities at Grande Prairie, while the 0 and 500 plots differed significantly from the 1500 and natural plots at Peace River. Mean hourly soil temperature also decreased with increasing aspen cover and differed significantly between all plots for both site locations and soil depths at 5 and 20 cm (Table III).

Extremes of air temperature (minima and maxima) increased with reduction in aspen density. Mean daily minima increased with increasing aspen density, while mean daily maxima followed a decreasing trend (Table IV). At Grande Prairie,

Table II. Mean hourly temperature of frost events (hours with temperature $<0°C$ in the zero aspen plots)

		Aspen density (stems/ha)			
Location	Year	0	500	1500	Natural
Grande Prairie	2003	$-1.95a$	$-1.68ab$	$-1.52b$	$-1.08c$
	2004	$-1.47a$	$-1.07a$	$-0.87ab$	$-0.36b$
Peace River	2003	$-1.44a$	$-1.34a$	$-1.11b$	$-1.07b$
	2004	$-1.13a$	$-1.07a$	$-0.72b$	$-0.68b$

Note: The period monitored is 8 May–30 September 2003 and 19 May–3 September 2004 for Grande Prairie and 9 May–29 September 2003 and 19 May–2 September 2004 for Peace River. Means with same letter are not significantly different.

Table III. Mean hourly temperature during 1 June – 31 August 2004

		Aspen density (stems/ha)			
Location	Sensor	0	500	1500	Natural
Grande Prairie	Air 1 m	13.96*a*	13.75*a*	13.74*a*	13.67*a*
	Soil 5 cm	13.34*a*	13.17*b*	12.67*c*	12.16*d*
	Soil 20 cm	12.88*a*	12.43*b*	11.81*c*	11.67*d*
Peace River	Air 1 m	13.70*a*	13.68*a*	13.27*b*	13.14*b*
	Soil 5 cm	12.86*a*	11.52*b*	11.38*c*	10.54*d*
	Soil 20 cm	12.18*a*	10.41*b*	10.16*c*	9.51*d*

Note: Means with same letter are not significantly different.

Table IV. Mean daily air temperature – minima and maxima during 1 June–31 August 2004

	Aspen density (stems/ha)			
Location	0	500	1500	Natural
Grande Prairie				
Min	4.99*a*	5.61*ab*	5.69*ab*	6.42*b*
Max	23.16*a*	22.80*a*	22.13*a*	20.79*b*
Peace River				
Min	7.58*a*	7.61*a*	7.71*a*	11.94*b*
Max	21.56*a*	21.12*a*	19.70*b*	19.54*b*

Note: Means with same letter are not significantly different.

minima were significantly different between the zero and natural plots; maxima were not different between the 0, 500 and 1500 plots, while all these plots were different from the natural plot. At Peace River, the natural plot differed significantly from 0, 500 and 1500 plots for minima; the natural and 1500 plots differed from zero and 1500 plots for maxima.

The amount of accumulated heat during the growing season, expressed as growing degree hours, was inversely related to aspen cover at both sites for all years (results shown only for 2004, Figure 4). The Grande Prairie site had more accumulated heat than the Peace River site for air, while the soil heat indicated much larger differences between plots at the two site locations.

Discussion

Our study provides further evidence indicating increasing risk of frost with the reduction in overstory density. The incidence of frost was inversely related to aspen cover, and our findings are consistent with previous studies in the boreal forest (Groot & Carlson, 1996; Pritchard & Comeau, 2004; Voicu & Comeau, 2006). The occurrence of frost was more frequent in the zero aspen than in the natural aspen; however, there was no clear gradient between the 500 and 1500 plots, suggesting that density alone in young spaced stands may not be a reliable indicator of frost incidence.

Frost events at Grande Prairie occurred more often and were more intense than frosts at Peace River. In addition, at Grande Prairie frost occurrence increased with the reduction in aspen cover in a linear fashion, while no such effect was observed at Peace River. Topographic characteristics may explain these differences, as the Grande Prairie site is located in a low-lying basin at the base of a gradual slope, while the Peace River site is located on a topographic rise that would experience more wind and air mixing.

Temperatures detected at the two locations during the three years of this study are unlikely to cause major frost injury to spruce seedlings. One should note that during radiative frost events, temperature closer to the ground is likely to be lower than our measurements and younger seedlings may suffer more damage. However, it is possible that freezing nights followed by mornings of intense light may have led to reduced photosynthesis rates through

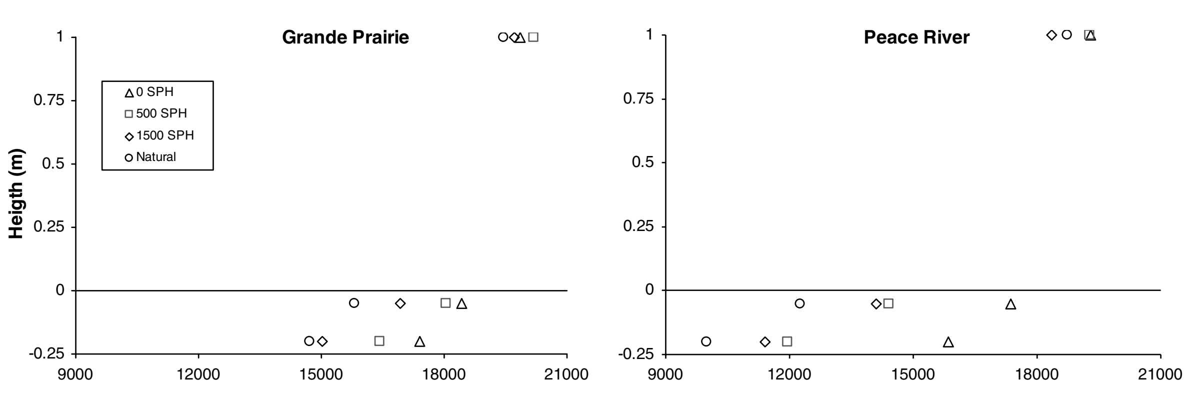

Figure 4. Growing degree hours (GDH is sum of hourly average temperatures $>5°C$) for the four aspen densities at the two study locations (1 June–31 August 2004) for soil at 5 and 20 cm and air at 1 m. SPH represents overstory density in stems per hectare.

photoinhibition. Partial cover could be beneficial by maintaining higher nocturnal air temperature and shading the day after the frost event, leading to reduced physiological damage (Langvall & Örlander, 2001; Lundmark & Hällgren, 1987). Therefore, partial cover would address trade-offs between nighttime frost protection and incoming-day radiation for photosynthesis, while protecting understory seedlings against photoinhibition.

Mean air temperature over the summer months was not significantly affected by density at Grande Prairie, while there was a significant increase in the zero and 500 plots compared with 1500 and natural plots at Peace River. Our findings confirm the expectation of increased air temperature with reduction in overstory cover for Peace River as reported by Weng et al. (2007), while no such differences among overstory densities were detected at Grande Prairie, in agreement with Langvall and Ottosson Löfvenius (2002). These results indicate further that temperature regimes may be site specific. Spacing of aspen in boreal mixedwood sites is usually associated with colonization of grasses (e.g. *Calamagrostis canadensis* [Michx.] Beauv.), consequently shifting the surface of radiative transfer. Moreover, daily extremes (minima and maxima) were significantly increased by density reduction, in agreement with previous studies (Rambo & North, 2009). Reduction in forest cover is associated with higher maxima for air temperature, but also with increased wind speed, evapotranspiration and vapor pressure deficit, leading to stomatal closure and reduction in photosynthesis (Bladon et al., 2006).

Soil temperature increased significantly with reduced aspen cover at our sites, consistent with previously published results (Ma et al., 2010; Parker et al., 2009). Despite extensive evidence, the importance of soil temperature is often overlooked in ecophysiological studies (Aussenac, 2000). Soil temperature is even more relevant in boreal regions, as several studies indicated that low soil temperature is a major limitation to plant productivity, affecting biomass partitioning (Vogel et al., 2008), root growth and nutrient uptake (Lahti et al., 2005) and water balance (Mellander et al., 2006). However, partial cover may help mitigate the impact of grasses that are considered stronger competitors for water than aspen in boreal mixedwoods (Voicu & Comeau, 2006). On the other hand, partial cover could buffer hydrological impacts on sites prone to a rise in water table following harvesting (Jutras et al., 2006).

Our results indicated that the amount of accumulated heat is inversely related to aspen density. Differences among plots for air heat appeared to be small, while these differences were larger for soil at 5 and 20 cm; given that the growing season is short, even small differences may become important. Accumulated heat influences growth of white spruce, as suggested by site preparation experiments in Northern Interior of British Columbia (Bedford et al., 2000). While there is an increased risk of damage owing to radiative frost, spacing of overstory aspen may improve growth on sites where temperature is a limitative factor.

Several practical recommendations can prove useful for management of boreal mixedwood sites. Careful site selection to avoid frost-prone sites (e.g. high-elevation areas, valleys, low-lying terrain) may reduce the risk of frost occurrence (Stathers, 1989). Other strategies may include: (1) selection of planting spots in suitable microsites (e.g. the vicinity of logs, stumps and higher areas); (2) site preparation treatments that alter the seedling microenvironment, such as soil properties, and the overall energy balance; and (3) maintaining some degree of woody vegetation cover, which may result in reduced temperature extremes, while also providing daytime shading to reduce problems with photoinhibition (Langvall et al., 2001; Lundmark & Hällgren, 1987). Reduction in overstory cover will increase the availability of light in the understory, as well as increase soil temperature.

In conclusion, this study provides further indications that maintaining partial aspen cover may provide frost protection to planted white spruce in young boreal mixedwoods. However, these benefits will be apparent only on those sites where there is an actual risk of frost injury occurring. In addition to frost, reduction in aspen density increased air temperature extremes and soil temperature. Further studies are needed to provide information on the impact of nonvisible frost injury, interaction with other microclimatic conditions, site factors and resource availability and to develop more accurate frost hazard ratings for boreal forest sites in Canada.

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