Aspen regeneration on log decking areas as influenced by season and duration of log storage

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Abstract This study assessed aspen regeneration on decking areas as affected by season of log deck building and duration of log storage; as well as root wounding, soil compaction, and slash depth. On former decking areas that were built after a summer harvest, aspen regeneration was 50% lower and root death 35% greater compared to former decking areas of a fall harvest. Duration of log storage after a fall harvest had little effect on aspen regeneration; short (1.5–3 months) or long (11 months) storage resulted in similar regeneration. Slash load was greatly increased on decking areas while root wounding and soil bulk density were only slightly increased compared to controls. For best management practices, log storage after summer harvest should be avoided especially when logs are kept over the growing period when suckering occurs. Additionally, removing the interwoven mat of slash covering decking areas and limiting machine traffic to frozen soil will ensure vigorous suckering.

Keywords *Populus tremuloides* · Boreal forest · Harvesting traffic · Landings · Slash accumulation · Root damage · Soil compaction

Introduction

Numerous studies have reported insufficient aspen sucker establishment (Bates et al. 1993; Shepperd 1993; Navratil 1996; Kabzems 1996; Stone and Elioff 1998; Smidt and Blinn 2002; Berger et al. 2004; McNabb 1994; Corns and Maynard 1998; Stone 2001; MacIssac et al. 2006; Zenner et al. 2007) and growth (Bates et al. 1993; Corns and Maynard 1998; Kabzems and Haeussler 2005) on designated skid trails, haul roads, and landings after harvesting. These areas can occupy up to 20% of cutovers (Kabzems and Haeussler 2005; MacIssac et al. 2006), and poor growth of regenerating aspen on such a large area could cause a shift to a lower site index than it was originally (Kabzems and Haeussler 2005).

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Landings or decking areas are of particular concern as they are the most heavily impacted (Berger et al. 2004). Typically, poor regeneration on landings has been attributed to the disturbances caused by concentrated-skidder traffic on these areas (Shepperd 1993; Berger et al. 2004); however decking and storage of the logs might also have an impact (Navratil 1996). After trees have been delimbed the logs are often stored in a pile (log deck) next to the road. In some instances the log deck is hauled immediately and the impact is thought to be negligible (Navratil 1996), but more often hauling is delayed. The delay allows logs to dry for up to a year so that haul weights are reduced, or it allows for drier or frozen haul road conditions (R. Butson, Personnel communication, Alberta Pacific Ltd).

The impact that log deck building and storage has on aspen regeneration is not known, but it may have several negative effects. A log deck could act as a physical barrier to emerging suckers preventing them from photosynthesizing. As a result, the carbohydrate reserves of the root system in the newly cut area would not be maintained and portions of the root system might die, which would cause poor regeneration once the log deck is removed (DesRochers and Lieffers 2001; Landhäusser and Lieffers 2002). The large volume of logs and bark on the decking area could also produce leachates that are high in phenols. High concentrations of phenols from aspen-debris can cause a decrease in the growth of aspen (Conlin 2001). The impacts of log storage are likely greater the longer the log deck is stored because a larger amount of carbohydrates will be lost to maintenance respiration (DesRochers et al. 2002). The season of building a log deck could have an effect as well; a log deck built in the summer when soil temperatures are warm can result in a greater depletion of carbohydrates by respiration compared to the fall (DesRochers et al. 2002).

While log storage length and timing alone could negatively affect aspen regeneration, other conditions such as slash load and the effects of machine traffic, soil compaction and root wounding, could reduce aspen suckering on decking areas. Slash accumulation caused by delimbing can delay thawing and warming of the soil (Bella 1986) or act as a barrier to the emergence of suckers (Landhäusser et al. 2007). Soil compaction reduces root respiration and growth (Hatchell et al. 1970; Ruark et al. 1982); root wounding fragments the root system (Zahner and Debyle 1965); and the wounds can serve as entry points for decay (Basham 1988; Pankuch et al. 2003). All of these disturbances to the root system could lead to a reduction in the root's ability to produce adequate regeneration (Shepperd 1993).

The objective of this study was to assess aspen regeneration on log decking areas that had been reclaimed after hauling. The treatments were season of building of the decks, and secondly, duration of storage of logs on decks. Root condition, soil bulk density, and slash load were also evaluated to determine their influence on aspen regeneration.

Methods

Study area

The study was conducted within a 10,000 ha forestry planning unit of Alberta Pacific Forest Industries Ltd. located in the Boreal Mixedwood Ecoregion, 50 km northeast of Lac La Biche, Alberta (between 55°6′ to 55°10′N and 111°31′ to 111°41′W). This Ecoregion receives 380 mm of precipitation annually with the wettest months being June and July. Average temperatures range from 13.8°C in the summer to −10.5°C in the winter. Soils in this area are fine-textured gray luvisols, and the dominant cover type is aspen (*Populus tremuloides* (Michx.)) with minor components of white spruce (*Picea glauca* (Moench)

Voss), balsam poplar (*Populus balsamifera* L.), paper birch (*Betula papyrifera* (Marsh.)), and black spruce (*Picea Mariana* (Mill.) B·S.P.) in low areas (Strong and Leggat 1992).

From late June to late October of 2006, 1,100 ha of aspen-dominated sites in the planning unit were clear-cut using full tree harvesting methods. This involved cutting with a feller-buncher harvester, skidding the entire tree to a roadside decking area with grapple skidders, delimbing, and cutting the tree to length at the decking area. Following delimbing, the logs were stacked into decks 1–2 m in height and less than 2 m from the road side. Decking occurred within 2 weeks after harvesting began. Log decks were placed directly on the existing soil as a result there was no scraping or removal of any soil for the building of the decking area.

The dates when the log decks were built and when logs were hauled varied between cutovers. Cutovers selected for the study were (A) early summer logged (June to early July) and had the logs stored during the same growing season and were hauled in the fall (summer—short storage); (B) late summer logged (August to September) and had the logs hauled the same fall (fall—short storage); and (C) late summer logged (August to September) and had the logs hauled after the following growing season (fall—long storage) (Table 1). After the log decks were hauled, coarse slash was spread or piled by a bulldozer and burnt (R. Butson, Personnel communication, Alberta Pacific Ltd.). In most circumstances, however, there was still a consolidated layer of finer slash such as fine twigs, branches, and bark covering the former decking area.

Sampling design

In total 26 decking areas spaced a minimum of 250 m apart were examined. Each of these was paired with a control, i.e., a minimally disturbed area approximately 15 m from the edge of the harvested area but within 100 m of the log decking area. Five decks each were examined from the summer—short storage, and fall—short storage treatments and 16 were selected from the fall—long storage treatment areas (Table 1).

Because the log decks had been removed at the time of the study, their position was determined by the presence of bark debris near the haul road as delimbing was done on the decking areas (R. Butson, Personnel communication, Alberta Pacific). Once the presence of the log deck had been confirmed, eight subplots, on a transect running parallel

Table 1 Harvest information for log-deck storage treatment sites

Treatment	Replicates	Cut	Haul
Fall—long storage	6	7 August 2006	20-July-2007
	4	16 August 2006	23-July-2007
	2	11 August 2006	27-July-2007
	2	15 August 2006	27-July-2007
	1	1 September 2006	20-July-2007
	1	23 August 2006	25-July-2007
Fall—short storage	1	15 August 2006	30-September-2006
	2	15 August 2006	17-November-2006
	1	6 September 2006	30-November-2006
	1	2 September 2006	30-November-2006
Summer—short storage	2	6 July 2006	16-October-2006
	3	21 June 2006	17-November-2006

Cut date indicates the start of harvest and haul date is when the logs were removed from the log deck area to the haul road were positioned in the middle of the decking area (approximately 6 m from the road). The subplots were spaced a minimum of 5 m apart and a maximum of 15 m depending upon the length of the decking area. Subplots falling on stumps that prevented root and soil sampling or on areas with visible rutting, evidence of burnt slash, or on low spots were avoided by moving them 2 m further along the transect. A similar transect of eight subplots was established in the control area. The subplots for each transect were averaged so that each transect represented a replicate.

Measurements

In August of 2008, 2 years after harvesting, measurements of sucker density and height were made in each subplot for all treatments including the control plots. Measurements of root condition, soil bulk density, and slash coverage were taken in every second of the eight subplots. The number of aspen and balsam poplar suckers were counted in a circular 0.001 ha regeneration subplot (as balsam poplar constituted <2% of the suckers, they were not differentiated in the results from the aspen suckers). The height of the leading aspen sucker in each quarter of the regeneration subplot was also measured. Because only 1 year old suckers were found in the fall-long storage treatment, while the other treatments, including the control, had 2-years-old suckers, a comparison was made for first year growth among the treatments. First year growth for the 2-years-old suckers was calculated based on a ratio of first to second year growth. The ratio was determined by randomly sampling 100 suckers and measuring first and second year growth separately using bud scars.

Root condition was assessed by spading a 32 cm by 32 cm pit in the centre of every second subplot. All aspen and balsam poplar roots greater than 0.5 cm and less than 2.0 cm in diameter (considered the dominant suckering roots (DesRochers and Lieffers 2001)) were collected from each pit to a 15 cm-depth of the mineral soil. The roots were stored at 5°C and transported back to the laboratory. The total linear length of roots and the lengths of root that was blackened and/or dead were measured. The proportion of dead to total length was then calculated. The number of visible wounds that covered more than 1 cm^2 of surface area of the roots were also counted, and expressed as the number of wounds per linear meter of root.

The core method was used to determine soil bulk density (Blake and Hartage 1986). Soil cores (325 cm^3) were taken from the top 10 cm of mineral soil. The soil was taken back to the laboratory where it was dried to constant weight at 80°C. Rocks or organic matter greater than 0.3 cm in diameter was removed by sieving and their weight and volume was subtracted from the core volume. The dried soil was weighed and soil bulk densities were calculated as g/cm^3.

Slash depth was quantified by taking the average depth of slash debris from three spots within a 0.25 m^2 at the center of each plot. The depth was measured from the upper layer of slash to the top of the original soil LFH layer.

Data analysis

An initial comparison was made between the decking and control areas. This involved grouping all variables from the three log deck treatments into one. The comparison was made with a one-way ANOVA using the GLM procedure in SAS (SAS Institute, version 9.1). The statistical model was

$$Y = \mu + T + \varepsilon$$

where Y was the mean of the variable (sucker density, first year height of the leading sucker, percent dead root, number of wounds, soil bulk density, or slash depth); μ was the population mean for the variable; T was the effect of the treatment (decking area or control); ε was the random error. A means separation test was not used as there were only two treatments.

A separate set of one-way ANOVAs was used to compare the three log deck treatments. The statistical model and variables tested were the same but the treatments were summer—short storage, fall—short storage, or fall—long storage. Unlike the other variables, sucker density on log deck areas was found to have a significant relationship with the sucker density of the paired control. Thus, sucker density was analyzed with ANCOVA using the sucker densities from the paired controls as covariates. The model tested was similar to that of the ANOVA except X was included as the covariate.

$$Y = \mu + T + X + \varepsilon$$

Provided the ANOVA or ANCOVA was significant, two planned comparisons were made using the LSD means comparison test: summer—short storage versus fall—short storage to determine the impact of season of log deck building and fall—long storage versus fall—short storage to assess the effects of storage duration.

A final set of one-way ANOVAs was used to evaluate any difference between the decking areas of the treatment sites. Sucker density and first year height of the leading suckers from the paired controls of the three decking treatments were compared. The statistical model was the same as used for the previous ANOVA. No means separation tests were performed as none of the ANOVAs were significant.

For all ANOVAs and the ANCOVA the variable residuals met the assumptions of normality based on the Shapiro–Wilk test and homogeneity of variances using Bartlett's test. The assumptions for the covariate used in ANOCVA were assessed graphically. An alpha value of 0.05 was used to determine significance in all tests.

Multiple regression analysis was used to examine the relationships between suckering density or height with root wounding, soil bulk density, and slash depth. Data from all treatments and the control was used, and dummy variables were used to account for the effect of the treatment. However, using stepwise selection in the regression procedure in SAS, root wounding, soil bulk density, and slash depth were not useful predictors in the model.

Results

General impact of decks

The vigor of aspen regeneration and amount of living root was significantly reduced on log decking areas (Table 2). Sucker density on decking areas was 16,659 stems ha^{-1} (across all decking treatments) while controls had nearly three times the density with 47,047 stems ha^{-1} (Fig. 1a). First year height growth of the leading suckers on decks was about half that of the controls; 55 cm on the decks and 95 cm in the control (Fig. 1b). As well, on decking areas 58% of the roots were dead compared to 33% for the control (Fig. 1c).

Root wounding, soil bulk density and slash load were significantly greater on the decking areas than the controls (Table 2). Roots had 2.2 wounds per meter on decking

Table 2 Results of one-way ANOVAs for the comparison between all log deck and control areas

Response variables	*df*	*F*-ratio	*P* value
1. Sucker density	1	73.53	<0.0001
2. First year height	1	95.56	<0.0001
3. Dead roots	1	20.86	<0.0001
4. Root wounding	1	13.93	0.0005
5. Soil bulk density	1	8.62	0.0050
6. Slash depth	1	54.68	<0.0001

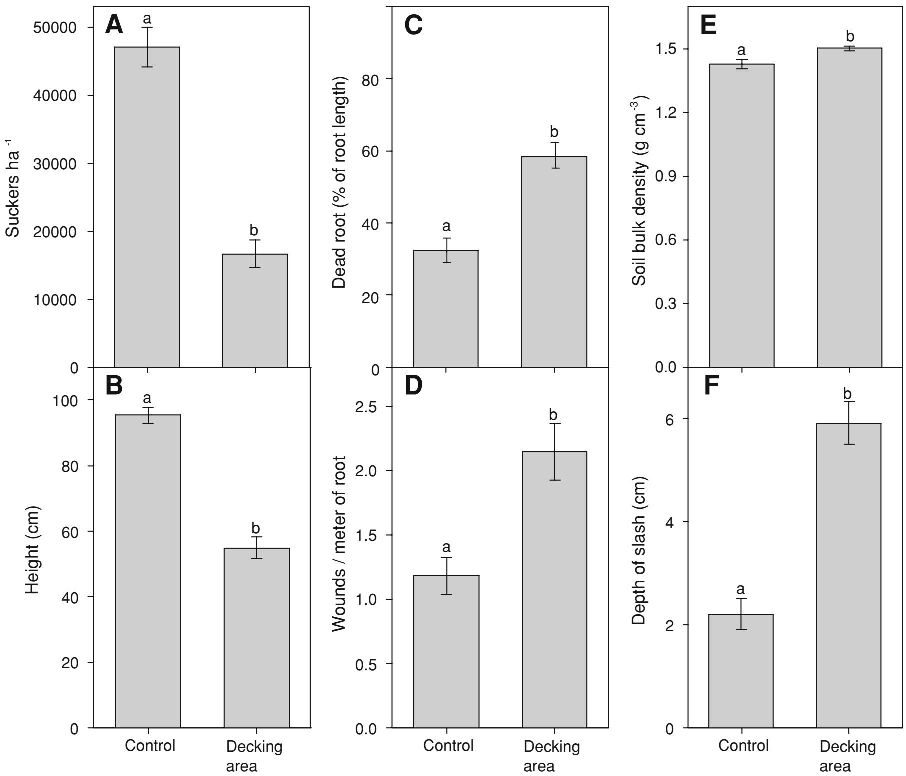

Fig. 1 Comparisons between minimally disturbed areas of a cutover (control) and decking areas, **a** Sucker density of aspen. **b** First year height growth of the leading suckers. **c** Percent of dead roots by root length, 0.5–2.0 cm in diameter. **d** Density of wounds greater than 1 cm^2 on aspen roots 0.5–2.0 cm in diameter. **e** Bulk density of the top 10 cm of mineral soil. **f** Depth of slash such as bark and branches. *Different letters* indicate statistically significant differences for each graph

areas compared to 1.2 for the control areas (Fig 1d). Soil bulk density on decks (1.50 g cm^{-3}) was 5% higher than the controls (1.43 g cm^{-3}) (Fig. 1e). The difference in slash depth between decking areas and controls was large with an average of 5.9 cm on the decks and 2.3 cm in the control (Fig. 1f).

Impact of season of log deck building

Building log decks during a summer harvest had a significant negative impact on sucker densities and the amount of living roots (Table 3). Suckering on decking areas that were harvested in the summer and had 3–5 months of log storage had half the density of suckers (7,574 stems ha^{-1}) compared to fall harvest with 1.5–3 months of log storage (16,472 stems ha^{-1}) (Fig. 2a). The season of establishing log decks did not affect the height of suckers. The first year height of the leading suckers for both treatments was approximately 45 cm (Fig. 2b). Condition of the root system in decking areas was different between the two treatments. Two summers after logging, 85% of the length of root system was dead in the decking areas of summer harvested sites compared to 50% in the fall harvested sites (Fig 2c).

Root wounding, soil bulk density, and slash load were not affected by the season of log deck building. The trend, however, was for more wounds in the fall-harvested sites (2.9 wounds m^{-1}) compared to summer decks (1.9 m^{-1}) (Fig. 2d). The mean bulk density was 1.50 g cm^{-3} (Fig 2e) and slash depth was 6.1 cm for both treatments (Fig. 2f).

There were no differences in sucker densities or height growth between the controls (non-decking areas) of these two treatments (Table 4). Sucker density (44,313 stems ha^{-1}) and height growth (92 cm) were similar to the average of all controls (Fig. 1a, b).

Impact of log storage duration

The density of aspen suckers and the condition of the root system was not affected by the duration of log storage after a fall harvest (Table 3). A mean density of 19,641 stems ha^{-1} was found on long storage areas (11 months) compared to 16,472 stems ha^{-1} for short storage (1.5–3 months) (Fig. 3a). First year height growth of the leading suckers was different between the two treatments with the taller suckers being on sites with long storage of logs (Fig 3b). The condition of the root systems was similar between the long and short storage. The ratio of dead to living roots was not different as approximately half of the total lengths of roots were dead in both treatments (Fig. 3c).

Log storage duration did not affect root wounding, soil bulk density, or slash (Table 3). Each treatment had 2–3 wounds m^{-1} of root (Fig. 3d). Soil bulk density was on average 1.50 g cm^{-3} (Fig. 3e) and slash was about 6 cm deep (Fig. 3f).

Table 3 One-way ANOVAs and means separation test results for comparison made between the three log deck storage treatments: summer—short storage (summer) with fall—short storage (fall) and fall—short storage (short) and fall—long storage (long)

Response variables	Source of variation	*df*	*F*-ratio	*P* value	Comparison (*P* value)	
					Summer-fall	Short-long
1. Sucker density	Treatment	2	3.50	0.0479	0.0148	0.4658
Density (control)	Covariate	1	8.08	0.0095		
2. First year height	Treatment	2	3.74	0.0393	0.8864	0.0352
3. Dead roots	Treatment	2	5.88	0.0087	0.0187	0.7973
4. Root wounding	Treatment	2	1.56	0.2325		
5. Soil bulk density	Treatment	2	0.03	0.9726		
6. Slash depth	Treatment	2	0.07	0.9321		

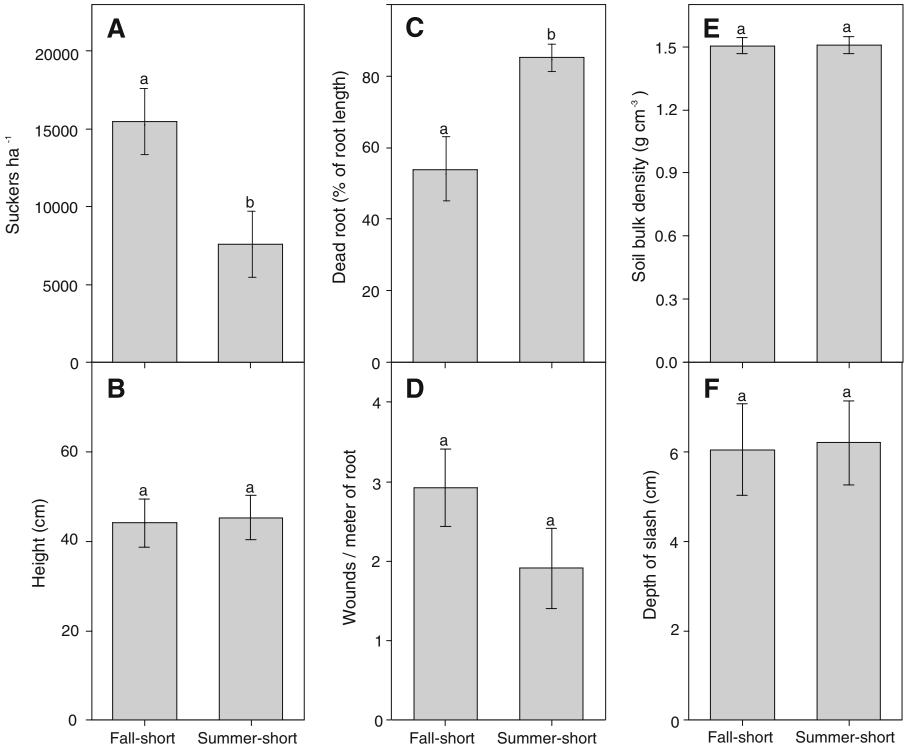

Fig. 2 Comparisons between log decks that were built in an early summer harvest followed by 3–5 month of deck storage (summer-short storage) compared to decks that were built in the fall and hauled 1.5–3 months after (fall-short storage). **a** Sucker density of aspen. **b** First year height growth of the leading suckers. **c** Percent of dead roots by root length, 0.5–2.0 cm in diameter. **d** Density of wounds greater than 1 cm^2 on aspen roots 0.5–2.0 cm in diameter. **e** Bulk density of the top 10 cm of mineral soil. **f** Depth of slash such as bark and branches. *Different letters* indicate statistically significant differences for each graph

Table 4 One-way ANOVA results for the comparison between the paired controls of each of the log deck treatments

Response variable	*df*	*F*-ratio	*P*-value
Sucker density	2	0.29	0.7500
First year height	2	0.64	0.5383

There were no differences between the controls (non-decking areas) of these two treatments (Table 4), and sucker density and height growth were approximately equal to the overall average of the control (Fig 1a, b; 47,431 stems ha^{-1} and 96 cm).

Discussion

The season of log-deck building had a substantial impact on aspen regeneration. Decking areas where the log decks were built during a summer harvest and stored until the upcoming fall, had aspen sucker densities half that of decking areas that were constructed in the fall and hauled shortly after. The decrease in aspen regeneration on decking areas in

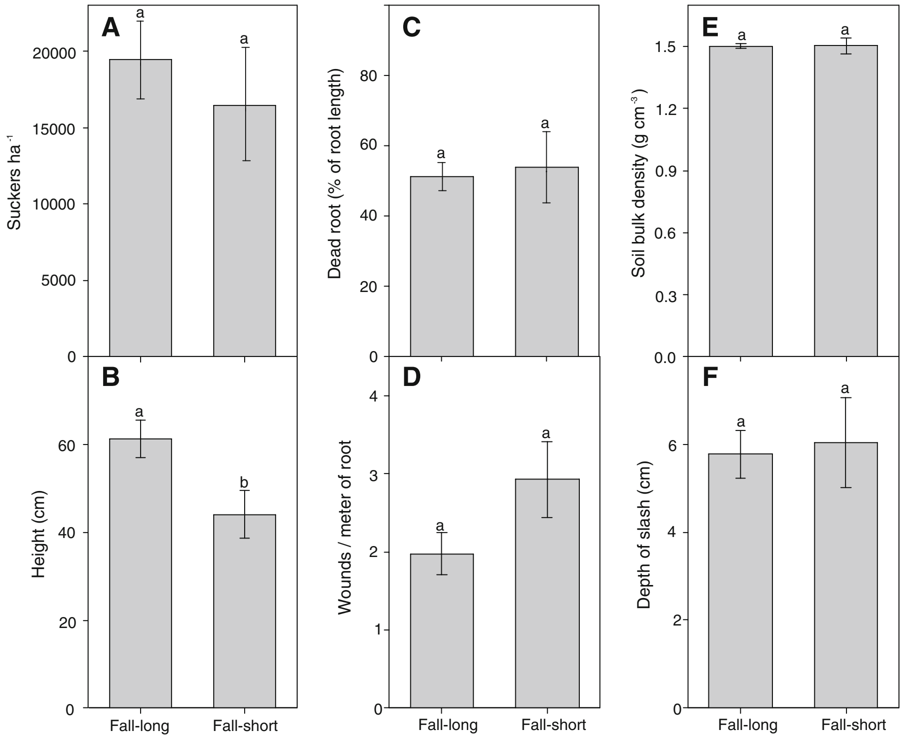

Fig. 3 Comparisons between decks with 11 months of log-deck storage after a fall harvest (fall-long storage) compared to decks where the log deck was removed 1.5–3 months after a fall harvest (fall-short storage). **a** Sucker density of aspen. **b** First year height growth of the leading suckers. **c** Percent of dead roots by root length, 0.5–2.0 cm in diameter. **d** Density of wounds greater than 1 cm^2 on aspen roots 0.5–2.0 cm in diameter. **e** Bulk density of the top 10 cm of mineral soil. **f** Depth of slash such as bark and branches. *Different letters* indicate statistically significant differences for each graph

the summer months has typically been attributed to increases in soil compaction, root wounding, and slash accumulation due to unfrozen and wetter soil conditions (Bates et al. 1993). These factors have been linked to increased root death (Bella 1986; Shepperd 1993) which would cause a decrease in sucker density (DesRochers and Lieffers 2001). However, all of these conditions were similar between the summer and fall treatments (Fig. 2) despite wetter soil conditions during the summer treatments (R. Butson, Personnel communication, Alberta Pacific Ltd.). Also, the root wounding tended to be greater on the fall decks with short storage. Additionally, poor regeneration after summer logging has often been linked to low root carbohydrate reserves in the summer (Bates et al. 1993; Landhäusser and Lieffers 2002), but there were no differences in sucker density and height growth between the controls of the summer and fall treatments suggesting that season of harvest had little direct impact on sucker density; this is supported by other studies (Mundell et al. 2008; Mulak et al. 2006).

The cause of poor regeneration on the summer decking areas is likely related to the log deck itself. The log deck was placed on a root system at a time when soil temperatures were high and when suckering would naturally occur. The suckers produced were either unable to emerge from the soil as the log deck acted as a physical barrier, or if they did, they were in darkness and unable to photosynthesize. The warm soil conditions caused high root respiration (DesRochers et al. 2002) and the inability of suckers to photosynthesize would have depleted carbohydrate reserves, which have been linked to the death of portions of aspen root systems and poor sucker growth (e.g., DesRochers and Lieffers 2001; Landhäusser and Lieffers 2002). This likely explains the large die-off of roots in the summer decking area and the poor suckering in general (Fig. 2c).

In contrast to the season of log deck construction, the duration of log storage appeared to have little effect on aspen sucker density on the decking area when constructed in the fall (Fig. 3a). These treatments had different time-spans for sucker regeneration growth; the short storage had 2 years of growth while the long storage had only 1 year before sampling. Self-thinning of aspen suckers can occur between the first and second season in high density situations where losses of 25% are not uncommon (Peterson et al. 1989). However, in regenerating stands where initial sucker densities are low, e.g., less than 20,000 stems/ha, thinning is minimal in the second year (Krasny and Johnson 1992; David et al. 2001). The slightly higher sucker densities on the long compared to the short storage sites can likely be explained by some thinning occurring in the short storage, but it is probable that sucker densities on the long storage areas would have been comparable to the densities on short storage areas if it had had one more season of growth. Height growth may also have been impacted by the different age of suckers in this comparison as shoot dieback may have occurred after the first year (Peterson and Peterson 1992) in the short storage sites and thus reduced measurements of height growth on the fall-short storage (Fig. 3b).

In the fall harvest, the presence of the log deck likely did not have an incremental impact on aspen regeneration for several reasons. Mundell et al. (2008) showed when aspen is cut in late summer, there was no root suckering before the following growing season. Therefore, it can be assumed that the root system did not sucker under the log decks in the fall and deplete their carbohydrate reserves as suggested for the summer decking areas. However, these root systems also did not sucker under the log deck the following growing season as we did not find any two-year-old suckers on these decking areas. The likely reason that the root system failed to sucker in the summer under the deck was related to the insulating nature of the log deck, coupled with greater freezing during the prior winter. Typically snow acts as an insulating layer and can prevent the ground from freezing deeply. However, in the case of a log deck, the snow will accumulate on top of the log deck, but since the ends of the deck remained open, there was a break in the insulating layer. As a result cold air could move between the logs and contact the ground resulting in a deeper penetration of frost into the ground. We propose that in the spring, the ground around the log deck melted and soil temperatures increased; however, under the log deck, soil temperature remained low as the deck intercepted radiation that would typically warm the soil. Lieffers and Van Rees (2002) recorded that soils froze earlier under a loose layer of coarse slash that had intercepted snow; these areas also remained cool over the following growing season. As soil temperatures in the boreal forest are already cool (Strong and Leggat 1992) the log deck could prevent the soils from reaching the 9°C necessary for suckers to grow (Landhäusser et al. 2006). Further, cool soils decreased root respiration (DesRochers et al. 2002). Consequently, root carbohydrate reserves could remain relatively unchanged and suckering potential could be expected to be sustained once the log deck was removed.

As long-term storage of log decks failed to have an impact on aspen regeneration when constructed in the fall, the hypothesis that leachates from these logs could affect aspen regeneration (Conlin 2001) can be negated. Height growth was actually greater after long-term storage of the log deck compared to the short-term storage. Similarly, Landhäusser et al. (2007) found relatively little impact of the leachates generated from 4 cm of chipping debris from aspen and it appears that the leachates from a deck of logs does not reach the threshold that damages aspen regeneration.

Regardless of log deck storage, regeneration on decking areas was poor, and this reinforces the large body of literature showing poor aspen regeneration on landing areas (Bates et al. 1993; Navratil 1996; Berger et al. 2004; MacIssac et al. 2006; Zenner et al. 2007). While many studies have implicated soil compaction for low sucker densities (Bates et al. 1993; Shepperd 1993; Stone and Elioff 1998), increases in bulk density observed in these studies were 10–30%, i.e., much greater than the 5% we observed in our study. Small increases in bulk densities have been found to actually increase sucker density while decreasing height growth (Stone 2001; Kabzems and Haeussler 2005). As a result, the significant decreases in sucker density on decking areas can most likely be attributed to either root wounding or slash accumulation. Root wounding in this study was much lower than that observed by Shepperd (1993) on skid trails, while our density of wounds was similar to that of Fraser et al. (2004), who actually saw an increase in sucker density with that degree of wounding. However, root wounding can lead to the entry of decay and disease which can reduce height growth and the effects of wounding and the entry of decay can be delayed (Basham 1988). Therefore, wounding may not have impacted sucker density, but it could have resulted in a decrease in sucker height that was observed.

We believe that slash depth is one of the main causes of low sucker density in our study. The reduction of sucker density in our study is consistent with the results of Corns and Maynard (1998) and Landhäusser et al. (2007) who saw 30–50% reductions in sucker density with a chipping residue depth of 4–10 cm because the residue acted as a barrier to sucker emergence. The slash on decking areas was similar to chipping residues as it was composed of a thick interwoven layer of bark and small branches and likely had a similar effect. Also, slash has an insulating effect which keeps soil temperatures low and will negatively influence height growth of the sucker regeneration (Bella 1986; Lavertu et al. 1994).

However, while slash depth likely had a significant influence on sucker density, increased soil bulk density and wounding can not be ignored as causes detrimental to aspen regeneration. Soil compaction and root wounding (Shepperd 1993; Bates et al. 1993) are dependent on soil conditions such as texture and moisture content during landing construction and skidding operations (Shepperd 1993; McNabb et al. 2001). Unfavorable soil conditions appear not to have been a significant factor in our study, but under different conditions, compaction and root wounding may have a larger impact.

In conclusion, building and storage of log decks during the growing season significantly reduced regeneration densities below the suggested minimum of 15,000 stems ha^{-1} (David et al. 2001), and storing logs over the summer should be avoided during summer logging operations. On the other hand, log deck storage after a fall or winter harvest for nearly a year may have little incremental impact on aspen regeneration beyond that as a result of building the deck itself. The amount of interwoven slash left on decking areas even after the clean-up may be a major factor limiting aspen regeneration. This mat of debris should be carefully removed in the reclamation of the decking area. However, care must be taken to remove the debris without an excessive removal or damage to the aspen root system as a result of blading too deep. In addition, avoiding excessive soil compaction or direct damage to the root system during operation would likely improve aspen regeneration in these problem areas; consequently logging on frozen ground should be the preferable option.

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