

# Post-fire Regeneration of Boreal Forests in Northeastern Ontario

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## Abstract

*We examined the effects of pre-fire stand composition and season of fire on post-fire regeneration of the boreal forests in northeastern Ontario. One hundred twenty upland stands were surveyed in 2002 and 2003 from burns that occurred between 1983 and 1998. Prefire stand composition was determined from measurements of all stems > 9.5 cm DBH (at 1.3 m) in 400 m<sup>2</sup> plots. Post-fire regeneration density and composition were determined in three 25 m<sup>2</sup> subplots in each plot. Species-specific regeneration density was positively related to its pre-fire species percent basal area composition, for jack pine (*Pinus banksiana*), poplar (*Populus* spp.), white birch (*Betula papyrifera*), black spruce (*Picea mariana*) and late successional species, balsam fir (*Abies balsamea*), white spruce (*Picea glauca*) and white cedar (*Thuja occidentalis*). Poplar, white birch, and black spruce seedling densities were significantly higher on sites burned in the summer, but seedling densities did not differ between spring and summer burns for jack pine and late successional species. Jack pine and poplar densities were significantly higher in younger burns, but age of burn did not affect density of the other species.*

## Introduction

Wildfire is the dominant natural stand-initiating disturbance in Canadian boreal forests (Rowe and Scotter, 1973; Van Wagner, 1983). Most boreal tree species have strategies to cope with fire and recolonize burns, either by seed or vegetative means. Jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*) use serotinous or semi-serotinous cones to protect seeds and disperse them after fire (Greene *et al.*, 1999). Trembling aspen (*Populus tremuloides*), balsam

poplar (*Populus balsamifera*), and white birch (*Betula papyrifera*) regenerate vegetatively through root suckers or stump sprouts (Perala, 1990; Perala and Alm, 1990; Greene *et al.*, 1999), or seed in from outside the burn (Greene and Johnson, 2000). Fire sensitive species such as tamarack (*Larix laricina*), white spruce (*Picea glauca*), white cedar (*Thuja occidentalis*) and balsam fir (*Abies balsamea*), however, can only seed into a burn from the unburned edges or residual patches within the burn (MacLean, 1960; Dix and Swan, 1971; Greene and Johnson, 2000). Seed dispersal is usually limited to about 300 m (Sims *et al.*, 1990; Greene and Johnson, 2000) for most tree species except for poplars, which can disperse wind-borne seeds for several kilometres (Perala, 1990).

Post-fire stand composition has been reported proportional to pre-fire composition for stands dominated by jack pine, aspen, and black spruce while the sucker-originating trembling aspen has an advantage in initial regeneration densities (Dix and Swan, 1971; St. Pierre *et al.*, 1992; Lavoie and Sirois, 1998; Greene and Johnson, 1999; Greene *et al.*, 1999). Black spruce stands shift to jack pine dominated stands when both species were present in the pre-fire stand (Lavoie and Sirois, 1998; Nguyen-Xuan *et al.*, 2000). Dispersal in black spruce can sometimes last several years and with a delay in germination for up to two years (Thomas and Wein, 1985). Post-fire regeneration of white birch, white spruce, balsam fir and white cedar is poorly documented in terms of timing and densities. The effects of season and age of burn on post-fire stand composition and density are also unknown.

The majority of boreal post-fire successional studies are from western Canada, including the Yukon (Johnston *et al.*, 2004), Alberta (Peterson and Peterson, 1992), Saskatchewan (Dix and Swan, 1971), and in northern Quebec (Sirois and Payette, 1989; St. Pierre *et al.*, 1992). Few studies have compared pre- and post-fire stand compositions (Wang, 2002; 2003) or examined the effects of fire season or age of burn on regeneration. These knowledge gaps need to be addressed to better understand their importance in regeneration of burned stands.

Specifically, our objectives will address the following questions:

- 1) How does prefire stand composition influence postfire regeneration on upland sites?
- 2) How do fire season and age of burn influence regeneration density?

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## Materials and Methods

### Data Collection

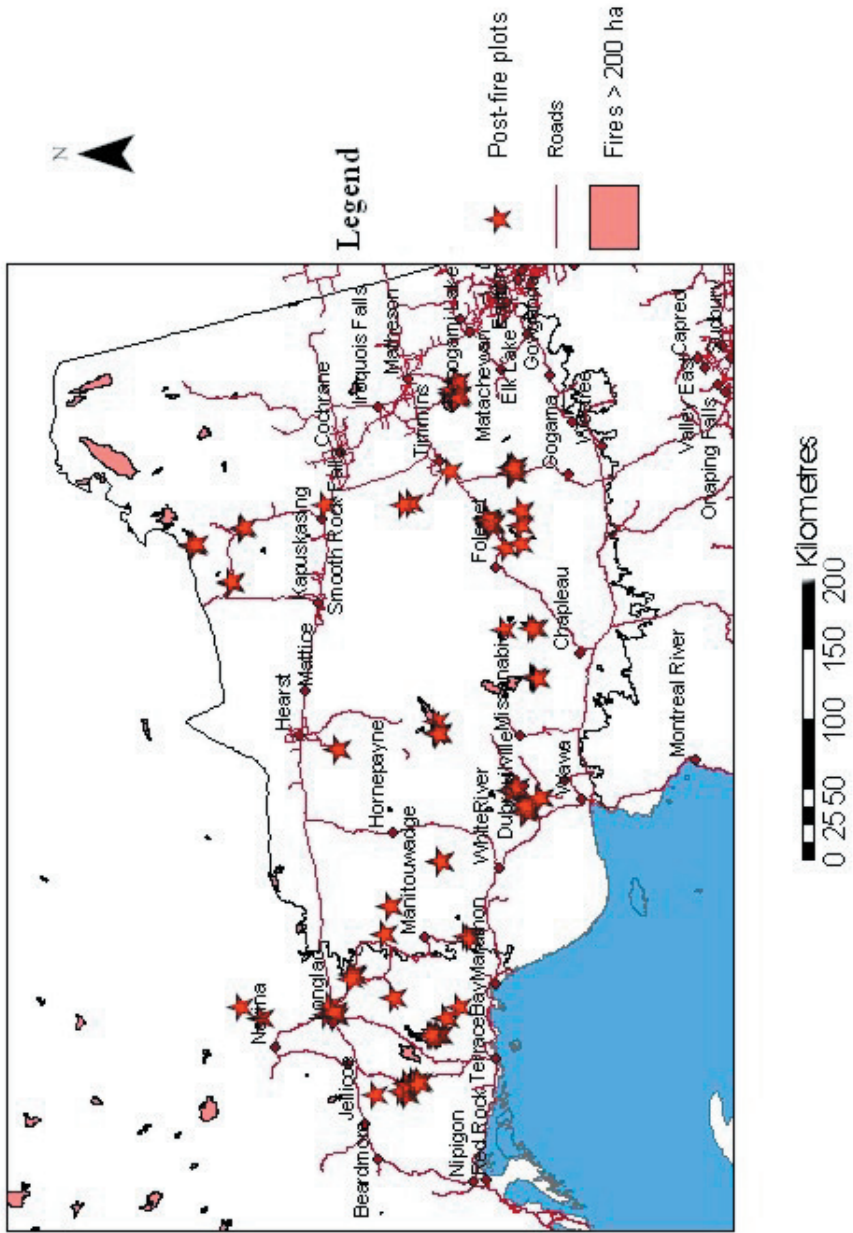
One hundred twenty upland post-fire sites were sampled within Site Regions 3E and 3W (Hills, 1959) of northeastern Ontario (Figure 1). The area is classified as southeastern boreal forest within Rowe's (1972) Missinaibi-Cabonga forest section. Dominant tree species on uplands include jack pine, trembling aspen, balsam poplar, white birch, black spruce, white spruce, balsam fir and white cedar (Rowe, 1972).

Fire history information including burn locations, date and size was obtained from electronic databases maintained by the Air, Fire and Flood Management Branch of the Ontario Ministry of Natural Resources. Sampling was done between June and October in 2002 and 2003. We sampled 36 burns that had occurred between 1984 and 1998. Sites were sampled at least 5 years after the burn, allowing enough time for tree establishment, as the majority of trees are established within five years of a fire (St. Pierre *et al.*, 1992; Johnston *et al.*, 2004) (Table 1). Burn size ranged from 4 ha to 17 676 ha. Fire start dates ranged from April 28 to August 20. In each burn, one to 12 sites were sampled, depending on the variability of prefire stand conditions. Study sites were deliberately selected to represent stands previously dominated by jack pine, aspen, white birch, black spruce, and late successional species that included white spruce, balsam fir and white cedar. Soil moisture regime ranged from dry to moist and was determined for each site based on Taylor *et al.* (2000). Sites were treed prior to the burn and were not silviculturally treated after the burn.

Pre-fire stand basal area, species composition, and stand age were determined for each site with a 400 m<sup>2</sup> circular plot (radius 11.28 m) (Table 1). Diameter at breast height (DBH, 1.3 m) and species were recorded for all trees that were alive at the time of the fire and had a minimum diameter of 9.5 cm, using a similar method described by Wang (2002). Of the nine species found, tamarack occurred on one and balsam poplar on three sites.

Regeneration was assessed from three circular 25 m<sup>2</sup> subplots within each main plot (Hayden *et al.*, 1995). The first plot direction was randomly selected and the other two were 120° apart. Distances from the plot centre were random. Within each subplot, all tree seedlings were recorded by species and height class. Height class data are not reported in this paper. Jack pine, aspen, white

Figure 1. Plot locations in Site Region 3E, northeastern Ontario. Burns > 200 ha between 1984 and 1998 are also shown.



Dominance Type	Number of Burns	Number of Plots by Season		Age of Burn (yrs)	Pre-fire Basal Area (m <sup>2</sup> /ha)	Prefire Percent Basal Area by Species*									
		Spring	Summer			Po	Bw	Pj	Sb	Sw	Bf	Ce	L		
Jack pine	15	16	8	8.2	21.46	1.4	5.1	73.1	15.4	1.8	1.9	1.3	0		
Aspen	14	14	6	7.9	25.61	69.5	10.5	2.1	6.9	6.2	4.8	0	0		
White birch	10	8	8	8.0	16.76	11	64.8	2.8	6.8	6.6	8	0	0		
Black spruce	22	23	18	10.1	16.65	0.7	6.4	8.2	74.9	1.9	7.5	0.2	0.1		
Late successional	14	8	11	8.8	22.01	11.96	12.37	2.12	10.13	27.80	26.92	8.98	0		

\*Species codes: Po = trembling aspen and balsam poplar (combined), Bw = white birch, Pj = jack pine, Sb = black spruce, Sw = white spruce, Bf = balsam fir, Ce = white cedar, L = tamarack.

**Table 1.** Summary of sampled postfire plots by stand type with number of burns sampled, number of plots by season of burn, age of burns and pre-burn stand basal area and percent basal area by species (N = 120).

birch and black spruce constituted 96.2% of the regeneration. Tamarack, white spruce, balsam fir, white cedar, white pine (*Pinus strobus*), balsam poplar and red maple (*Acer rubrum*) were found on one to 23 sites and these species constituted 3.8 % of the regeneration.

## Data Analysis

Pre-fire percent basal areas were determined for each species. White spruce, balsam fir and white cedar were combined into a late successional species group because of their similarity in post-fire regeneration characteristics (Greene *et al.*, 1999). Balsam poplar was combined with trembling aspen in all analyses. Burns were classified as spring burns (May-June) or summer burns (July-August).

The effects of pre-fire species composition, measured by percent basal area ( $BA_i$ ), season of burn ( $S_j$ ,  $j = 1, 2$ ), and age of burn ( $A_k$ , years since burn) as a covariant on species-specific regeneration density and species composition ( $Y_{ijkl}$ ) were examined using the following model [1]:

$$Y_{ijkl} = \mu + BA_i + S_j + BA \times S_{ij} + A_k + \varepsilon_{l(ijk)}$$

where  $\mu$  and  $\varepsilon$  are the overall mean and experimental error, respectively. To examine total seedling density, the  $BA_i$  and  $BA \times S_{ij}$  were removed from model [1].

Data were tested for normality, linearity, and homogeneous variance (Neter *et al.*, 1996). Square-root transformations were applied where necessary. Seedling densities were analyzed using stepwise linear regressions at a significance level of  $\alpha=0.05$  in the General Linear Model procedure (SYSTAT 10).

## Results

Total seedling density was significantly affected by season and age of burn (Table 2). Seedling densities on sites of summer burn had four-fold higher densities than that of spring burns. Total seedling density also significantly decreased with age of burn.

Density of individual species including the late successional species was significantly positively related to the pre-fire percent basal area of the respective species (Table 2; Figure 2a-e). For poplar, white birch and black spruce, more seedlings were found in summer burns than spring burns (Figure 3). Post-fire seedling density decreased significantly with age of burn for jack pine and poplar (Table 2; Figure 4), but age of burn did not significantly affect seedling density for the other species. Season of burn interacted with percent basal area for all four species and the late successional species group (Table 2). Summer burns had a significantly greater increase in seedling density with increasing pre-burn percent basal area than spring burns for all species except poplar. For poplar, spring burns had a greater increase in density with percent basal than did summer burns (Figure 2c).

## Discussion

Pre-fire species specific percent basal area had a significant effect on post-fire regeneration density of boreal tree species in northeastern Ontario. It explained the highest amount of variance in seedling density for jack pine (31.9%), white birch (18.2%) and black spruce (38.8%), and although significant, explained less of the variance for poplar (13.0%) than did season (20.8%). This reflected seed availability through aerial seedbanks for jack pine and black spruce (Dix and Swan, 1971; Sirois and Payette, 1989; Larsen and MacDonald, 1998; Charron and Greene, 2002), and the relationship between seedling density and basal area (Greene and Johnson, 1999). Late successional species regeneration had the least amount of variation explained by the model. More of the variation was explained by the interaction of basal area with season (9.0%) than by pre-fire percent basal area (6.8%).

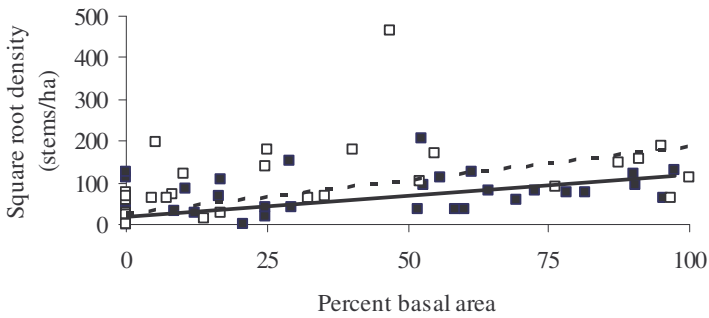
The dual means used by hardwoods for colonizing burns (seed and vegetative regeneration), compared to conifers, can reduce the relationship between basal area and seedling density. Long-distance hardwood seed dispersal (Safford *et al.*, 1990), especially for poplar (Perala, 1990), allows colonization of sites where these species were previously absent, reducing the relationship between seedling density and percent basal area and making it difficult to predict postfire poplar density (Heinselman, 1981; Perala, 1990; Johnston *et al.*, 2004). This was reflected in the lower variance explained for poplar and white birch regeneration density compared to jack pine and black spruce. We found seed-origin poplar more often than the literature would suggest (Horton and Hopkins, 1966; McDonough, 1979; Peterson and Peterson, 1992). Almost half

**Table 2.** Regeneration density in relation to its pre-fire percent basal area (BA), season of burn (S), and age of burn (A) for jack pine, poplar, white birch, black spruce, and late successional species (N = 120).

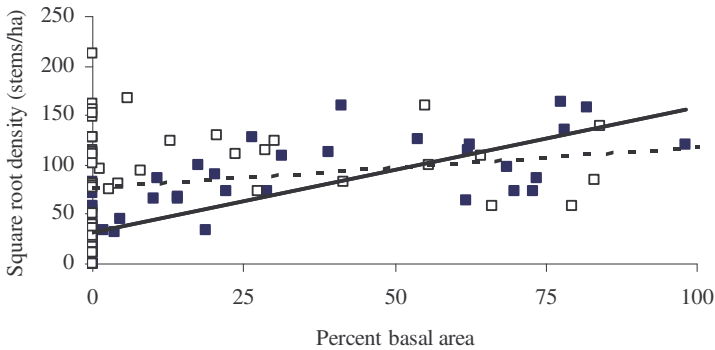
Source*	df <sup>†</sup>	MS	F-ratio	P	% VE <sup>†</sup>
<i>Total regeneration density</i>					
A	1	73462	14.22	<0.001	7.7
S	1	262674	50.83	<0.001	27.5
Error	117	5165			
<i>Jack pine regeneration density</i>					
A	1	16961	6.26	0.014	3.1
BA	1	172193	63.59	<0.001	31.9
S*BA	1	24638	9.10	0.003	4.6
Error	116	2708			
<i>Poplar regeneration density</i>					
BA	1	34496	27.53	<0.001	13.0
A	1	28399	22.66	<0.001	10.7
S	1	55098	43.97	<0.001	20.8
S*BA	1	13126	14.02	<0.001	4.96
Error	115	1253			
<i>White birch regeneration density</i>					
BA	1	89445	19.96	<0.001	18.2
S	1	29528	6.6	0.012	6.0
S*BA	1	18929	4.22	0.042	3.8
Error	116	4480			
<i>Black spruce regeneration density</i>					
BA	1	127926	71.7	<0.001	38.8
S	1	7236	4.06	0.046	2.2
S*BA	1	15299	8.58	0.004	4.6
Error	116	1784			
<i>Late successional species regeneration density</i>					
BA	1	3083	7.02	0.009	6.8
S*BA	1	4263	9.71	0.002	9.5
Error	117	439.2			

\*Seedling densities were square root transformed.

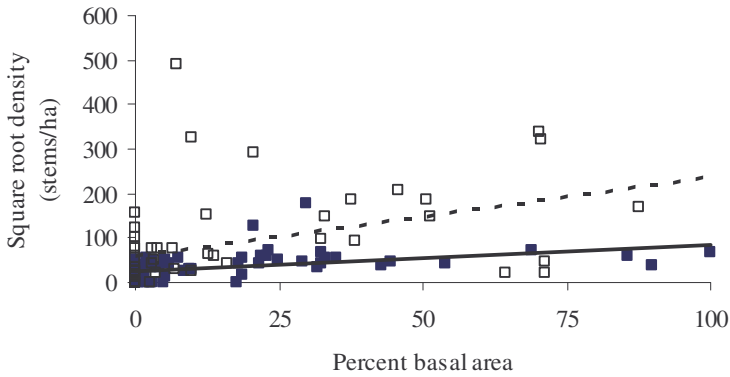




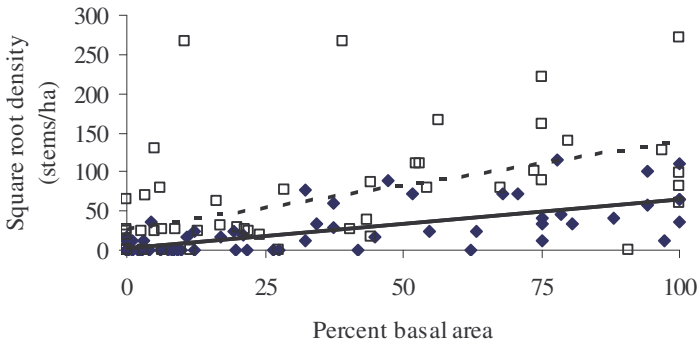
**Figure 2a.** Scatterplots and fitted regression lines of percent basal area in relation to seedling density and season of burn (■ = spring burn, □ = summer burn) for jack pine (spring:  $y = 0.97x + 18.46$ ,  $R^2 = 0.4$ ,  $P = 0.001$ , summer:  $y = 1.58x + 30.07$ ,  $R^2 = 0.33$ ,  $P < 0.001$ ). Fitted regression lines are solid for spring burns and dashed for summer burns.



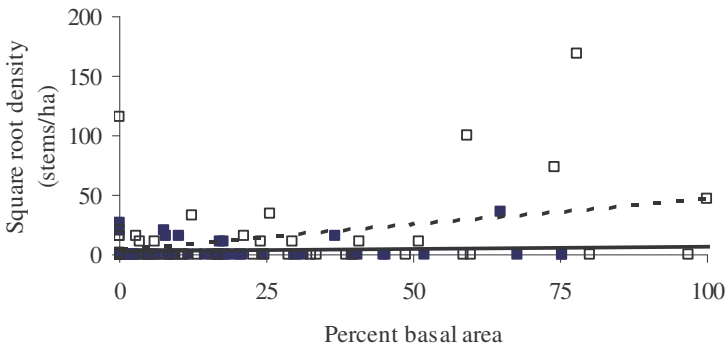
**Figure 2b.** Poplar (spring:  $y = 1.19x + 29.54$ ,  $R^2 = 0.586$ ,  $P < 0.001$ , summer:  $y = 0.443x + 77.68$ ,  $R^2 = 0.042$ ,  $P = 0.15$ ).



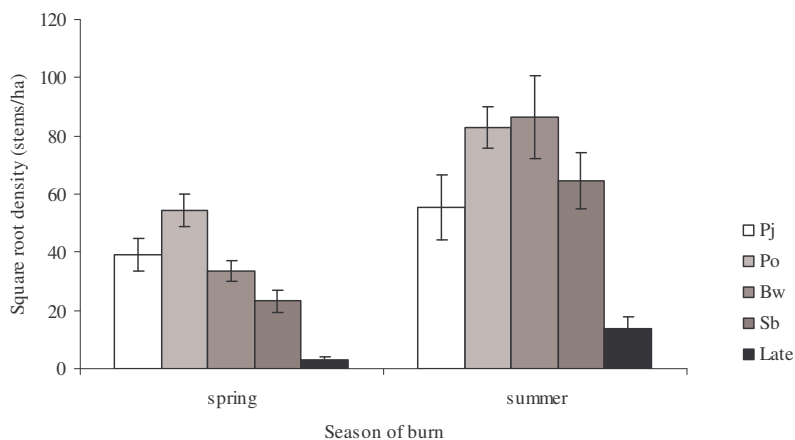
**Figure 2c.** *White birch* (spring:  $y = 0.63x + 23.52$ ,  $R^2 = 0.22$ ,  $P < 0.001$ , summer:  $y = 1.71x + 61.7$ ,  $R^2 = 0.162$ ,  $P = 0.003$ ).



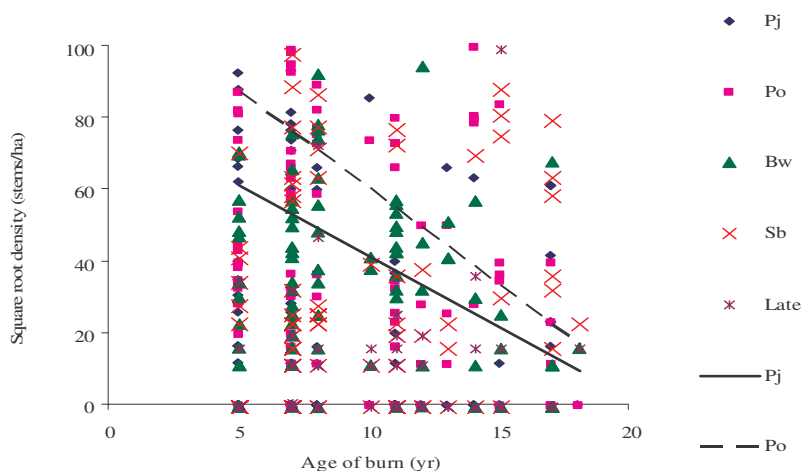
**Figure 2d.** *Black spruce* (spring:  $y = 0.65x + 3.17$ ,  $R^2 = 0.529$ ,  $P < 0.001$ , summer:  $y = 1.33x + 24.79$ ,  $R^2 = 0.348$ ,  $P < 0.001$ ).



**Figure 2e.** *Late successional species* (spring:  $y = 0.031x + 2.88$ ,  $R^2 = 0.006$ ,  $P = 0.5$ , summer:  $y = 0.41x + 4.75$ ,  $R^2 = 0.121$ ,  $P = 0.012$ ).



**Figure 3.** Season of burn and mean seedling density for jack pine (Pj), poplar (Po), white birch (Bw), black spruce (Sb) and late successional species (Late).



**Figure 4.** Species-specific regeneration density in relation to age of burn for 120 post-fire plots in northeastern Ontario. Fitted regression lines for jack pine ( $y = -3.93x + 81.3$ ,  $R^2 = 0.043$ ) and poplar ( $y = -5.05x + 109.6$ ,  $R^2 = 0.13$ ) are significant ( $P < 0.05$ ). Species codes are the same as for Figure 3.

of the surveyed sites had seed-origin aspen and most of these sites did not have aspen before the burn (Vasiliauskas and Chen, unpublished data).

Late successional species formed a minor component of the total regeneration (< 3%), and were restricted to sites within 300 m of a live seed source (Heinzelman, 1981; Greene and Johnson, 2000). They also had the least amount of variance explained by pre-fire percent basal area (6.8%). Their low abundance reflected the shift to dominance by pioneer species after fire and can also indicate the unsuitability of the site for these species immediately after a fire. Although untested, unburned stands and patches were observed to be broadly similar in composition to the adjacent burned plots (Vasiliauskas and Chen, unpublished data), so a higher percentage of late successional species in unburned patches would increase the likelihood of them seeding into burned areas soon after a fire. Our findings reflect the traditional concept of post fire succession, whereby sites are dominated by pioneer species after a fire (Bergeron, 2000), and late successional species do not start to dominate an area until several decades after a fire, originating from unburned patches within a stand (Galipeau *et al.*, 1997; Popadiouk *et al.*, 2003). This emphasizes the importance of unburned patches and edges within a burn in maintaining late successional species on the landscape (Galipeau *et al.*, 1997; Asselin *et al.*, 2001).

Season of burn significantly affected total post-fire seedling density and density of poplar, white birch and black spruce. Higher white birch and black spruce stem densities on summer burns could give these species an advantage in stand dominance over others. However, poplar seedling density will be higher in summer burns where the pre-burn percent basal area was < 65%; otherwise, spring burns will have higher poplar densities. Deeper burns in summer fires can reduce aspen suckering due to root mortality (Horton and Hopkins, 1966; Wang, 2003). These same burns can also expose more mineral soil, providing more opportunities for poplar to establish by seed on new sites the following spring.

Age of burn was a poor predictor of regeneration density, explaining the least amount of variance in jack pine, poplar and total stem density. Most likely this is because the sites were at the stand initiation stage, and crown closure had not yet occurred. A decrease in density with age reflects self-thinning of post-fire stands, starting soon after the fire, especially of aspen suckers (Greene and Johnson, 1999; Wang, 2003).

Our study can contribute towards the understanding of boreal stand dynamics in northeastern Ontario. Four species (jack pine, poplar – primarily trembling aspen, white birch and black spruce) will dominate sites after fire, proportionate to their dominance before the fire (Greene and Johnson, 1999). Stands dominated by late successional species will shift to dominance by the above-mentioned species, and the presence of late successional species is dependent on the proximity of a live seed source. Season of burn and age of burn are also important factors for several of the species tested.

Forest managers need to know stand compositions of burned areas before decisions are made regarding management interventions, such as planting. Before any interventions are done, surveys need to be conducted on stands where a desired future stand composition and density may differ from what will happen naturally.

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