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Forest floor protection during drilling pad construction promotes resprouting of aspen

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ABSTRACT

Drilling pads that are used to explore petroleum reserves in the boreal forest are often only used for a short time. We studied the vegetative regeneration potential of aspen (*Populus tremuloides*) through root suckers as a means to rapidly recover forest vegetation in these disturbed sites. We compared protecting the original forest floor under a layer of subsoil during the leveling of drilling pads, with the current practice of stripping off the forest floor and topsoil and placing it back on the site (Rollback) in the re-contouring of the reclamation phase. We also tested three techniques of delineating the forest floor so that it can be effectively uncovered during the reclamation phase. After re-contouring and top soil placement on the sites, we assessed the extent of surface disturbance, soil temperature, soil bulk density, and the density and height of aspen regeneration. Aspen suckers were tallest, had the highest density and had better survival when the forest floor was protected compared to the standard Rollback treatment. When protecting the forest floor, delineating the original forest floor from the subsoil cover resulted only in small differences in the aspen regeneration among delineation treatments with little impact on soil compaction and only moderate effects on soil surface disturbance. The study indicates that protection and the careful uncovering of the forest floor with or without using a delineation layer should be a preferred strategy for temporary drilling pad construction and their subsequent reclamation in aspen-dominated boreal forests.

1. Introduction

In-situ extraction of oil in the Athabasca oil sands region located in Alberta's boreal forest results in significant forest fragmentation from numerous temporary drilling pads used to explore the oil sands deposits. Drilling is usually done in winter to take advantage of frozen soil conditions for easier access of equipment. The drilling requires flat areas, nearly 1 ha in size, on which the rig equipment can be established. In most cases these drilling pads may be needed for less than a month. Current regulations require that prior to leveling the pad all suitable organic forest floor (L, F, H horizons) and the mineral top soil (A, B horizons) up to 15 cm depth is to be stripped off the entire drilling pad (Alberta, 2007). This salvaged mix of organic forest floor and mineral top soil (forest floor material) is stockpiled and then placed back onto the surface after the drilling pad is re-contoured (Rollback). Such extensive forest floor salvage, however, is an aggressive mitigation measure that may not be necessary for the entire drilling pad.

During the construction of a level drilling pad, particularly on sloping ground, one part of the pad is cut into the hill side while the other part is filled with the cut material. On the cut portion of the pad (upper slope) the removal and placement of the salvaged forest floor material is likely the only strategy for the recovery. Conversely, on the fill side of the pad (lower slope), it might be unnecessary to strip off the original forest floor with its propagule bank. This has been suggested by Osko and Glasgow (2010) as a technique with potential to reduce the wellsite footprint, but not been yet tested. To achieve this, the upper slope (cut) subsoil material would be directly placed on the undisturbed forest floor during leveling, thereby protecting the original forest floor on the lower slope position during the drilling operation. Once the drilling is completed, the fill material on the lower slope would be removed to re-expose the original forest floor. One of the difficulties of this operation relates to the careful removal of the deposited subsoil material from the protected forest floor using large machinery without causing excessive damage to the original forest floor underneath. For that, a clear delineation of the protected forest floor from the fill material might also be important.

This study focussed on techniques that could accelerate the restoration of tree cover on these temporary drilling pads by taking

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advantage of the vigorous clonal regeneration potential of trembling aspen (*Populus tremuloides* Michx.). Aspen, like many other boreal forest plant species has the ability to regenerate vegetatively as an adaptation to wildfire (Greene et al., 1999; Frey et al., 2003; Rydgren et al., 2004). Site capture and canopy development by trees is an important aspect of forest restoration (Macdonald et al., 2011); therefore the suckering vigor (e.g., sucker density and height) of the aspen regeneration is an important first step in the recovery of these heavily disturbed sites.

In this study we compared the vigor of aspen regeneration following three distinct treatments: of conventional forest floor salvaging and subsequent replacement; of the protection of the original forest floor during the construction of the drilling pad; and of operational clear-cut logging. We also examined three different strategies to delineate the original forest floor from the subsoil fill and evaluated their impact on the regeneration vigor of aspen. To explore the underlying factors that could limit aspen regeneration, we also monitored variables that are known to potentially influence aspen sucker regeneration such as soil temperature, soil disturbance and compaction, and the retention of woody debris.

2. Methods

2.1. Study site

The study site is situated in North Eastern Alberta in the Central Mixedwood Subregion of the Boreal Forest Natural Region of Alberta (Beckingham and Archibald, 1996). The climate in this subregion is characterized by long cold winters and short wet summers. Monthly mean air temperatures vary from −17 °C in January to +17 °C in July and mean annual precipitation is 475 mm with 71% occurring as rain and 29% as snow (Devon, 2012). As a result of glaciation the terrain is rolling and parent materials are composed of a glaciofluvial veneer over morainal tills. The forest cover is patchy and locally even-aged, a result of the fire regime in the site, creating a mosaic of forest patches of different size, ages and composition (Greene et al., 1999).

The research area was a 40 ha cutblock (55°24′N, 110°44′W) which was slightly sloped and faced south–southeast and the soil was an Ortho Gray Luvisol, soil texture was a silty sand. The area was clearcut harvested in late fall of 2011 by Alberta-Pacific Forest Industries Inc. The original forest stand was a mature 80-year-old aspen dominated mixed wood stand (20 m tall) with some interspersed white spruce (*Picea glauca* (Moench) Voss) both in the overstory and understory. Six sites (40 m × 60 m pads) were selected in late January 2012 and the entire study was laid out and executed by the end of February. The size of a site (pad) corresponds to approximately half the area of a conventional drilling pad. The pads were chosen in areas that were originally aspen dominated and had similar original slopes (5–9%) and aspects (ranging from South to Southeast to allow for a conventional cut and fill operation.

2.2. Treatments

Each of the six pads was divided into four treatment plots. The upper half (upper slope) of the pad (20 m × 60 m) was the cut portion where the forest floor material was stripped and salvaged in a stockpile; hereafter, we use FF to describe the stripped and stockpiled forest floor material that is eventually moved back to the recontoured site during reclamation. The FF was stockpiled close to the pad area while the underlying subsoil was eventually moved downslope to the lower half of the pad to level the pad with the subsoil (fill). After reclamation, the upper half of the pad became the Rollback (RB) treatment area (see below). The lower half (lower slope) of the pad (20 m × 60 m) had the original forest floor retained. That half was divided into three plots (20 m × 20 m) which were assigned to one of three different treatments that delineated the original undisturbed forest floor from the subsoil fill material; an untreated (No Barrier (NB)) where the fill was directly placed on the original forest floor; a Geotextile (GT) treatment where a tough woven plastic mat was rolled out on the original forest floor prior to placing the fill; and a Freezing (FR) treatment, where 56 m^3 of water was applied to create a 12–17 cm layer of compacted and hard frozen snow–ice mix (verified by drilling to the soft original forest floor layer). Although the NB treatment was supposed to be directly placed on the original forest floor the areas were covered with 33 cm of snow at the time of fill placement and this snow eventually compacted to a 10–13 cm layer between the original forest floor and the subsoil (see below). A fifth plot (20 m × 20 m) was selected adjacent to each pad (within 15 m) to serve as an untreated but harvested Control, thereby completing a research block (Fig. 1C).

For FF salvage, the upper half of the pad had the L, F, H horizons and about 15 cm of the mineral soil (mostly Ae and occasionally some upper B horizon) stripped with a D6R_{xw} caterpillar bulldozer. The FF was temporarily stockpiled on the upper edge of the pad (Fig. 1A). An attempt was made to salvage to a depth of 15 cm in one lift to reduce aspen root breakage and damage. During the leveling process, the material from the B and C horizons were used as fill over the three forest floor protection plots on the lower half of the pad (Fig. 1B). The bulldozer padded its way into the protected plots by pushing the subsoil from the upper slope down onto the forest floor protection plots of the lower slope; this resulted in an increased thickness of the subsoil fill from the upper edge of the forest floor protection plot to the lower edge. Once leveled with subsoil, the forest floor protection plots were uniformly trafficked

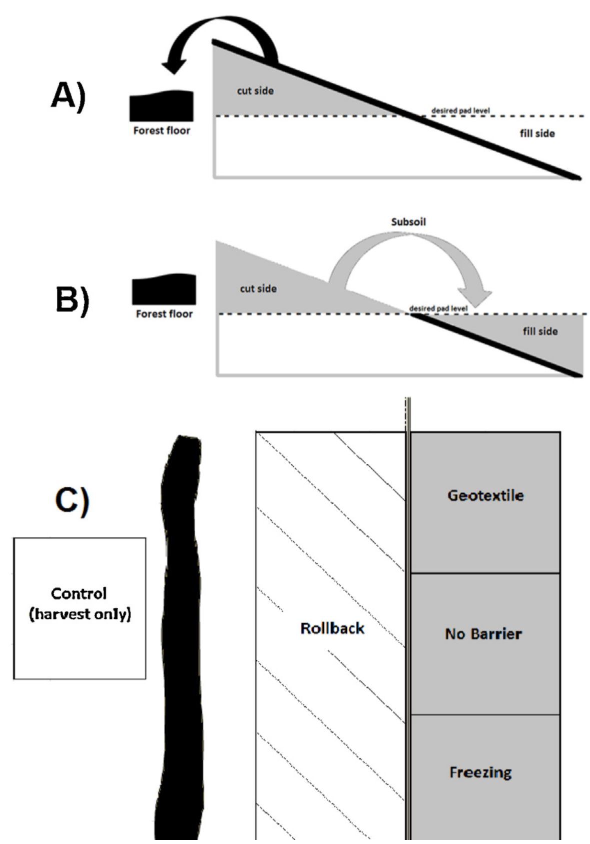

Fig. 1. Schematic of drilling pad leveling procedure and forest floor handling, as well as individual block layout.

with a fully loaded, off-road, 30 ton rock truck to imitate the use of heavy vehicles on the pad during rig operation. The truck moved back and forth to apply at least one single tire pass over the entire surface area of the pad. To assess capping thickness and soil compaction subsequent to trafficking, we staked out a grid of 12 sample points for each plot prior to fill and measured elevation three times before and after fill and after truck trafficking, using a Total Station for recording position and elevation (Leica Flexline Ts09, St. Gallen, Switzerland). The thickness of subsoil application on each sample point was determined by subtracting pre and post construction elevation. Subsoil fill depth was on average 74 cm for the sample plots, but depth over the entire experiment ranged from nearly 0 to more than 125 cm moving from the upper to the lower slope position. On average, subsoil elevation was reduced by about 8 cm by the applied truck traffic on the pad.

After lying idle for about three weeks, the level pads were deconstructed to uncover the original forest floor beneath the subsoil and the entire upper slope was re-contoured in late March of 2012, prior to thaw which is common operational practice. Accordingly, a back hoe (Komatsu PC200) fitted with a large toothless finishing-bucket was used to peel off the subsoil (and Geotextile) until it uncovered the original forest floor; the subsoil material was then dumped upslope. A bulldozer was used to spread and re-contoured the subsoil on the upper portion of the pad. Finally, the salvaged FF was rough dumped back onto the re-contoured upper slope using the backhoe completing the RB treatment; care was taken to minimize machine traffic over the protected and salvaged FF.

2.3. Measurements

In mid April of 2012, after deconstructing the pads, the positions of the three transects, with their four sample points were re-established in each of the forest floor protection plots (see above), of each block, before regrowth. A quadrat (1 m × 1 m) was centred over each sample point and in each we estimated percentage cover of slash and exposed subsoil residue, and used categorical measures (yes/no) for the evaluation wheel rutting, cutting through the LFH to the mineral soil (gouging) and root exposure.

Within each quadrat, cover of woody logging slash, was assessed digitally by photographs taken straight downward (90° angle against the slope, 360 quadrats, using a standard height), with a camera (Pentax Optio W90. Mississauga, Ontario); picture dimension 4000 × 3000 pixels and 72 dpi resolution. The percentage cover of colors coded as slash within the 1 m × 1 m square was assessed using Image Analyser (GSA v3.9.5, Rostock, Germany).

Daily soil temperature at 10 cm depth during the growing season (mid-April to early-October in 2012) was monitored in the centre of each treatment plot (total of 30 locations) with HOBO data loggers (Onset Computer Corporation, Bourne, Mass). In each treatment plot, three soil bulk density samples of the underlying mineral soil were taken from the 8 m position of each transect; samples were from 0 to 10 cm depth. To assess bulk density we used the core method (Blake and Hartage, 1986). Additionally, soil bulk density was assessed in more detail (all 12 subplots) in the NB treatment to evaluate the impact of subsoil thickness on forest floor compaction.

At the end of the first growing season (August 2012), suckers were tallied in each treatment plot at the same 12 sample points. A circular 10 m^2 regeneration plots was centred over each sample point and aspen suckers were counted and the tallest sucker was measured. A second 1 m^2 subplot was positioned at each centre point and the height of all stems was recorded to estimate mean height; these data were compared to edaphic data in regression analysis. In August of the second growing season (2013), all measurements of aspen regeneration were repeated for the Rollback, Control and NB treatment. The other two forest floor protection treatments were not re-measured as all three protection treatments had similar regeneration success in year one and all had achieved near crown closure in year 2.

2.4. Data analysis

First and second year data on sucker regeneration variables were compared using repeated measures ANOVA to determine their change over time, as well as differences among the three treatment types (Rollback, NB and Control). Blocks were used as a random statement to reduce the error term. To test for treatment effects among the three forest floor protection treatments (NB, GT, and FR) one-way ANOVA was performed on sucker density and height variables. For the statistical analyses all sub-plots (1 m^2 or 10 m^2) within one treatment plot were averaged for a total of 6 replicates for each treatment combination ($n = 6$) before running mixed model ANOVAS in Statistical Analysis System (SAS 9.2, Cary, North Carolina). Sucker density and maximum height were log transformed to meet the assumptions of homogeneity of variance (using Levene's test). Comparisons of means across treatments was done using the least square difference (LSD) means comparison test ($\alpha = 0.05$).

Differences in edaphic and disturbance factors among Rollback, NB and Control and then again among the forest floor protection treatments were also analysed using one-way ANOVAs or Kruskal–Wallis *k*-sample-and Multtest for the those variable where transformation did not meet the assumption of homogeneity of variance (minimum temperature). Relationships between soil bulk density, wheel rutting, forest floor gouging and root exposure with aspen regeneration variables on the same sample points were explored using linear regression analyses. Soil temperature vs. slash cover and soil bulk density as well as soil bulk density vs. subsoil thickness were compared on similar sample points using regression analysis. A significance level of $\alpha = 0.05$ was used for all analyses.

3. Results

After the first growing season (year 1), average aspen sucker density was with 89,722 stems ha^{-1} greatest in the NB treatment, followed by the harvested Control with 59,347 stems ha^{-1}, and only 8736 stems ha^{-1} in the Rollback treatment ($p < 0.001$; Fig. 2).

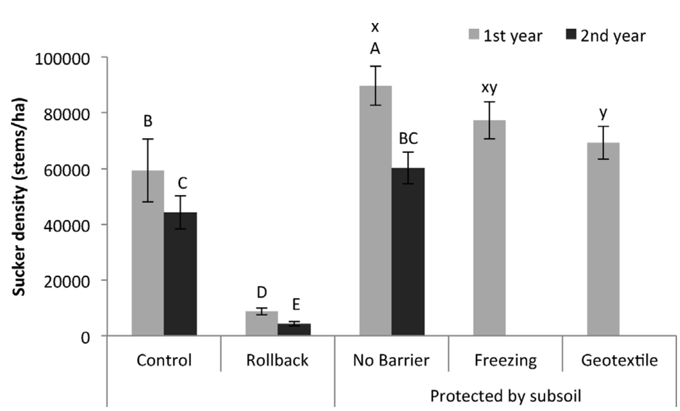

Fig. 2. Mean density of aspen suckers (±S.E.) in relation to treatments based upon the 10 m^2 plots. Means with different letters indicate statistically significant differences ($\alpha = 0.05$). Capital letters indicate differences among the three main treatments in year 1 and year 2 (Control, Rollback and No Barrier). Small letters indicate differences among the forest floor protection treatments.

After the second growing season (year 2) sucker density had declined in all three treatments compared to the previous year ($p < 0.001$) and the Rollback treatment continued to have the lowest density with 4333 stems ha^{-1} compared to the Control which averaged 44,277 stems ha^{-1} and the NB with 60,277 stems ha^{-1} ($p < 0.001$). This decline was not equal in proportion, however, as sucker mortality was 46% in the Rollback compared to only 10% in the Control ($p = 0.001$) and 30% in NB resulting in a significant year by treatment interaction ($p < 0.001$).

The number of 10 m^2 regeneration plots that contained at least one sucker relative to the number of plots measured (% stocking) was not different between the Rollback (99%), the Control and NB treatments (100%) after the first growing season; however, after the second growing season, the stocking in the Rollback decreased to 92%, while it remained 100% in the other two treatments ($p = 0.035$).

Mean height of suckers in the first year was 10 cm in the Rollback compared to 37 cm in the Control and 40 cm in the NB treatments ($p < 0.001$) (Fig. 3).

In the second year mean sucker height doubled in all three treatments from the year before; however, as the suckers in the Rollback were much shorter in the first year, the difference in height between the Rollback and the other two treatments became even larger, resulting in a year by treatment interaction ($p < 0.001$). A similar response was observed for maximum sucker height where in the first year the tallest suckers were about 19 cm in the Rollback compared to 112 cm in the Control and 137 cm in the NB treatment (Fig. 4).

Although all dominant suckers grew in height in the second growing season, the difference in maximum sucker height among treatments became larger with dominant suckers being 185 cm tall in the NB treatment compared to 28 cm in the Rollback. This also resulted in a significant year by treatment interaction term for the maximum sucker height ($p < 0.001$).

Across the three forest floor protection (delineation) treatments aspen sucker density was overall very high, but it did vary somewhat among the three treatments ($p = 0.019$). Densities were the lowest with 69,250 stems ha^{-1} in the GT treatment and the highest in the NB treatment (89,722 stems ha^{-1}) with the FR treatment occupying the mid-range (77,347 stems ha^{-1}) (Fig. 2). However, in all three treatments sucker density was high enough to reach crown closure in the second growing season. Mean sucker height was not different among the three treatments ($p = 0.427$); while the dominant sucker in the NB treatment was on average 26 cm taller compared to the FR treatment ($p = 0.026$) and not different from the GT treatment (Figs. 3 and 4). An interesting observation, specific to the NB treatment in fall 2012, was that aspen in this treatment had lost all foliage by October 15th whereas in all other treatments leaves had just started to senesce.

Although soil bulk density increased with soil loading on the forest floor protection plots ($p < 0.001$) (Fig. 5), the average soil bulk density across the plot for the NB treatment (1.60 g cm^{-3}) was not significantly higher than for the harvested only Control (1.59 g cm^{-3}) and the Rollback (1.54 g cm^{-3}) ($p = 0.637$).

In addition, there was no correlation between sucker density ($p = 0.266$) or mean sucker height ($p = 0.639$) with soil bulk density and there were no differences in mean sucker density ($p = 0.657$) or mean height ($p = 0.837$) among slope position within the NB treatment.

The presence of exposed roots was highest in the Rollback (96%) and the occurrence of forest floor gouging was highest in the NB treatment compared to the Control (Table 1).

The Control, however, had more slash than either the NB or the Rollback treatments. Comparing the three forest floor protection treatments, NB tended to have the greatest forest floor gouging, ruts and exposed roots and the least amount of slash residue. Forest floor gouging increased sucker density ($R^2 = 0.191$; $p = 0.033$), whereas sucker height was not affected by gouging ($R^2 = 0.062$; $p = 0.241$).

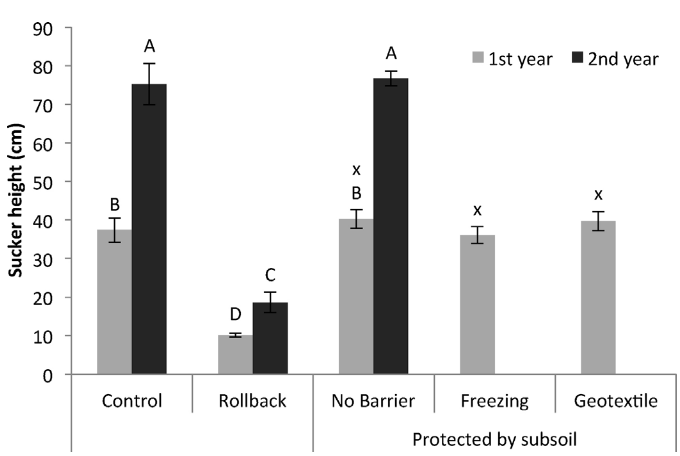

Fig. 3. Mean sucker height (±S.E.) based upon the 1 m^2 subplots in relation to recovery treatments. Means with different letters indicate statistically significant differences ($\alpha = 0.05$). Capital letters indicate differences among the three main treatments in year 1 and year 2 (Control, Rollback and No Barrier). Small letters indicate differences among the forest floor protection treatments.

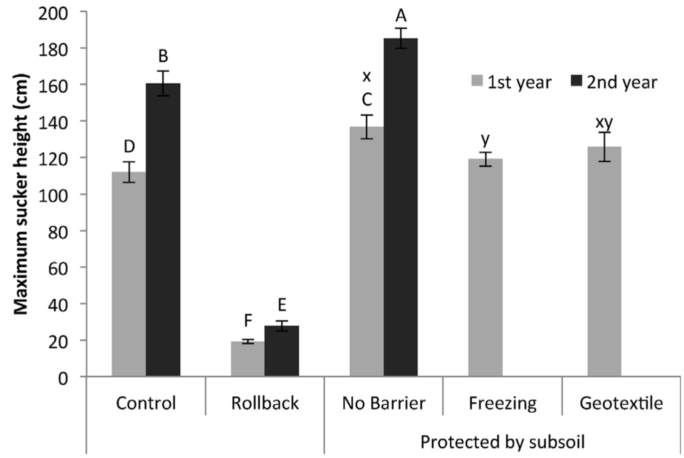

Fig. 4. Maximum sucker height (±S.E.) based upon the 10 m^2 plots in relation to recovery treatments. Means with different letters indicate statistically significant differences ($\alpha = 0.05$). Capital letters indicate differences among the three main treatments in year 1 and year 2 (Control, Rollback and No Barrier). Small letters indicate differences among the forest floor protection treatments.

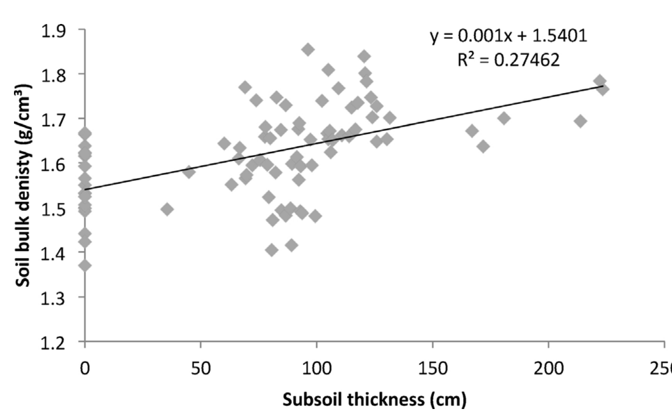

Fig. 5. Soil bulk density in relation to thickness of the subsoil fill. All data originate from the Control and NB treatment ($n = 86$).

Table 1
Percent surface area disturbed by machine traffic, covered with slash or subsoil residue. For gouging, exposed roots, and wheel ruts are based on the proportion of subplots within a treatment plot that contained these conditions. Means with different letters indicate statistically significant differences ($\alpha = 0.05$). Capital letters indicate differences among the three main treatments (Control, Rollback and NB), while small letters indicate differences among the three forest floor protection treatments.

	Control	Rollback	No Barrier	Freezing	Geotextile
Gouging*	13 B	NA	43 A x	28 y	24 y
Exposed roots	18 C	96 A	44 B x	24 y	31 xy
Wheel ruts	30 B	61 A	40 AB x	32 x	22 x
Residual subsoil	NA	NA	14	9	8
Slash residue	40 A	10 C	18 B x	27 y	29 y

* Forest floor gouging.

Table 2
Mean, maximum and minimum daily soil temperatures (°C) in relation to recovery treatment. Data were collected from June 7th to October 7th. Means (±S.E.) with different letters indicate statistically significant differences ($\alpha = 0.05$). Capital letters indicate differences among the three main treatments (Control, Rollback and NB), while small letters indicate differences among the three forest floor protection treatments.

	Control	Rollback	No Barrier	Freezing	Geotextile
Mean	12.3 C (0.7)	16.0 A (0.6)	13.8 B x (0.8)	13.0 y (0.5)	13.1 xy (0.6)
Maximum	18.7 C (1.4)	28.3 A (2.2)	21.7 B x (1.8)	18.7 y (1.0)	20.2 xy (1.3)
Minimum	6.2 A (0.4)	2.0 B (1.4)	5.8 A x (0.5)	6.6 x (0.4)	6.2 x (0.6)

Daily mean and maximum soil temperature in the rooting zone (10 cm depth) were highest in the Rollback treatment and lowest in the Control (Table 2).

Minimum temperatures were lower in the Rollback treatment – giving this treatment the greatest daily temperature fluctuation. For the forest floor protection treatments, the NB treatment tended to have the higher maximum soil temperatures. Soil temperature was negatively correlated with slash cover ($R^2 = 0.574$; $p < 0.001$; Fig. 6).

However, sucker density ($R^2 = 0.102$; $p = 0.122$) and sucker height ($R^2 = 0.015$; $p = 0.574$) were not related to slash cover across this experiment.

4. Discussion

This study shows that if temporary drilling pads are constructed on top of an intact forest floor and deposited materials are removed before the beginning of the growing season, aspen can vigorously sprout from its root systems and quickly dominate the site. This rapid recovery is comparable to the successional trajectory of sites after surface disturbances such as fire or logging. Compared to the current approach for reclaiming the entire pad using the stripping and rollback of FF, there were more than 10 times as many aspen suckers which were three times as tall in forest floor protection plots. Further, the density of aspen suckers on the forest floor protection even exceeded the density of the Control (normal clear cut plots) by ~30,000 stems ha^{-1}. The excellent sprouting in the NB treatment could potentially be linked to the removal of much of the slash during the clean-up of the subsoil, which removed only a physical barrier but also led to increased soil temperatures. Elevated soil temperatures stimulate the growth of the suckers (Landhäusser et al., 2003). Both trends continued on in the second year of assessment and in fact the height of the Rollback treatment fell further behind that of the forest floor protection. It is clear that protection of forest floor during the winter construction of drilling pads allows for a rapid recovery of aspen forests comparable to forest regeneration following clearcut logging in winter. Intact forest floor provides abundant and healthy aspen roots that are ready for suckering (Frey et al., 2003); provided that the pad is deconstructed and rolled back prior to the start of the growing season. Small lateral roots (<2 cm in diameter) produce many suckers (Kemperman, 1978; DesRochers and Lieffers, 2001; Frey et al., 2003). Maintenance of the original root system, with its stored C reserves (Landhäusser and Lieffers 2003; Landhäusser et al., 2012) is important to the elongation and above-ground emergence of aspen suckers following disturbance (Schier and Zasada, 1973). Intact root systems also increase the growth and success of suckers, since intact roots access more water and nutrients through their fine roots.

Interestingly, the Rollback plots had also much higher relative sucker mortality than the other two treatments indicating that the sucker density and leaf area development on roots is essential to the success of sucker regeneration. Sucker development from root fragments is dependent soil depth and reserves stored in the root fragments (Wachowski et al., 2014). The Rollback caused severe root wounding and fragmentation to the original root system. Such damage likely leads to root fungal infection (Pankuch et al., 2003), decreased sucker health (DesRochers and Lieffers 2001; Renkema et al., 2009) and subsequently to high fragment mortality (Wachowski et al., 2014).

Although initial sucker densities were different between the FR and NB treatments, both treatments exceeded the sucker densities of the harvested Control. This indicates that sucker numbers were sufficient to produce a closed aspen canopy in the second growing season. This is supported by the observation that mean sucker height was not different among the three forest floor protection treatments, but there was a strong trend for more suckers in the NB treatment ($p = 0.054$) and lower performance in the FR treatment. The somewhat lower sucker density and shorter maximum sucker height in the FR treatment could possibly be attributed to a delayed sucker establishment in the FR treatment as low soil temperatures can inhibit sucker growth (Schier and Zasada, 1973); thus, suckers were smaller and less numerous, because they had less time to emerge and grow (Landhäusser and Lieffers, 1998; Landhäusser et al., 2006). Further, the higher incidence of gouging of the forest floor surface in the NB treatment resulted in higher soil temperatures due to lower slash cover and exposed mineral soil. Gouging might also have enhanced suckering, since light wounding of an intact and connected root system can stimulate additional suckering (Fraser et al., 2003, 2004; Renkema et al., 2009). The only feature of concern in the NB treatment was the early senescence of suckers, compared to the GT or FR. The underlying factors are not clear; however, this could point to an effect of nutrient depletion, because less of the organic forest floor and

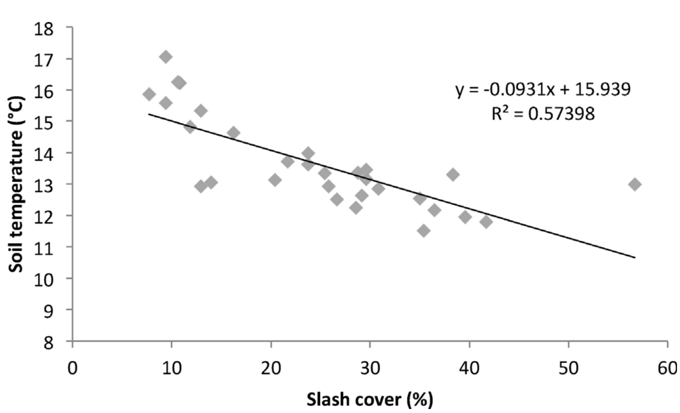

Fig. 6. Mean soil temperature in relation to slash cover. Temperature data represent seasonal averages over the treatment plots ($n = 30$).

slash material was available for decomposition/mineralisation, or because of higher temperatures speeded up the seasonal processes and growth was completed earlier, as fall soil temperatures declined more rapidly in the NB treatment than in the other treatments.

Sucker height growth in the second year also tended to be lower in the NB compared to the Control treatment. However, these aspects will require further monitoring. Slash load was found to reduce growing season soil temperature in our study; however it could not be linked to sucker regeneration. Higher slash loads can inhibit soil warming (Lieffers and Van Rees, 2002) that limits root growth and respiration (DesRochers et al., 2002) and can hinder suckers from penetrating to the surface (Landhäusser et al., 2007).

Studies have linked lower sucker densities with increased soil compaction (e.g., Bates et al., 1993). In our study soil loading caused a weak increase in bulk density with higher loading, but this increase in bulk density did not negatively affect the suckering response; we therefore believe that using subsoil to build the pad and as a buffer to protect the forest floor was an effective means for protecting the aspen root system.

Among the forest floor protection treatments, our study indicates that the NB treatment likely was better than the other two treatments; however, it needs to be noted that at the time of the fill placement all plots were covered by 33 cm of snow which was eventually covered with the fill. Although not intended, this snow layer did provide a visual cue for the operator to separate the protected forest floor from the fill. In conditions without snow or with less skilled operators, the FR treatment may be preferable. The Geotextile (GT) treatment was comparable to the NB, in terms of sucker regeneration, but due to the much greater effort of applying and removing this treatment it cannot be recommended at a larger scale. According to the operators it would take at least twice as long as to remove the fill from the GT plots than from the NB and FR treatment plots. It was much easier task for the operator to remove the fill material from the FR treatment with its thick and hard snow–ice mix, because it provided a solid barrier above the protected forest floor for the bucket to slide against during the cleanup of subsoil.

4.1. Conclusions and management implications

In conclusion, for boreal aspen mixedwood stands, FF salvage and rollback treatments would only be appropriate in those areas that require materials to be removed to level the pad (i.e., the upper slope position). Here careful FF salvage and rough dumping of the material during reclamation could be moderately effective in restoring aspen stands. Supplemental planting of seedlings might be necessary in these areas. Salvage depth of this material should be driven by rooting depth of the aspen and include most of the available root mass to maximize propagule availability and include suitable mineral soil material (e.g., without an inclusion of unsuitable soil horizons such as heavy clays) (Wachowski, 2012). Forest floor protection is a good option for forest reclamation of temporary well pads (particularly for aspen) and should be applied in winter but likely could be used in other seasons, especially the early spring or fall seasons, provided that the recontouring/cleanup is done at a time to provide regeneration with enough time to grow and establish. Furthermore, operator training to recognize forest floor and understand its value for site recovery is crucial to the successful implementation of forest floor protection.

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