7.0 DECIDUOUS REGENERATION ONE YEAR FOLLOWING WILDFIRE AND HARVEST IN ASPEN-DOMINATED MIXEDWOODS OF NORTH-CENTRAL ALBERTA

Dan A. MacIsaac and Susan Crites

The objective of the deciduous regeneration subproject of the Fire and Harvest Residual Project was to determine the differences in deciduous regeneration between burned and harvested two-year post-disturbance stands. Furthermore, to relate this response to observed stand and microsite conditions as well as to determine the ecological differences between the two disturbance regimes, in order to explain regeneration differences. Regeneration and microsite conditions were sampled in mill-hectare plots from three harvested and three fire-origin stands in north-central Alberta.

Aspen suckers comprised 68% and 99% of the deciduous regeneration in the harvested and fire-origin stands, respectively. Aspen density was significantly higher in the fire-origin stands (99,470 stems ha^{-1}) compared to the harvested stands (13,010 stems ha^{-1}), whereas average height was slightly greater in the harvested stands (103.5 cm *vs* 93.6 cm). These differences are related to the different ecological processes that follow as a consequence of the two disturbance types. Regeneration was not uniform between the three stands of fire and harvest-origin, due to differences in site conditions between the different stands. The microsite factors of moisture, slope position and disturbance type had a significant and clear effect on regeneration response. High moisture and lower slope position combined to impede suckering as did the surface disturbance and compaction associated with roads and landings. Conversely, the effects of aspect, slope angle, distance to residual, slash and downed woody material had a negligible effect on regeneration.

In spite of the different disturbance modes, most of both the harvested and fire-origin stands have a good probability of meeting the new deciduous regeneration standards at year five. The two areas where the regeneration may not be sufficient to meet the establishment survey standards would be insufficient stocking in the harvested stands (especially H951) due to heavy grass competition, and height growth below the acceptable minimum of 80 cm in the fire-origin stands, due to too much shading by the high number of residual snags (particularly stands F951 and F952). However, it is expected that most of these stands should meet the standards by year five.

Introduction

During the past fifteen years, trembling aspen (*Populus tremuloides* Michx.) has become an important commercial tree species in Alberta. This species is known to be well-adapted to the boreal forest disturbance regime, and can produce dense suckers after disturbances such as fire (Bailey and Wroe 1974, Bartos et al. 1994, Shepperd 1996) and harvesting (Bartos and Meugger 1982). While these two stand-replacement agents *may* result in *superficially-similar* post-disturbance conditions, they can result in very different regenerating conditions (Crouch 1986) and it is important to understand the effects of these disturbance types as part of effective forest management (Bartos and Mueggler 1982). This is especially true, given that contrary to widely-held views, aspen regeneration is not nearly always successful following harvest (Bates et al. 1993).

There are many factors that influence deciduous regeneration in aspen-dominated forests following disturbance by fire and harvesting, including parent stand conditions, the timing and severity of the fire, harvesting effects, physical site factors and post-disturbance residual stand conditions (Bates et al. 1989, Perala 1995).

Pre-disturbance parent stand conditions include parent stand tree density and stocking, age, vigour, clonal variability and the health of the parent stand (Brown and DeByle 1987 cf. Bates et al. 1989). Fire characteristics include the timing and severity of fire, its spatial configuration and rate of spread (Bates et al. 1989, Quintillio et al. 1991). Fire can stimulate suckering through increased soil temperatures by increasing soil warmup through removal of the duff layer, and blackening the soil surface (Bates et al. 1989).

Harvesting effects include the season and method of harvest, the degree of soil disturbance, and the abundance and distribution of slash (Bates et al. 1989). Areas of high slash abundance can negatively influence regeneration by reducing soil temperatures through shading (Bates et al. 1989). Some soil disturbance during harvest will promote suckering, while too much will reduce it (Shepperd 1996). Soil compaction during harvesting and skidding will cause changes in soil bulk density, aeration, and porosity (Bates et al. 1993). The amount of equipment traffic during harvest will influence the deciduous regeneration. While balsam poplar will regenerate from seed on exposed mineral soil along skid trails, there will not be much aspen suckering if there is a high degree of soil compaction.

Site factors that influence deciduous regeneration after fire and harvest include soil texture, slope position and drainage, slope angle and aspect (Ffolliott and Gottfried 1991). Aspen growing on fine-textured soils may be susceptible to post-harvest regeneration problems due to delayed soil-warming and reduced aeration (Bates et al. 1993). Slope position and orientation (angle and aspect) and soil moisture influence soil temperature, which in turn influences aspen suckering (Crouch 1986). Moisture status can be inferred from slope position and the understory plant community which existed prior to disturbance (elements which will still exist the year after disturbance in harvested stands). This is a major factor in deciduous regeneration as it effects soil moisture and aeration.

Post-disturbance stand conditions include density and spacing of residuals, and abundance, size, and distribution of downed woody material in fire-origin stands. Other factors include abundance and distribution of roots and coppice stumps.

Based on the above, it is acknowledged that many factors influence the initial regeneration and subsequent growth of deciduous species after harvesting or wildfire disturbances. A discussion of these factors is found in DeByle and Winokur (1985), Bates et al. (1988, 1989, 1993) and Peterson and Peterson (1992).

The objective of the deciduous regeneration subproject of the Fire and Harvest Residual Project was to determine the differences in deciduous regeneration (trembling aspen, balsam poplar and white birch) between burned and harvested two-year post-disturbance stands, and to relate this response to observed stand and microsite conditions. An additional objective was to determine the ecological differences between the two disturbance regimes, and use this to help explain regeneration differences, to see if these disturbance types can ever be similar or what similarities and differences they may have.

Field Methods

Three stands of harvest origin and three stands of fire origin were selected for this study. Five of the six stands occur within the Central Mixedwood Natural Subregion[1]. The sixth, stand H951, is located on the northeastern flank of the Pelican Mountains, an outlier of the Lower Foothills natural Subregion. The harvested stands are in the Athabasca-Calling Lake area, while the fire-origin stands are in the 1995 Mariana Lakes burn, 50-90 km south of Fort McMurray.

Harvested stands were logged in the winter of 1994-95 and the fire-origin stands burned in May 1995. Although the overall Fire and Harvest Residual study was examining stand response in one-year old stands, the regeneration information was collected in the fall of 1996, two growing seasons after disturbance.

[1] The natural subregion designation is based on: Natural regions and subregions of Alberta. [natural region map]. 1994 Land Information Services Division, Alberta Environmental Protection, Edmonton, Alberta. 1 sheet.

In order to accommodate the 10 one ha sampling sites used in other aspects of this project, each of the three harvested stands was represented by two sub-stands, located within 500 m of each other. These sub-stands ranged in size from 18.7 ha to 30.2 ha. In the harvested stands, regeneration data was collected throughout the whole stand. In the fire-origin stands, regeneration data was collected within the 10 one ha sampling sites.

Data on deciduous regeneration and associated microsite conditions were collected in the harvested and fire-origin stands, within 1.78m radius plots (10 m^2) situated along a systematic grid. Both the plot size and grid pattern and intensity were consistent with the operational regeneration survey guidelines developed by the Alberta Land and Forest Service and specified in the 1990 Alberta Regeneration Survey Manual[2]. The plot size allowed comparison of these results with other regeneration information. As well, a systematic grid method allowed stand-level regeneration attributes to be compared to information from the plots. All areas of the harvested stands were surveyed in this systematic grid, including roads and landings.

In the harvested stands, regeneration assessment plots were spaced 60 m apart. This spacing was consistent with the sampling intensity specified for stands of the sizes used in this study, based on the 1990 Alberta Regeneration Survey Manual and resulted in between 124 and 144 plots per stand. In H953, the plot spacing of 60 m was based on a substand size of 27.5 ha. Based on this, there should have been 76 plots, but only 52 plots were sampled. This was because there were some large residual patches within the stand that were included in the pre-harvest stand size, but were not sampled, and the stand boundaries were somewhat irregular. In the rest of the stands there was more complete coverage of plots in irregularly shaped portions of the stand.

In the fire-origin stands, a 30 m plot spacing was used, giving 90 plots per stand. All the plots were established inside the 10 one ha sampling sites. A larger area was not used for sampling as was done in the harvested stands because pre-fire stand boundaries were difficult to determine with certainty.

Measurements

Most of the measurements were taken in both the harvest and fire-origin stands, although there were some that were specific to either the fire-origin or harvested stands. Variables listed below were measured at each 1.78 m radius sampling plot.

[2]Unpublished report, 1990, by the Reforestation Branch, Alberta Forest Service. Reprinted Nov. 1994 by Land and Forest Service, Alberta Environmental Protection, Edmonton. Pub. No. Ref. 70

Variables Measured in All Stands

a) Slope Aspect
The slope aspect (azimuth) was based on a compass reading to the nearest 5^0.

b) Slope Angle
Classes were: Flat, Gentle (< 5%), Moderate (6-15%), Steep (> 15%).

c) Slope Position
Classes were: Crest, Upper Slope, Mid-Slope, Lower Slope, Toe, Flat, Depression (from Luttmerding et al. (1990)).

d) Moisture Class
Classes were: Very Xeric, Xeric, Subxeric, Submesic, Subhygric, Hygric, Subhydric, Hydric (from Luttmerding et al. (1990)).

e) Stem Density
Density was recorded by deciduous species, based on all stems rooted in the plot at ground level. Deciduous saplings of all sizes and conditions were counted (even if they were dead), as long as they had regenerated since the disturbance. In this study, there was no minimum height limit. In these stands, the deciduous regeneration after two years of growth was always over 30 cm tall, which is the minimum height used in tallying regeneration according to the Alberta Land and Forest Service regeneration survey guidelines. Each deciduous stem was counted individually, even if several stems sprouted from the same parent stump.

f) Average Height
This was recorded by deciduous species, to the nearest 5 or 10 cm. It was not based on a numerical average, but on the overall observed average sapling height, excluding the tallest saplings and suppressed stems.

g) Advanced Regeneration
The density and average height of deciduous and conifer advanced regeneration (trees that were already established at the time of harvest) was recorded in each plot.

h) Density of Residual Stems (in harvested stands) of patches within 10 m of the regeneration plot or Remaining Snag Density (in fire-origin stands) of stems within 10 m of the regeneration plot.

For harvested stands the classes were: Individual Tree, Small (<5 Trees), Medium (6-10 Trees), Large (10+ Trees). In the fire-origin stands, snag density was based on the number of stems in the canopy or sub-canopy, within 10 m of plot centre. This was a rough estimate, with no counts done. Classes were: None, Light (< 10 stems), Moderate (10-25 stems), Dense (> 25stems).

i) Slash Index (in harvested stands) or Downed Woody Material (in fire-origin stands).

This was a composite index that combined abundance and stem size. This index only included the wood deposited on the ground during or after harvest or fire, and did not include the pre-harvest material.

Abundance Cover Classes were: None, Light (0-10%), Medium (10-35%), Dense (> 35%).
Size: Size Classes were: Fine (<10 cm diameter), Coarse (>10 cm diameter).

The combined classes were: None, Light Fine, Light Coarse, Medium Fine, Medium Coarse, Dense Fine, Dense Coarse.

j) Residual Species (in harvested stands) or Original Stand Tree Species (in fire-origin stands).

In the fire-origin stands, this was based on burned canopy trees and did not include advanced regeneration or trees less than 10 cm DBH, or trees that were not the same height as or close to the canopy level. In all stands, species were listed in order of relative abundance, from most to least abundant.

<u>Variables Measured Only in Harvested Stands</u>

a) Plot Location
The plots were recorded as being on a Logging Road, Skid Trail, Landing, Slash Pile, Other (rest of the stand). This was a rough designation of major disturbance only, as there was heavy marsh reed grass (*Calamagrostis canadensis* (Michx.) Beauv.) cover over most of the stand, so minor soil disturbance would be difficult to detect.

b) Distance to Residual (with residual defined as live trees having DBH > 10 cm)
Classes were: None, Close to Residual (2 to10 m from edge), Edge of Residual (0-2 m from edge), Within Residual.

Methods of Analysis

Descriptive statistics were calculated, by species and for all deciduous species combined, by stand and by disturbance type (fire and harvest). For the harvested stands, descriptive statistics were run on substands within stands.

A variety of data transformations were used on regeneration density and height variables in an attempt to normalize the data prior to analysis, following the approach outlined in Sabin and Stafford (1990) and Zar (1984). The W-test for normality (Shapiro and Wilk 1965) as extended by Royston (1982) for sample sizes less than 2000 was used for all the variables. This normality assessment was done separately for harvested and fire-origin stands. For all variables, there were specific transformations which consistently improved the distribution towards normality. For density variables this was a square root transformation, while for height variables, untransformed data most approximated a normal distribution. These transformed data were used in the analysis of variance and canonical correspondence analysis.

A nested ANOVA linear model was developed to test regeneration response, as appropriate for the experimental design (SAS Institute Inc. 1991). The model was:
regeneration response = disturbance type + stand (disturbance type) + error.
For the ANOVA, complete model statistics are presented in this report, following the recommendation of Warren (1986).

While data transformations improved the data parameters, in most cases normal distribution and equal variances for each group were not attained. For this reason, non-parametric statistics were used for additional analysis. Differences in regeneration between stands within treatments were analysed using a Kruskal-Wallis one-way analysis of variance on the ranked scores. If this test showed that differences in the median values among the stands were statistically significant (P = <0.001), then Dunn's all pairwise multiple comparison procedure (multiple means test) was used to isolate the stand or stands that differed from the others. This is a conservative test, in that it is less likely to indicate significant differences between groups than other tests (Day and Quinn 1989). The Mann-Whitney rank sum test was used to determine differences in regeneration response between fire-origin and harvested stands, with all stands combined.

The relationship between plot-level microsite conditions and the regeneration response was studied using several approaches. Multiple means tests using all-pairs and paired-comparisons were used to determine differences in regeneration occurring in plots grouped by microsite variable classes. Multiple linear regression models were used to determine which microsite variables explained most of the variation in regeneration response.

Analysis was also done that tested the effect of combined slope and azimuth on deciduous regeneration, using a cosine and sine transformation method from Stage (1975, c.f. Wagner and Radosevich 1991). This was done with a regression test using cosine and sine transformations with 225 degree phase shift (assumes that southwest exposure gives best growth). The model used was:
regen = a*slope-angle*cosine(azimuth-225) + b*slope-angle*sin(azimuth-225) - c*slope angle

Data analysis was performed using SAS for UNIX Version 6 (SAS Institute Inc. 1990), Sigmastat for Windows Version 2.0 (SPSS Inc.) and Quattro Pro for Windows Version 8.0 (Corel Corporation Ltd.).

Results

Regeneration in Harvested vs Fire-Origin Stands

There were significant differences ($P<=0.001$) in stem density between harvested and fire-origin stands for all deciduous species combined and for aspen and balsam poplar separately (Fig. 7.1a, 7.1b, Appendix 7.1). Aspen strongly dominated the deciduous regeneration, accounting for approximately 70% and 99% of the deciduous regeneration in harvested and fire-origin stands, respectively (Appendix 7.1). Aspen regeneration averaged 13,010 ± 820 stems ha^{-1} for harvested stands, and 99,470 ± 4,930 stems ha^{-1} for the fire-origin stands. Balsam poplar density was 5,830 ± 620 stems ha^{-1} for harvested stands, and 170 ± 50 stems ha^{-1} for fire-origin stands. There was no significant difference ($P=0.665$) in birch density between harvested (290 ± 80 stems ha^{-1}) and fire-origin stands (260 ± 70 stems ha^{-1}).

Average regeneration height was significantly different ($P<=0.001$) between harvested and fire-origin stands for all deciduous species combined and for all species separately (Figs. 7.2a, 7.2b, 7.3a, 7.3b, Appendix 7.2). In all cases, average height was taller in harvested stands compared to fire-origin stands. Overall mean deciduous height was 105.6 ± 1.5 cm for harvested and 92.5 ± 1.9 cm for fire-origin stands (Appendix 7.2). Results were similar for aspen. The greatest height difference was with balsam poplar, which had an average height of 106.9 ± 2.7 cm for harvested stands, and only 36.7 ± 4.4 cm for fire-origin stands. The latter was based on a balsam poplar presence in only 15 of the 270 plots surveyed in these stands.

Regeneration Within Disturbance Types

Total deciduous regeneration density within harvested stands ranged between 15,190 ± 1,400 stems ha^{-1} and 22,380 ± 1,890 stems ha^{-1}, with H951 having significantly lower densities than the other two stands ($P<0.05$) (Fig. 7.1a and Appendix 7.1). Aspen density was not significantly different within the three harvested stands ($P= 0.463$ in Kruskal-Wallis one-way analysis of variance on the ranked scores), ranging from 11,130 ± 1,210 stems ha^{-1} and 15,100 ± 1,640 stems ha^{-1} (Fig. 7.1a and Appendix 7.1). Balsam poplar density was approximately 7,500 stems ha^{-1} in H952 and H953, and significantly lower ($P<0.05$) at 2,410 ± 460 stems ha^{-1} for H951. Birch density was also variable, with densities ranging from 180 ± 110 stems ha^{-1} and 450 ± 150 stems ha^{-1}, with H953 having significantly higher densities than the other two stands ($P<0.05$).

In fire-origin stands, total deciduous regeneration density was significantly different between all three stands ($P<0.05$), ranging from 38,840 ± 4,920 stems ha^{-1} in F952 to173, 500 ± 6,810 stems ha^{-1}, in F953 (Fig. 7.1b and Appendix 7.1). As the regeneration in fire-origin stands was almost exclusively aspen, the individual regeneration response for aspen was similar to that for total deciduous species (Fig. 7.1b and Appendix 7.1). Balsam poplar density was not significantly different between stands ($P<=0.001$), ranging from 110 ± 80 stems ha^{-1} to 220 ± 100 stems ha^{-1}. Birch density was more variable, with a significant difference ($P<0.05$) between F951 with no stems and F952 with 600 ± 180 stems ha^{-1}.

Average height of total deciduous regeneration in individual harvested stands ranged from 99.5 ± 2.8 cm to 110.5 ± 2.6 cm, with H952 having significantly smaller heights than the other two stands ($P<0.05$) (Fig. 7.2a and Appendix 7.2). Aspen height was more variable among harvested stands (ranging from 97.9 ± 2.4 cm to111.7 ± 2.2 cm), with H951 being significantly lower ($P<0.05$) (Fig. 7.2b and Appendix 7.2). Balsam poplar average height was significantly different at $P<0.05$ between H952 (97.8 ± 4.8 cm) and H953 (118.0 ± 2.8 cm). Birch height in harvested stands ranged from 87 to 110 cm, but was not significantly different ($P=0.756$).

Average height of total deciduous regeneration in individual fire-origin stands was less variable than density in the same stands, although F953 had significantly taller saplings (113.2 ± 3.1 cm) than the other two stands ($P<=0.001$) (Fig. 7.2a and Appendix 7.1). Average aspen height in individual harvested was similar to the total deciduous height (Fig. 7.2b and Appendix 7.1).

Balsam poplar height in F953 was 57.5 ± 17.5 cm, while height in the other two fire-origin stands was less than 40 cm; however, these differences were not significant. This height difference was also not significant ($P=0.230$). There was also no significant difference in birch height between fire-origin stands ($P=0.792$), which averaged 60 cm.

<u>Effect of Microsite and Disturbance Factors on Regeneration Within Stands</u>

In harvested stands, aspen regeneration density was significantly greater in plots that were subhygric or drier, compared to hygric plots ($P<0.0001$). For balsam poplar, density was less affected by moisture class, as the species could grow in wetter conditions compared to the aspen, although the difference was still significant ($P = 0.014$). Aspen density was not significantly affected by attributes related to stand residuals including distance to the nearest residual ($P=0.08$) and size of the nearest residual patch ($P=0.11$). The results were similar for balsam poplar. Aspen height growth was not significantly affected by the moisture conditions ($P=0.06$), nor was balsam poplar ($P=0.65$).

In the harvested stands, aspen density was significantly greater in crest to mid slope positions compared with other slope locations ($P<0.001$) although aspen height was not influenced by slope position ($P = 0.910$).

For the harvested stands, a total of 15.2 percent of the area had been disturbed by logging roads (4.2%), skids trails (2.5%), landings (2.0%) and slash piles (6.4%). Total regeneration density in the harvested stands was significantly lower ($P<0.05$) in those plots that were placed on logging roads and landings compared to other areas of the harvested stands. For aspen alone, regeneration density was significantly lower ($P<0.05$) in those plots that were placed on slash piles (2,810 ± 800 stems ha^{-1}), as well as on logging roads (880 ± 535 stems ha^{-1}) and landings (1,380 ± 1,017 stems ha^{-1}) compared to undisturbed areas of the harvested stands (14,900 ± 929 stems ha^{-1}). While skid trails had only slightly over one-third of the stem density (5,500 ± 2,151 stems ha^{-1}) of the undisturbed area, the difference was not significant ($P>0.05$). Plots that had dense fine or dense course slash had significantly lower aspen density than plots with medium coarse, light fine and light coarse slash levels ($P<0.05$).

There was a significant difference between fire-origin stands ($P=<0.001$) in snag density in the vicinity of the $10m^2$ plots. Stand F953 was the driest and had the most upper-slope position of the three fire-origin stands (Table 7.1), although the differences were not significant ($P = 0.069$ for moisture and $P = 0.208$ for slope position). However, this was reflected in significantly more regenerating aspen stems ($P<0.05$) and taller-than-average saplings in this stand compared to the other stands, as well as the presence of more snags (Table 7.2 and Appendix 7.3). In the fire-origin stands, there were no significant differences in aspen density and height in plots located in different moisture and slope position microsite classes ($P>0.05$). Aspen density and height was also not significantly affected by attributes related to post-fire snag characteristics including snag density ($P>0.05$).

Regression analysis on aspen density using the combined effect of slope and aspect yielded an r^2 value of 0.02 for the harvested stands (DF = 1, F Value=5.9, Prob>F=0.0152) and an r^2 value of 0.02 for the fire-origin stands (DF = 1, F Value=6.9, Prob>F=0.0088).

Comparison of Regeneration to the Revised 1997 Deciduous Standard

Provincial regeneration standards have recently been revised for deciduous stands in Alberta[3]. The Establishment Survey is to be carried out between 3 and 5 years after harvest. As such, the results reported from this study cannot be directly compared with those standards. However, a comparison was made to give a general idea if these regenerating stands might meet the standards at age 3 to 5. Analysis was based on an individual stand basis, rather than stands grouped by disturbance type, as the

[3] Addendum to the Alberta Regeneration Survey Manual. Unpublished report, April 1997, by Land and Forest Service, Alberta Environmental Protection.

assessment unit for regeneration in Alberta is the harvested stand.

Two types of stocking assessment were done (Table 7.3). The first assumed no minimum stocking height, and assessed a plot as stocked if there was at least one deciduous stem in the plot. This assumed that those stems would reach the minimum regeneration height of 80 cm after 5 years. The second assessment based stocking on the minimum height of 80 cm as specified in the regeneration stand survey guidelines. It is considered a more conservative test, as some plots not specified as stocked would in fact have the minimum height attained by age 5. It was used to determine the potential that some stands would not reach the standard due to insufficient regeneration height.

Discussion

Regeneration in Harvested vs Fire-Origin Stands

The difference in aspen regeneration density between fire origin stands and harvested stands was due to ecological differences between the two disturbance types, rather than inherent differences in site conditions. As Bailey and Wroe (1974) have noted, any disturbance that increases soil temperature stimulates aspen suckering. Light surface fires may weaken aspen, resulting in later mortality with few suckers (Weber 1990). More moderate burns can stimulate aspen suckering (Bates et al. 1989) by removing apical dominance of canopy trees with minimal root mortality (Schier et al. 1995 cf. Bartos et al. 1994). Repeated or severe burns can diminish subsequent aspen regeneration (Bates et al. 1989, Perala 1995). Most of the fires in undisturbed aspen stands in Alberta are of a low intensity (Quintilio et al. 1991) and it is generally agreed that aspen stands can be difficult to burn (Kay 1997). The fire intensity in the aspen stands that were burned in the Mariana Lakes fire that established the fire-origin stands in this study appears to have been optimal to result in high regeneration densities: severe enough to kill all the parent trees, but not too severe as to kill the lateral root systems. This condition led to increased regeneration response.

The timing of the fire event also enhanced sucker production. With a mid-spring burn, the newly exposed burned ground would absorb more solar insolation, thus increasing soil temperatures and enhancing suckering. Fires in aspen stands in central Alberta showed a decline in growth of shrubby species after the fire (Quintilio et al. 1991) as is noted for other regions in North America (Bartos et al. 1994). Reduction in understory vegetation in the fire-origin stands would enhance the sucker development. In spite of large numbers of fire-killed snags on site, regeneration density was high through all areas of the fire-origin stands. This may because aspen has been noted to show strong regeneration in even small openings (Groot et al. 1997).

Another factor influencing the lower densities in post-harvested stands was the greater amount of grass cover in harvested stands, particularly H951 and H953 compared to fire-origin stands (e.g., F953). Bartos et al. (1994) indicate that initially, grass abundance decreases after fire. In some cases, water table levels may rise after clear-cutting (Crouch 1986), producing conditions favourable to grass production. Marsh reed grass was very dense and tall (about 1.5 m) on the north facing slopes in the harvested stands. This heavy grass cover results in lower soil temperatures thus impedes aspen regeneration (Quintilio et al. 1991). Conversely, the marsh reed grass was shorter (about 60 cm tall) and more sparse on the more southerly-facing aspects of the same stands. It was noted that the upper slopes were associated with the highest aspen densities along with some beaked hazelnut (*Corylus cornuta* Marsh.) and green alder (*Alnus crispa* (Ait.) Pursh). On the upper slopes, especially south facing, the aspen density was highest, although the tallest saplings were found on the moister sites. Because the abundance of grass and shrub species was not measured as part of the sampling protocol, the influence of these species on microsite conditions and deciduous regeneration are only speculative.

The taller deciduous regeneration in the harvested stands compared to fire-origin stands may be due to the timing of the two disturbance events. The fire occurred in late May, with sucker response initiated later in the growing season compared to the harvested stands which were harvested prior to the start of the growing season. Peterson and Peterson (1992) indicate that suckers that develop early in the growing season grow taller than those generated later on. The second factor may be the additional shade in the fire-origin stands caused by the more dense residual snags present. While initial high densities were stimulated by the fire event, subsequent growth in the fire-origin stands may be slower. As well, a greater proportion of root carbohydrates may have been used in the production of high number of suckers, with fewer carbohydrates available for the subsequent height growth of each one.

It has been postulated that geographic separation of the harvest vs fire-origin stands used in the study could have an influence on the regeneration response. In a study on parent stand age and harvesting treatment on aspen regeneration in widely-separated stands in the Slave Lake and Calling Lake region of Alberta, analysis showed that the geographical separation had no effect on the treatment response (Grewal 1995). Consistency in stand conditions of the different disturbance types is the more important factor to control, as has been done in the FAHR project.

<u>Differences in Regeneration Between Individual Stands Of the Same Disturbance Type</u>

Differences in deciduous regeneration density and height between the different fire-origin stands were related to differences in parent stand condition, landform and average microsite conditions. In fire-origin stands F951 and F952, the ten 100m x 100m plots were located in uniform areas of the stands, and only presented a portion of the canopy and understory conditions that existed prior to the fire. While the topography for stands F951 and F952 was rolling, the sites were located on ridge tops, avoiding the wetter depressions between. For example, while there were areas of black spruce throughout stand F951 the sampling plots were not located in these areas. Stand F953 was much more uniform, and this may have had an effect on the regeneration density.

The significant differences in regeneration density between the three fire-origin stands may be partly due to differences in parent material (surficial geology). Stand F953 is underlain by the Horse River till-hummocky moraine which has a silty-clay texture, and is generally thin with an undulating topographic expression (Maher 1974). Stand F951 is underlain by the Horse River till-hummocky moraine. It also has a silty-clay texture, but is generally thick with a rolling topographic expression. Stand F952 is underlain by the more coarse Kinosis till-hummocky moraine which is of loam composition with numerous pebbles and boulders. It is generally thick, with a more undulating, hilly topography (Lindsay et al. 1957). This stand is also adjacent to a kame moraine composed of sand and gravel (Maher 1974).

Stand H952 appeared to be more nutrient poor than H951 and H953. It had the appearance of a first year growing season after harvest, rather than second year, in terms of general ground cover. Therefore, the aspen was easier to detect, with a lower chance of missing stems. Therefore, density might be higher compared to 1 and 3, because those stands had more grass. Grass was taller and more lush in the wetter areas, with a commensurate less aspen - but there was some balsam poplar. This stand had more slash and a greater stump density than stands H951 and H953. The parent stand probably had a greater volume. Unlike H951 and H953, in H952 the slash was removed from the deck areas and distributed on the logging road, which may have contributed to the higher overall densities, by making more area available for aspen regeneration.

While the experimental objective had been to select three similar stands of each disturbance type, there were differences in the stand conditions that resulted in significant differences in deciduous regeneration between stands of the same disturbance type. Even within stands, there was substantial spatial variation in the deciduous regeneration. This heterogeneity in response was also noted by Beckingham (1993). This variation is mostly related to topographic variation as well, which in turn affected physical conditions such as soil moisture and drainage and biological parameters such as the amount of grassy cover.

Effect of Microsite and Disturbance Factors on Regeneration within Stands

This study attempted to link the variation in microsite conditions found throughout the stands with the observed response in regeneration. However, there are a variety of microsite factors that can have a strong effect on the performance of regeneration in the mixedwoods of Alberta (Brown and Navratil 1995), and the specific combination of factors are not easy to define. A variety of analytical approaches indicated, however, that the factors that had the strongest influence on aspen regeneration were slope position, moisture class, and surface disturbance. Other factors including slope and aspect, and residual characteristics did not have the same level of correlation.

In the six stands selected for this study, the slope position appears to be a factor in the initial deciduous regeneration. It is closely tied in with moisture status, and drainage. Higher slash abundance and the presence of nearby residuals may be associated with lower regeneration densities, although not significantly in most cases. While aspect and slope angle can influence deciduous regeneration (through influence on soil temperature and moisture), for the selected stands, at this early stage of regeneration, it did not have a major influence (e.g., stand H953). Other studies (e.g., Beckingham 1993) have shown that aspen regeneration is quite variable within a stand after harvest, especially in areas of undulating topography. Areas of highest aspen density were noted along ridge tops and higher ground, with little or no regeneration in depressional areas. This situation was also found in all three harvested stands in this study, and has been confirmed by analysis. The greatest impediment to successful aspen regeneration in these stands is the high grass cover in stands H951 and H953, and the undulating topography which precludes the aspen from depressional areas. Other factors which were not measured include the amount of shrub and grass cover; both can reduce suckering.

Comparison of Regeneration to the Revised 1997 Deciduous Standard

In general, it appears that most of the harvested and fire-origin stands have a good probability of meeting the new deciduous regeneration standards at year five (Table 7.3). The exception is stand H951, due to a low density (15,200 stems ha^{-1}) and potentially low stocking. In the prairie provinces, aspen densities after disturbance can be greater than 100,000 stems ha^{-1} in the first few years (Peterson and Peterson 1992). Densities of less than 40,000-50,000 at this stand age would be considered low (Steneker 1976, Bella 1986). Stocking was relatively low in the harvested stands, particularly in stand H951. However, the new regeneration standards specify an average density of 7,000 stems ha^{-1} by year 5.

The maximum stocking has probably already been achieved in these stands as most suckers are formed the first (Peterson and Peterson 1992) or second (Bartos and Mueggler 1982) year after disturbance, and will decline to lower levels during the 3-5 year regeneration assessment period set out in the regulations. In comparison, aspen density peaked at 48,375 ± 4,982 stems ha^{-1} two growing seasons after harvest in aspen stands near Meadow Lake, Saskatchewan (Maynard and MacIsaac 1998). The regeneration density was 38,750 ± 3,854 stems ha^{-1} and 42,875 ± 3,950 stems ha^{-1} in the first and third growing season, respectively, after harvest. These results also conform to Bates et al.'s 1988 finding that aspen regeneration density is often greatest the first or second year after harvest. For this reason, the stocking levels noted from the stands this study are probably the maximum levels that may be expected, and consequently, stand stocking may not be met in one or more stands. It is argued, however, that several thousand aspen suckers at least 2 m tall at the end of the fifth growing constitute a successfully regenerated stand (Shepperd 1996), a condition which will probably exist on these sites.

Notwithstanding the above statement, the high densities in the fire-origin stands will probably decline rapidly in the next few years. Many of the stems measured in 1996 were suppressed and shaded by the larger saplings, as reflected in the lower average height on those stands. It is estimated that at least 30% of them would not be alive the following year. The aspen in the burn stands exhibited a lot of shoot die back, with shepherd's crook symptom due to twig and leave blight caused by *Venturia macularis*. This fungal pathogen is very widespread on the young regenerating aspen (Hiratsuka et al. 1995). Balsam poplar appears to be less affected by this fungus. Aspen is susceptible to many pathogens during the first few years of regeneration (Shepperd 1996) which may lead to early rapid declines in density, although this is considered normal and may not have a strong influence on subsequent yields (Bates et al. 1989).

Conclusions

Two growing seasons after disturbance, there were significant differences in deciduous regeneration between stands of harvest and fire-origin. Densities of aspen were higher in the fire-origin stands, whereas average height was slightly greater in the harvested stands. These differences are due to the different ecological processes that follow as a consequence of the two disturbance types. High aspen sucker densities after the fire are probably due to increased soil temperature through removal of litter and above ground biomass and a darker surface right after the spring fire. As well, these density differences may be due to impeded suckering due to high grass cover on the harvested sites. The harvested stands had significantly taller suckers for all three deciduous species compared to the fire-origin stands.

Regeneration was not uniform between the three stands of fire and harvest-origin. The density and height differences were significant for most species for most stands within a disturbance type. This variation in response between stands within disturbance types are related more to variations in site conditions in the different stands.

The microsite factors of moisture, slope position and disturbance type had a significant and clear effect on regeneration response. High moisture and lower slope position combined to impede suckering as did the surface disturbance and compaction associated with roads and landings. Conversely, the effects of aspect, slope angle, distance to residual, slash and downed woody material had a negligible effect on regeneration. A synthetic index that combined slope and aspect also had a negligible correlation with aspen regeneration.

In general, it appears that, in spite of the different disturbance modes, most of both the harvested and fire-origin stands have a good probability of meeting the new deciduous regeneration standards at year five. The two areas where the regeneration may not be sufficient to meet the establishment survey standards would be insufficient stocking in the harvested stands (especially H951) due to heavy grass competition, and height growth below the acceptable minimum of 80 cm in the fire-origin stands, due to too much shading by the high number of residual snags (particularly stands F951 and F952). However, it is expected that most of these stands should meet the standards by year 5.

References

Bailey AW, Wroe R. 1974. Aspen invasion in a portion of the Alberta parklands. Journal of Range Management 27(4):263-266.

Bartos DL, Mueggler WF. 1982. Early succession following clearcutting of aspen communities in northern Utah. Journal of Range Management 35(6):764-768.

Bartos DL, Brown JK., Booth GD. 1994. Twelve years biomass response in aspen communities following fire. Journal of Range Management. 47(1):79-83.

Bates PC, Blinn CR, Alm AA. 1993. Harvesting impacts on quaking aspen regeneration in northern Minnesota. Can. J. For. Res.23:2403-2412.

Bates PC, Blinn CR, Alm AA. 1988. Factors affecting the regeneration of quaking aspen. Minnesota Agricultural Experiment Station, St. Paul, Minnesota. Station Bulletin 587.

Bates PC, Blinn CR., Alm AA. Aspen Stand Development Following Harvest in the Lake States Region. Northern Journal of Applied Forestry1989, 6, pp. 178-83.

Beckingham JD. 1993. Classification of aspen regeneration on five cutblocks in the Edson Forest of Alberta. Prepared for Can. For. Serv., North. For. Cent. Edmonton, AB. Unpublished. 26 p.

Bella IE 1986. Logging practices and subsequent development of aspen stands in east-central Saskatchewan. For. Chron. 62: 81-83.

Brown KM, Navratil S. 1995. Analysis and interpretation of the research microsite projects in Alberta: effects of silvicultural and environmental factors on the post-planting performance of crop trees and competing vegetation. Can. For. Serv., North. For. Cent., Edmonton, Alberta and Land and Forest Serv., Edmonton, AB. Canada-Alberta Partnership Agreement in Forestry 33 PAIF A8029-138. 87 p.

Crouch, GL. 1986. Aspen regeneration in 6- to 10-year old clearcuts in southwestern Colorado; Fort Collins, Colorado: USDA For. Serv., Rocky Mountain For. Range Exp. Stn.Research Note RM-467.

Day RW, Quinn GP. 1989. Comparisons of treatments after an analysis of variance in ecology. Ecol. Mono. 59: 433-463.

DeByle NV, Winokur RP, editors. 1985. Aspen: ecology and management in the Western United States. USDA Forest Service, Gen. Tech. Report RM-119.

Ffolliott PF, Gottfried GJ. 1991 Mixed conifer and aspen regeneration in small clearcuts within a partially harvested Arizona mixed conifer forest; Fort Collins, Colorado: USDA For. Serv., Rocky Mountain Forest and Range Exp. Stn. Research Paper RM-294.

Grewal H 1995. Parent stand age and harvesting treatment effects on juvenile aspen biomass productivity. The Forestry Chronical 71(3): 299-303.

Groot A, Carlson DW, Fleming RL. 1997. Small openings in trembling aspen forest: microclimate and regeneration of white spruce and trembling aspen; Sault Ste. Marie, ON: Can. For. Serv., Great Lakes For. Res. Cent.NODA/NFP Technical Report TR-47.

Hiratsuka Y, Langor DW, Crane PE. 1995. A field guide to forest insects and diseases of the prairie provinces. Nat. Resour. Can., Can. For. Serv., Northwest Reg., North. For. Cent., Edmonton, AB. Spec. Rep. 3. Edmonton, Alberta.

Kay CE. 1997. Is aspen doomed? Journal of Forestry 95: 4-11.

Lindsay JD, Heringa PK, Pawluk S. Odynsky W. 1957. Exploratory soil survey of Alberta Map Sheets 84-C (east half), 84-B, 84-A, and 74-D. Preliminary Soil Survey Report

58-1. Research Council of Alberta, Edmonton, Alberta.

Luttmerding HA, Demarchi DA, Lea EC, Meidinger DV, Vold T. 1990. Describing ecosystems in the field. 2nd. B.C. Min. For., Victoria, BC. MOE Manual 11.

Maynard DG, MacIsaac DA. 1998. Soil nutrient and vegetation response to patch clear cutting of an aspen forest near Meadow Lake, Saskatchewan. Can. Jour. Soil Sci. 78: 59-68.

Maher JG, cartographer. 1974. Surficial geology of the Waterways NTS Mapsheet 74D. 1:250,000. Geology by L.A. Bayrock and T.H.F. Reimchen, 1973. Alberta Research Council, Edmonton, Alberta

Perala DA.1995. Quaking aspen productivity recovers after repeated prescribed fire; St. Paul, Minnesota: USDA For. Serv., North Central Forest Experimental Station. Research Paper NC-324.

Peterson EB, Peterson NM. 1992. Ecology, management, and use of aspen and balsam poplar in the prairie provinces. For. Can., Northwest Reg., North. For. Cent, Edmonton, AB. Special Report 1. 252 p.

Quintilio D, Alexander ME, Ponto RL. 1991. Spring fires in a semimature trembling aspen stand; Edmonton, AB: Nat. Resour. Can., Can. For. Serv., Northwest Reg., North. For. Cent. Information Report NOR-X-323. 30 p.

Shepperd WD. 1996. Response of aspen root suckers to regeneration methods and post-harvest protection; Fort Collins, Colorado: USDA For. Serv., Rocky Mountain For. Range Exp. Stn. Research Paper RM-RP-324. 8 p.

Sabin TE, Stafford SG. 1990. Assessing the need for transformation of response variables. Forest Research Laboratory, Oregon State University, Corvallis. Special Publication 20. 31 p.

SAS Institute Inc. 1990. SAS/STAT User's Guide, Version 6: Cary, NC.

SAS Institute Inc. 1991. SAS System for Linear Models. Third edition. Cary, NC. 329 p.

Shapiro S.S, Wilk M.B. 1965. An analysis of variance test for normality (complete samples). Biometrika 52:591-611.

Steneker GA. 1976. Guide to the silvicultural management of trembling aspen in the prairie provinces. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, AB. NOR-X-164.

Wagner R, Radosevich SR. 1991. Interspecific competition and other factors influencing the performance of Douglas-fir saplings in the Oregon Coast Range. Can. J. For. Res. 21:829-835

Warren WG. 1986. On the presentation of statistical analysis: reason or ritual. Can. J. For. Res. 16:1185-1191.

Weber MG. 1990. Response of immature aspen ecosystems to cutting and burning in relation to vernal leaf-flush. For. Ecol. Mgmt. 31:15-11.

Zar, J.H. 1984. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, New Jersey.

Table 7.1 Average microsite conditions for each stand[1].

Stand	Number of Plots	Moisture Class[2]	Slope Position Class[3]	Slope Angle (degrees)	Aspect (Azimuth)
H951	135	5.43	3.51	0.96	201.5
H952	144	5.19	3.28	0.10	202.0
H953	124	5.12	3.12	1.19	139.0
Total	403	5.25	3.31	1.09	188.1
F951	90	5.38	3.44	0.88	199.3
F952	90	5.51	3.72	1.06	165.7
F953	90	5.37	3.36	0.94	306.9
Total	270	5.42	3.51	0.96	228.5

1. Data for all variables is based on mean values for each stand.
2. Average moisture class lies between 5 (Mesic) and 6(Subhygric) for all stands.
3. Average slope position class lies between 3 (Mid Slope) and 4 (Lower Slope) for all stands.

Table 7.2 Average condition of residuals (including snags) and downed woody material for each stand[1].

Stand	Residual Distance Class[2]	Residual and Snag Density Class[3]	Downed Woody Material Class[4]
H951	0.60	2.45	-
H952	0.80	2.84	-
H953	0.67	2.96	-
Total	0.69	2.76	-
F951	-	1.65	6
F952	-	1.90	6
F953	-	2.45	6
Total	-	2.00	6

1. Data for all variables is based on mean values for each stand, except for downed woody material, which shows the most common class.
2. Distance to residual lies between class 0 (none closer than 10 m) and class 1 (adjacent to or on edge) for all harvested stands.
3. Residual density lies between class 2 (<5 stems) and class 3 (6-10 stems) for all harvested stands. Post-fire residual and snag density ranges from class 1 (Light (< 10 stems)), through class 2 (Moderate (10-25 stems)), to class 3 (Dense (> 25stems)) for all fire-origin stands.
4. Class 6 is light, coarse DMW.

Table 7.3 Deciduous regeneration compared to new 1997 deciduous regeneration standards.

Stand	Area (ha)	Plots	Stem Density per $10m^2$ plot	Stocking based on Criteria A[2]	Stocking based on criteria B[3]
H951	57.2	135	15.2	77.8	68.9
H952	58.2	144	22.4	90.3	67.4
H953	46.2	124	19.7	86.3	76.6
F951	10.0[1]	90	87.4	95.5	38.9
F952	10.0	90	38.8	85.6	43.3
F953	10.0	90	173.5	100.0	95.5

1. The regeneration assessment plots for the burned stands were all placed within the ten $100m^2$ vegetation plots, giving a total coverage of 10 ha.
2. With criteria "A", stocking is defined as the percentage of plots that have at least one deciduous stem, with no regard to size or condition.
3. With criteria "B", stocking is defined as the percentage of the plots that have at least one deciduous stem, with no regard to size or condition, and the average deciduous height for that plot is at least 80 cm.

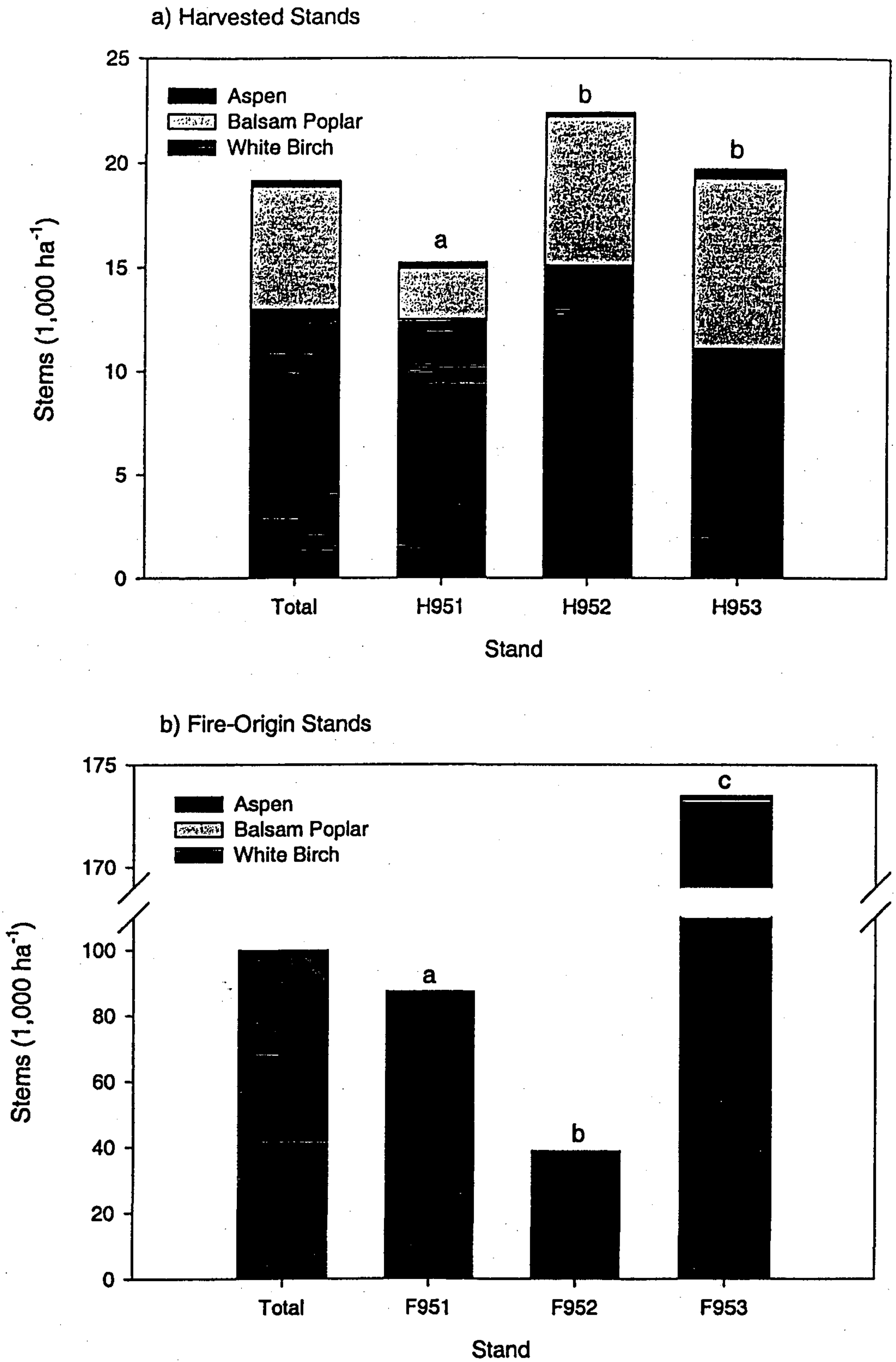

Figure 7.1 One-year post-disturbance density of deciduous regeneration for aspen, balsam poplar and birch and all species combined, by stand and for all stands combined for harvested (a) and fire-origin stands. Significant differences ($P<0.05$) in deciduous density between individual harvested and fire-origin stands using Dunn's pairwise multiple comparison test are shown by different letters.

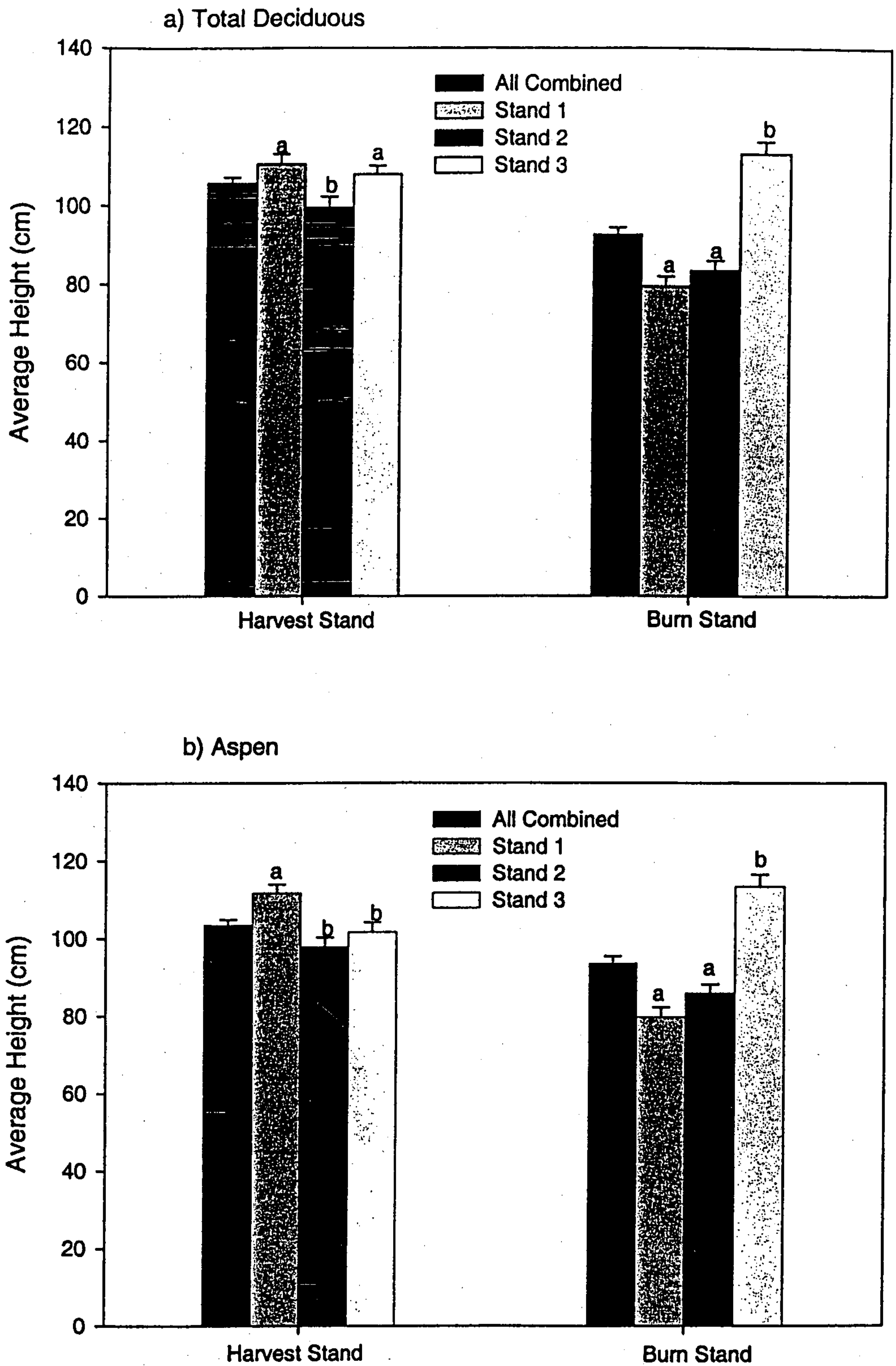

Figure 7.2 One-year post-disturbance height of deciduous regeneration for all species combined (a) and aspen (b), by stand and for all stands combined for each disturbance type. Significant differences (P<0.05) in deciduous and aspen height between individual harvested and fire-origin stands using Dunn's pairwise multiple comparison test are shown by different letters. Vertical lines indicate +1 standard error.

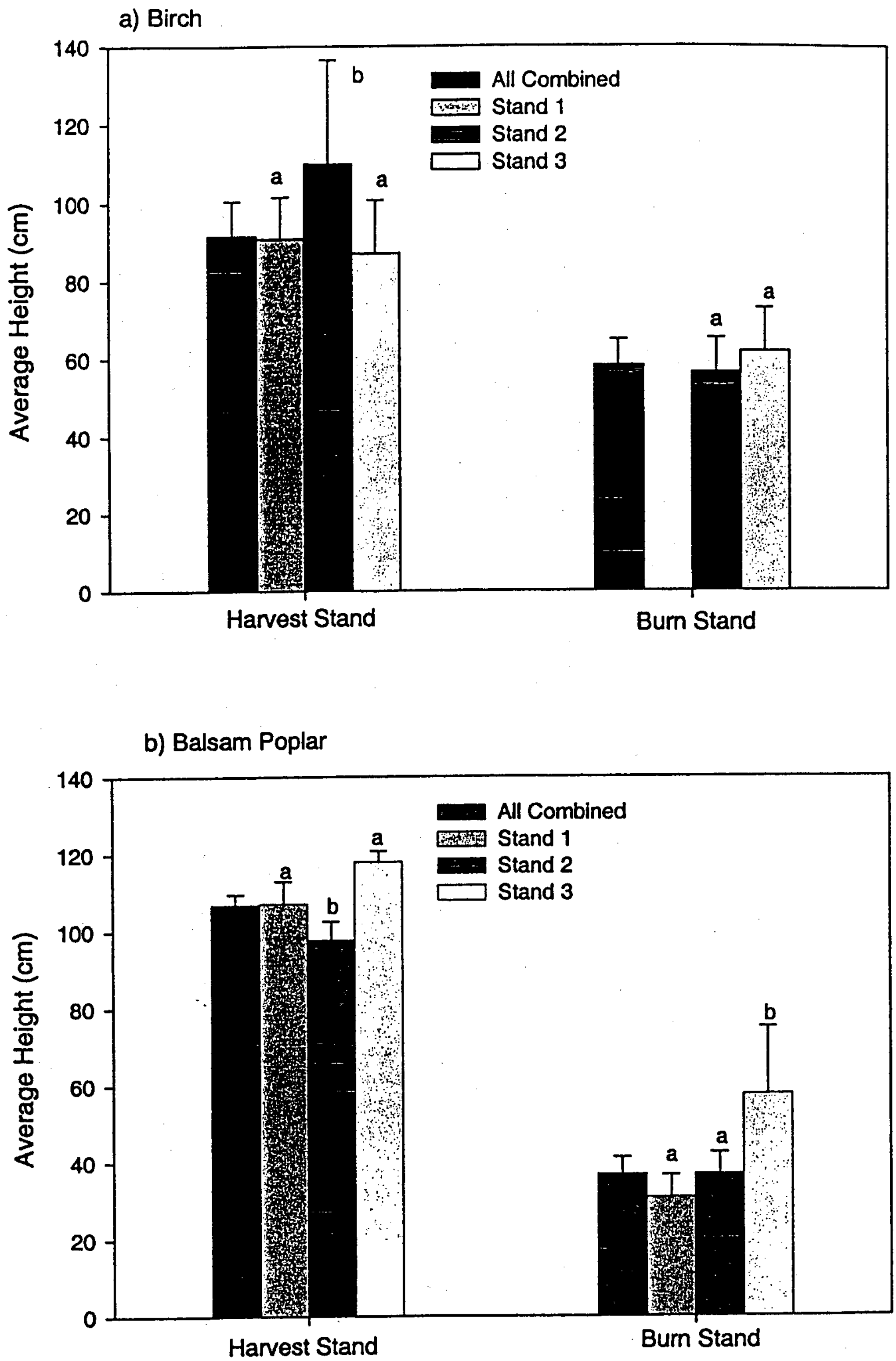

Figure 7.3 One-year post-disturbance height of deciduous regeneration for birch (a) and balsam poplar (b), by stand and for all stands combined for each disturbance type. Significant differences (P<0.05) in birch and balsam poplar height between individual harvested and fire-origin stands using Dunn's pairwise multiple comparison test are shown by different letters. Vertical lines indicate +1 standard error.

Appendix 7.1 Analysis of two-year post disturbance regeneration density.

Average Deciduous Density[1]

Source	DF	Mean Sq.	F Value	Pr > F
Disturbance [2]	1	4326.6	552.1	0.0001
Stand (Disturbance)	4	719.1	91.8	0.0001
Error	667	7.83	-	-

Least Squares Means[3] (Values are means (1,000 stems ha^{-1}) ± standard error of the mean)

Disturbance	Total	Stand 1	Stand 2	Stand 3
Harvested [4] a	19.15 (± 0.99)	15.19 (± 1.40)a	22.38 (± 1.89)b	19.70 (± 1.75)b
Fire-Origin b	99.90 (± 4.92)	87.35 (± 6.66)a	38.84 (± 4.92)b	173.50 (± 6.81)c

Aspen Density[1]

Source	DF	Mean Sq.	F Value	Pr > F
Disturbance [2]	1	5840.9	746.4	0.0001
Stand (Disturbance)	4	732.9	93.7	0.0001
Error	667	7.8	-	-

Least Squares Means[3] (Values are means (1,000 stems ha^{-1}) ± standard error of the mean)

Disturbance	Total	Stand 1	Stand 2	Stand 3
Harvested [4] a	13.01 (± 0.82)	12.52 (± 1.30)a	15.10 (± 1.64)a	11.13 (± 1.21)a
Fire-Origin b	99.47 (± 4.93)	87.13 (± 6.67) a	38.07 (± 4.96) b	173.20 (± 6.82)c

Balsam Poplar Density[1]

Source	DF	Mean Sq.	F Value	Pr > F
Disturbance [2]	1	278.1	121.1	0.0001
Stand (Disturbance)	4	18.3	7.9	0.0001
Error	667	2.3	-	-

Least Squares Means[3] (Values are means (1,000 stems ha^{-1}) ± standard error of the mean)

Disturbance	Total	Stand 1	Stand 2	Stand 3
Harvested [4] a	5.84 (± 0.62)	2.41 (± 0.46)a	7.10 (± 1.17)b	8.12 (± 1.35)c
Fire-Origin b	0.17 (± 0.05)	0.22 (± 0.10)a	0.18 (± 0.10)a	0.11 (± 0.08)a

1. Analysis performed with square root transformation for density variables.
2. Tests of hypotheses use the Type I MS.
3. Stand means in each row followed by the same letter do not differ significantly (P±0.05) in least squares means test.
4. Disturbance type in each row followed by the same letter do not differ significantly (P±0.05) in Tukey's range test.

Appendix 7.1 (concluded):

Birch Density[1]

Source	DF	Mean Sq.	F Value	Pr > F
Disturbance [2]	1	0.05	0.2	0.6550
Stand (Disturbance)	4	1.2	4.63	0.0011
Error	667	0.26	-	-

Least Squares Means[3] (Values are means (1,000 stems ha^{-1}) ± standard error of the mean)

Disturbance	Total	Stand 1	Stand 2	Stand 3
Harvested [4] a	0.29 (± 0.08)	0.27 (± 0.15)a	0.18 (± 0.11)a	0.45 (± 0.15)b
Fire-Origin a	0.26 (± 0.07)	0.0 (± 0.0) a	0.60 (± 0.18)b	0.19 (± 0.09)b

1. Analysis performed with square root transformation for density variables.
2. Tests of hypotheses use the Type I MS.
3. Means in each row followed by the same letter do not differ significantly (P±0.05) in least squares means test.
4. Disturbance type in each row followed by the same letter do not differ significantly (P±0.05) in Tukey's range test.

Appendix 7.2 Analysis of two-year post disturbance regeneration height.

Average Deciduous Height[1]

Source	DF	Mean Sq.	F Value	Pr > F
Disturbance [2]	1	24801.7	35.2	0.0001
Stand (Disturbance)	4	16902.9	24.0	0.0001
Error	593	704.3	-	-
Least Squares Means[3] (Values are means (cm) ± standard error of the mean)				
Disturbance	Total	Stand 1	Stand 2	Stand 3
Harvested [4]	105.6 (± 1.5)	110.5 (± 2.6)	99.5 (± 2.8)	108.0 (± 2.2)
Fire-Origin	92.5 (± 1.9)	79.3 (± 2.5)	83.4 (± 2.5)	113.2 (± 3.1)

Aspen Height[1]

Source	DF	Mean Sq.	F Value	Pr > F
Disturbance[2]	1	13163.1	22.7	0.0001
Stand (Disturbance)	4	16403.3	28.3	0.0001
Error	536	579.8	-	-
Least Squares Means[3] (Values are means (cm) ± standard error of the mean)				
Disturbance	Total	Stand 1	Stand 2	Stand 3
Harvested [4] a	103.5 (± 1.4)	111.7 (± 2.2)a	97.9 (± 2.4)b	101.7 (± 2.5)b
Fire-Origin b	93.6 (± 1.8)	79.7 (± 2.5)a	85.8 (± 2.3)b	113.3 (± 3.1)b

Balsam Poplar Height[1]

Source	DF	Mean Sq.	F Value	Pr > F
Disturbance[2]	1	68481.4	57.7	0.0001
Stand (Disturbance)	4	3840.9	3.23	0.0135
Error	193	1187.7	-	-
Least Squares Means[3] (Values are means (cm) ± standard error of the mean)				
Disturbance	Total	Stand 1	Stand 2	Stand 3
Harvested [4] a	106.9 (± 2.7)	107.2 (± 5.8)a	97.8 (± 4.8)a	118.0 (± 2.8)b
Fire-Origin b	36.7 (± 4.4)	30.7 (± 5.8)a	36.7 (± 5.6)a	57.5 (± 17.5)a

1. Analysis performed with no transformation for height variables.
2. Tests of hypotheses use the Type I MS.
3. Means in each row followed by the same letter do not differ significantly (P±0.05) in least squares means test.
4. Disturbance type in each row followed by the same letter do not differ significantly (P±0.05) in Tukey's range test.

Appendix 7.2 (concluded):

Birch Height[1]

Source	DF	Mean Sq.	F Value	Pr > F
Disturbance [2]	1	10965.7	8.53	0.0062
Stand (Disturbance)	4	455.5	0.35	0.7862
Error	34	1285.3	-	-
Least Squares Means[3] (Values are means (cm) ± standard error of the mean)				
Disturbance	Total	Stand 1	Stand 2	Stand 3
Harvested [4] a	91.6 (± 8.8)	90.8 (± 10.7)a	110.0 (± 26.5)a	87.0 (± 13.7)a
Fire-Origin b	58.1 (± 6.7)	-	56.4 (± 8.7)a	61.7 (± 11.1)a

1. Analysis performed with no transformation for height variables.
2. Tests of hypotheses use the Type I MS.
3. Means in each row followed by the same letter do not differ significantly (P±0.05) in least squares means test.
4. Disturbance type in each row followed by the same letter do not differ significantly (P±0.05) in Tukey's range test.

Appendix 7.3 Information from Alberta Research Council staff.

a) Downed woody material and residuals (snags and live trees)

	Volume of Downed Woody Material ($m^3 ha^{-1}$)				Snags (stems ha^{-1})			Residual Trees
	Diameter Classes (cm)				Diameter Classes (cm)			(stems ha^{-1})
Stand	5-9	10-19	>20	Total	10-19	>20	Total	
H951	25.61	57.54	60.29	143.43	0.87	20.00	20.87	12.30
H952	36.71	69.55	40.69	146.94	2.00	8.60	10.60	22.17
H953	23.73	40.50	45.26	109.49	10.40	21.20	31.60	78.95
All Combined	28.68	55.86	48.74	133.29	4.42	16.60	21.02	37.81
F951	10.48	71.22	11.95	93.65	292.00	409.60	701.60	0.50
F952	5.76	41.73	25.15	72.64	100.80	274.80	375.60	0.50
F953	15.96	60.10	4.76	80.82	525.60	528.00	1053.60	0.50
All Combined	10.73	57.68	13.95	82.37	306.13	404.13	710.27	0.50

b) Soil information from soil pit dug in nearby stands

Stand	Soil Order	Stoniness	Drainage
F951	Luvisol	slightly	moderately well-imperfectly
F952	Luvisol	slightly	moderately well
F953	Luvisol	slightly	well
H951	Brunisol	slightly	imperfectly
H952	Luvisol	slightly	well
H953	Luvisol	none	rapidly

FIRE AND HARVEST RESIDUAL (FAHR) PROJECT: The Impact of Wildfire and Harvest Residuals on Forest Structure and Biodiversity in Aspen-Dominated Boreal Forests of Alberta

A Final Report

7.0 DECIDUOUS REGENERATION ONE YEAR FOLLOWING WILDFIRE AND HARVEST IN ASPEN-DOMINATED MIXEDWOODS OF NORTH-CENTRAL ALBERTA

Dan A. MacIsaac and Susan Crites

Abstract

The objective of the deciduous regeneration subproject of the Fire and Harvest Residual Project was to determine the differences in deciduous regeneration between burned and harvested two-year post-disturbance stands. Furthermore, to relate this response to observed stand and microsite conditions as well as to determine the ecological differences between the two disturbance regimes, in order to explain regeneration differences. Regeneration and microsite conditions were sampled in 10 m^2 plots from three harvested and three fire-origin stands in north-central Alberta.

Aspen suckers comprised 68% and 99% of the deciduous regeneration in the harvested and fire-origin stands, respectively. Aspen density was significantly higher in the fire-origin stands (99,470 stems ha^{-1}) compared to the harvested stands (13,010 stems ha^{-1}), whereas average height was slightly greater in the harvested stands (103.5 cm *vs* 93.6 cm). These differences are related to the different ecological processes that follow as a consequence of the two disturbance types. Regeneration was not uniform between the three stands of fire and harvest-origin, due to differences in site conditions between the different stands. The microsite factors of moisture, slope position and disturbance type had a significant and clear effect on regeneration response. High moisture and lower slope position combined to impede suckering as did the surface disturbance and compaction associated with roads and landings. Conversely, the effects of aspect, slope angle, distance to residual, slash and downed woody material had a negligible effect on regeneration.

In spite of the different disturbance modes, most of both the harvested and fire-origin stands have a good probability of meeting the new deciduous regeneration standards at year five. The two areas where the regeneration may not be sufficient to meet the establishment survey standards would be insufficient stocking in the harvested stands (especially H951) due to heavy grass competition, and height growth below the acceptable minimum of 80 cm in the fire-origin stands, due to too much shading by the high number of residual snags. However, it is expected that most of these stands should meet required regeneration standards by year five.