JACK PINE REGENERATION AT THE INTERNATIONAL CROWN FIRE MODELLING EXPERIMENT

W.J. de Groot and M.E. Alexander
Canadian Forest Service, 5320 - 122 Street, Edmonton, AB T6H 3S5, Canada

B.M. Wotton
Canadian Forest Service, 1219 Queen Street East, Sault Ste. Marie, ON P6A 2E5, Canada

P.M. Bothwell, C.N. Stefner, and D.H. Carlsson
Canadian Forest Service, 5320 - 122 Street, Edmonton, AB T6H 3S5, Canada

ABSTRACT

Factors affecting tree regeneration in the boreal forest after fire are poorly understood. We studied post-fire recruitment and early growth of jack pine (*Pinus banksiana*) seedlings in a prescribed burn experiment. We burned nine plots (0.56–2.25 ha) of mature jack pine trees near Fort Providence, Northwest Territories, Canada, by crown fires during 1997–2000 and collected depth of burn, post-fire duff depth, seed rain, post-fire precipitation, and temperature data to determine effects on seedling recruitment and early growth. Viable seed rain varied from 26.4 to 431.3 seeds/m^2 and was highly variable even between adjacent plots burned within days of each other. Viable seed rain had a highly significant effect on the initial establishment of jack pine seedlings which ranged from 6.9 to 79.1 seedlings/m^2 in the first year after burning. Depth of burn on eight plots ranged from 2.0 cm to 2.6 cm, and one plot had a significantly greater depth of burn of 3.6 cm. Depth of burn had no significant influence on seedling establishment or growth. Post-fire duff depth ranged from 2.0 cm to 5.5 cm, but the effect of this factor on seedling establishment was not statistically significant. We detected no significant effects by any of the tested factors on regeneration numbers after the second post-fire year, and the only reliable estimator of regeneration numbers after the second post-fire year was the previous years' regeneration number. Considerable variation occurred in seedling height growth rates. Mean height of third-year seedlings ranged from 5.6 cm to 22.8 cm. Data analysis indicated that pre-fire tree basal area had strong influence on seedling growth rate and this was presumed to be an indication of site quality differences between plots. Seedling numbers and height growth data continue to be collected in this ongoing study. Analysis of seed crop and fire behavior is in progress to determine their impact on viable seed rain.

keywords: crown fire, depth of burn, duff depth, jack pine, Northwest Territories, *Pinus banksiana*, regeneration, seedling height growth, viable seed rain.

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INTRODUCTION

Jack pine is a wide-ranging North American tree species and a major component of the Canadian boreal forest (Fowells 1965, Rowe 1972, Rudolph and Laidly 1990). Jack pine occurs in a diversity of fire regimes (Stocks et al. 2002), and its occurrence, distribution, and life history are closely related to fire (Cayford and McRae 1983, Gauthier et al. 1993). Jack pine persists in fire-prone boreal forests primarily because of cone serotiny, a trait that appears to be influenced by fire regime (Gauthier et al. 1996). A relatively low temperature of 50 °C is required to open the cones (Cameron 1953, Beaufait 1960), so even low-intensity fires are capable of releasing seed from the canopy of mature trees (Chrosciewicz 1988).

Jack pine seed release begins immediately after fire, but germination may be delayed by ash in the seedbed (Thomas and Wein 1985, Herr and Duchesne 1995). This may be an adaptation to prevent immediate post-fire germination when the soil is hot and dry in the post-fire environment. In general, seedling establishment is greatest on seedbeds with a shallow (<0.5 cm) humus layer over mineral soil (Chrosciewicz 1974). Seedlings that root in deeper organic layers have a higher mortality potential because the rooting zone of the seedling can dry out during extended periods of drought. Seedling establishment rates are often wide-ranging and can vary by as much as 1–2 orders of magnitude (e.g., Weber et al. 1987, Greene and Johnson 1999). This variation is often attributed to depth of burn and post-fire duff depth. Chrosciewicz (1974) also found that height growth of 2-year-old seedlings decreased sharply as post-burn humus depth increased from 1 cm to 3 cm.

Most jack pine regeneration studies have been conducted in southern and eastern boreal forests. However, fire is more frequent in western Canada (Stocks et al. 2002) and fires tend to grow to a larger overall size in the northern boreal region. Fire seasons are shorter in the north but burning conditions are often extreme (Simard 1973, Harrington et al. 1983). Because fire regime has such a strong influence on jack pine at the individual, population, and landscape levels (Gauthier et al. 1996), it is important to understand the role of fire in jack pine regeneration in the northwestern region of the boreal forest.

The purpose of this study was to examine the factors affecting jack pine seedling establishment and early post-fire growth in the northwestern boreal region. An experimental burning approach is necessary for this kind of study because depth of burn data collection requires pre-burn field work and wildfires do not provide the opportunity to do this before a stand is burned. For that reason, the International Crown Fire Modelling Experiment in the Northwest Territories was used for this study.

STUDY SITE

The International Crown Fire Modelling Experiment (Alexander and Stocks, *this volume*) is located approximately 50 km north of Fort Providence in the southwest portion of the Northwest Territories (Figure 1). The study site was a 70-year-old jack pine stand 10.9 to 13.8 m in height with an understory of black spruce (*Picea mariana*) ≤5.7 m in height. Jack pine trees within plots averaged 7.8 to 13.4 cm diameter at breast height (dbh), with stand densities of 1,341 to 4,492 stems/ha. Black spruce trees were 4.4 to 5.4 cm dbh and had densities of 513 to 3,245 trees/ha, although plots 3 and 4 had no black spruce trees reaching breast height. Stand basal area was 19.0 to 36.7 m^2/ha for live trees, and dead trees represented an additional 3.9 to 10.1 m^2/ha.

Average total annual precipitation measured at long-term weather stations in the study area region (Hay River and Yellowknife) was 342 and 267 mm, with a May–August rainfall of 146 and 117 mm, respectively (Atmospheric Environment Service 1993). During the study period, total rainfall at the study site from 7 May to 27 August was 230.8 mm (1997), 148.9 mm (1998), 125.7 mm (1999), 160.7 mm (2000), and 239.9 mm (2001). Rainfall periodicity was very similar between study years and there were very few rain-free periods longer than 8 days. The longest rain-free period was 14 days in 2000. The driest year (1999) had no rain-free periods longer than 8 days. Total annual growing degree-days (>5 °C) for Hay River and Yellowknife are normally 1,073 and 1,039, respectively. There was little variation in growing degree-days at the study site from 1997 to 2001: 28 May–24 August totals ranged from 985 to 1,027.

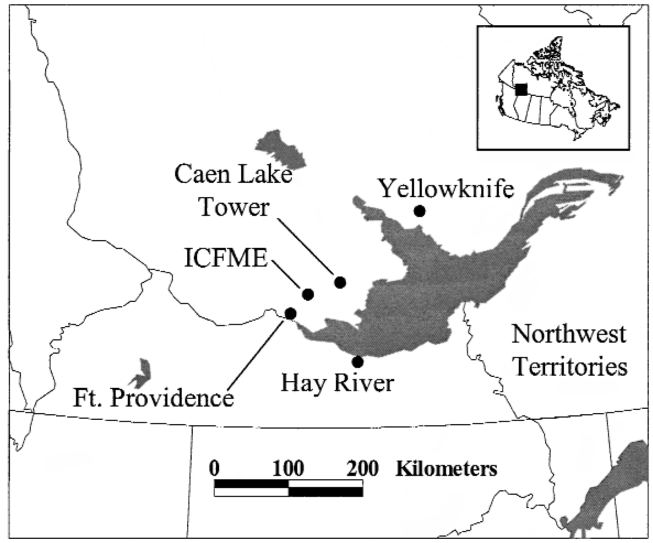

Figure 1. Location of the International Crown Fire Modelling Experiment (ICFME) and local weather stations, Northwest Territories. Shaded areas indicate lakes.

METHODS

We burned nine plots over a 4-year period (Table 1) and all plots were burned by a uniform fire front. We collected data on stand composition, density, tree diameter, tree height, basal area, and duff depth prior to burning. Immediately before ignition, we set depth of burn pins in each plot (McRae et al. 1979) using a systematic pattern along pre-established fuel transect lines. All plots were ignited using gelled fuel along the upwind plot edge, after which a running crown fire quickly developed. Depth of burn and duff depth were measured at each depth of burn pin within a few hours after each burn. Depth of burn was the difference between pre-burn and post-burn duff depths. Sample size for pre-burn duff depth, depth of burn, and post-burn duff depth ranged from 76 to 158 depending on plot size (Table 1). We collected a large number of samples because of the wide variation in depth of burn and duff depth that typically occurs due to microsite differences.

Table 1. Plot sizes and sample sizes for burn depth and post-fire duff depth measurements, jack pine seed traps, and regeneration quadrats, Northwest Territories, 1997–2000. Area of each seed trap was 1,326 cm^2, and each regeneration quadrat was 1 m^2. Burn depth and post-fire duff depth data were collected using point samples. There was no depth of burn or regeneration on the control plot.

			Sample size (*n*)		
Plot	Burn date	Plot size (m^2)	Burn depth and post-fire duff depth	Seed traps	Regeneration quadrats
A	1 July 1997	5,625	98	6	9
1	16 June 2000	22,500	156	25	25
3	28 June 2000	22,500	152	25	25
4	20 June 1999	22,500	150	16	25
5	4 July 1997	22,500	156	16	25
6	9 July 1997	22,500	152	16	25
7	5 July 1998	22,500	158	16	25
8	4 July 1998	22,500	153	16	25
9	19 June 1999	10,000	76	16	16
Control	Unburned	22,500	N/A	16	N/A

Immediately after each burn, we placed 6 to 25 (Table 1) 25.5 × 52-cm seed traps in the burned plots in a systematic grid pattern. In 1999, we also placed 16 seed traps in an unburned control plot. Seed traps were kept at least 25 m from the plot boundaries to ensure that seed collection was not influenced by edge effect. The number of seed traps used in each plot was variable due to plot size differences and availability of seed traps. We used 30-m spacing for seed traps in six of the 150 × 150-m plots (16 traps per plot), and 25-m spacing in the other two large plots when additional seed traps were available (25 traps per plot). In plot 9 (100 × 100 m), we spaced traps 16.7 m apart and 25 m from the plot boundaries to maintain a sample size of 16. Because plot A was only 75 × 75 m, we placed six traps 25 m from the plot boundaries using two lines of three traps with spacing of 25 m between lines and 12.5 m between traps in both lines. We restricted the sample size to six in plot A because increasing the number of traps would have greatly increased the sampling of seed-fall from the same tree in more than one trap. Although the limited sample size in plot A may have reduced the ability to detect a statistical difference in seed rain, it also reduced the possible introduction of a confounding factor due to repeated seed sampling from an individual tree that may not be characteristic of the whole plot. Seed traps had a fine mesh bottom screen and were elevated 5 cm above the ground to keep the seeds dry. The top screen was a coarse mesh to allow seeds to fall into the trap while preventing predation by birds and mice. Seeds collected from the traps in the autumn after the burn were tested for germination (Edwards 1987, Edwards and Wang 1995). To test for germination, we kept seeds on moist filter paper in a covered petri dish for a 28-day period at room temperature. Seeds that germinated (referred to as viable seed) were counted and removed. After 28 days, non-germinated seeds were cut open to determine the number of unfilled seeds.

The year following each burn, we established 9 to 25 (Table 1) permanent 1 × 1-m quadrats in a grid pattern in each plot to measure the number of seedlings. We kept these quadrats a minimum of 25 m from each plot edge and used a 3 × 3 grid pattern for the smallest plot (plot A), a 4 × 4 grid pattern for plot 9, and a 5 × 5 grid pattern for the remaining large plots. We measured jack pine regeneration in the plots starting in the autumn of the year after the burn (very little regeneration occurred in the same year as the burn), and recorded maximum seedling height for each quadrat starting in 2000. For each year of the project, we collected daily rainfall and temperature data during the summer growing season using an on-site weather station and a nearby fire weather station at Caen Lake Tower (Figure 1). Growing degree-days (average of daily maximum and minimum temperature) above 5 °C from 28 May to 26 August (the major portion of the growing season) was also calculated for each year.

Collection of post-fire seedling survival and growth data has been ongoing, but we analyzed current data to determine relationships of seedling establishment and growth to other factors. We compared means (Fisher's LSD; $P < 0.05$) to evaluate variation between plots in pre-burn duff depth, depth of burn, post-burn duff depth, viable seed rain, and seedling density 1 year after burning. We used regression to assess relationships between 1-year-old seedling density and burn depth, post-burn duff depth, and growing season rain-

Table 2. Mean (and SD) post-fire seed rain and subsequent regeneration of jack pine by treatment plot, Northwest Territories, 1997–2000. Letters indicate significant differences (shown only for years with complete data). Seedling density is recorded by years after the plot was burned; the latest year for each plot represents September 2001 data. There was no seed rain or regeneration on the control plot.

			Regeneration (seedlings/m^2)							
	Seed rain (seeds/m^2)		Year 1		Year 2		Year 3		Year 4	
Plot	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
A	26.4 D	7.2	10.2 D	6.2	11.3	6.4	11.3	5.9	11.9	6.1
1	74.2 D	45.8	9.3 D	6.1						
3	169.2 C	80.2	37.0 C	20.8						
4	431.3 A	95.0	79.1 A	29.3	70.7	26.8				
5	50.4 D	31.6	10.7 D	8.2	4.3	4.2	3.6	3.1	3.6	3.1
6	30.6 D	22.5	6.9 D	4.1	3.0	2.7	2.6	2.9	2.6	2.7
7	276.7 B	167.5	64.2 B	47.7	43.2	41.5	40.7	39.9		
8	170.6 C	74.1	21.0 D	24.8	8.9	9.7	8.5	8.7		
9	69.8 D	27.7	10.6 D	8.2	5.6	4.0				

fall using average plot data. Mean height of third-year seedlings (the post-fire year with the most available data) was compared between plots using Fisher's LSD ($P < 0.05$). Regression analysis was used to test relationship between seedling height and depth of burn, duff depth, total growing degree-days, and pre-fire live basal area (as an indicator of site quality) using average plot data. All analyses were conducted using SYSTAT 10 software (SYSTAT 2000).

RESULTS

Pre-burn duff depth for all sample points combined (n = 1,251) ranged from 0.9 to 22.9 cm, and the nine plot means ranged from 4.6 to 7.5 cm. Plots 1 and 6 had similar duff depths, and they were significantly deeper than all other plots. Depth of burn on all plots combined (n = 1,251) ranged from 0.1 to 22.5 cm, and eight of the plots had a mean depth of burn from 2.0 cm to 2.6 cm. Plot 3 had a significantly higher depth of burn (3.6 cm) than all the other plots. Post-burn duff depth (n = 1,251) ranged from 0.1 to 16.5 cm with average plot values of 2.0 to 5.5 cm. Plot 6 had the greatest post-burn duff depth, followed by plot 1. Both of these plots were significantly different from all others, including each other. Plots 8 and 9 had post-burn duff depths that were similar and slightly lower than plot 1, and were significantly different from all other plots. All other plots had lower post-burn duff depths and were statistically similar.

Post-fire viable seed rain was highly variable (Table 2). Comparison of means across all plots showed plots 4 and 7 had the greatest seed numbers and they were significantly different from all other plots, including each other. Plots 8 and 3 were similar to each other with slightly lower seed numbers. All the remaining plots were similar to each other and had the lowest seed numbers.

Seedlings counted after the first year of growth (Table 2) were highly variable and showed very similar trends to the post-fire viable seed rain. The greatest regeneration occurred in plots 4, 7, and 3, and each plot was significantly different from all others. Regeneration in the remaining plots was lower and there was no significant difference between them.

Regression analysis (n = 9 plots) showed viable seed rain (x) to be a highly significant factor affecting first-year regeneration (y) ($y = 0.007 + 0.192x$ [$r^2 = 0.94$]). Post-burn duff depth was not significant ($P = 0.07$) but it was somewhat influential ($r^2 = 0.39$) and showed a trend of decreasing seedling recruitment with increasing duff depth. A multiple regression of viable seed rain and duff depth did not improve the regression equation. No other factors had a significant influence on seedling establishment. Depth of burn and total summer precipitation in the first post-burn year were not significant factors affecting first-year regeneration. Seed rain was a reliable predictor of second-year regeneration numbers ($r^2 = 0.91$), but in the third year it was less influential ($r^2 = 0.72$) and not significant ($P = 0.07$). Seedling numbers in years 2–4 after fire (Table 2) were highly correlated to the previous years' value (r^2 = 0.86–0.95).

Height of third-year seedlings (Figure 2) was highly variable with heights on all plots ranging from 0.6 cm to 30.9 cm, and averaging 5.7 cm to 22.8 cm. Comparison of means showed no significant difference in 3-year-old seedling height between plots 7 and 8, or between plots 5 and 6. Seedling height in plot A was

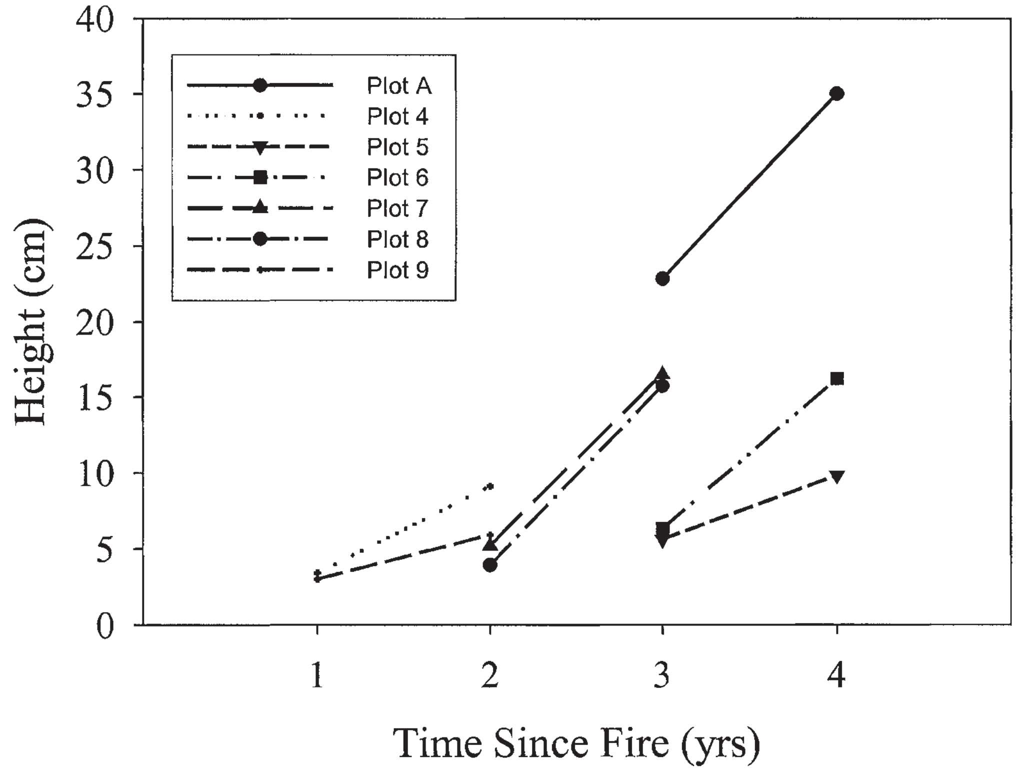

Figure 2. Mean jack pine seedling height by the number of years after prescribed fire, Northwest Territories, 1997–2001. Data represent measurements collected during September of 2000 and 2001.

significantly greater than in all other plots. Regression of seedling height on pre-fire live tree basal area, depth of burn, post-fire duff depth, and cumulative (3-year) growing degree-days after fire (n = 5 plots) showed basal area to be the only factor near significance (P = 0.06) and it explained 74% of the variance.

DISCUSSION

The regeneration data show high variability between plots, even for adjacent plots burned in the same year. In three out of the four years when burns were conducted, there was a 3- to 7-fold difference in first-year post-fire seedling density between adjacent plots that were burned within days of each other. Clearly, this cannot be explained by annual differences in precipitation regimes. These results suggest that seedling establishment is highly dependent on site-specific plot or fire conditions.

In this study, viable seed rain was the most important factor affecting the recruitment of new seedlings as it accounted for 94% of the variation in regeneration data. Duff depth is often cited as having an important influence on jack pine recruitment, but in this case it had only a small effect. This could be explained by the low range in average post-fire duff depth between plots (2.0 to 5.5 cm) and limited sample size (n = 9 plots) making it difficult to detect a significant influence by depth of burn. This explanation is supported by Chrosciewicz (1974) who found the greatest impact of depth of burn on jack pine seedling recruitment when the post-burn humus depth was less than 2 cm. More detailed collection of duff depth within regeneration plots is planned in order to provide a stronger analysis.

Because the burns in this study were conducted over a 4-year period and were only completed in 2000, there are limited regeneration data for later post-fire years. However, the current data indicate that viable seed rain no longer has a significant influence on regeneration numbers after the second post-fire year. At this point, it appears that modeling of seedling mortality in early post-fire years as self-thinning occurs will be based on the strong year-to-year relationship in regeneration numbers.

The current seedling height growth data show a strong dependence on pre-fire live tree basal area, which is presumed to be a site-quality effect. Future data collection as seedlings grow will provide a better opportunity for analysis of factors. It may be difficult to determine an influence by duff depth in this study because most plots have a duff layer >3 cm and Chrosciewicz (1974) found seedling growth rates to be highly variable when duff depths reached this level.

It was possible that the limited number of seed traps and regeneration quadrats in plot A might have prevented the detection of a significant difference in seed rain, regeneration number, and seedling height from other plots. However, inspection of the data and analysis results suggests that this is not a concern. Height of third-year seedlings in plot A was shown to be significantly greater than in all other plots, and this difference was quite obvious in the field data. Seed rain and first year regeneration in plot A were found to be not significantly different from many other plots and this is consistent with the plot means. Plot A also had standard deviations that were comparable or lower than the other plots, giving further confidence in the adequacy of the sample sizes.

The current modeling capability for post-fire jack pine recruitment is limited, although Greene and Johnson (1999) have developed a jack pine recruitment model. Given this model, we would expect a regeneration density of 2.2–4.5 seedlings/m^2 on the ICFME burn plots. This is considerably less than the 7–79 seedlings/m^2 that were measured on the plots, but that model does not include any fire or microsite variables. In this study, seed crop and physical fire characteristics (fire intensity, rate of spread, or flame duration) are the most likely causes for the highly variable seed rain and regeneration results, and this is currently under investigation in the ICFME project. Continued data collection and analysis of the ICFME burn plots will provide the opportunity to model jack pine recruitment and post-fire growth in greater detail.

CONCLUSIONS

The amount of jack pine viable seed rain was highly variable on the ICFME burn plots, even when adjacent plots were burned within a few days of each other. Viable seed rain was an important factor affecting initial jack pine recruitment. Duff depth had limited influence on seedling recruitment, but this could be attributed to moderate duff depths on all plots. Analysis of current data indicates early jack pine seedling growth to be strongly influenced by pre-fire live tree basal area, an indicator of site quality.

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