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# Regeneration of quaking aspen (*Populus tremuloides*) after fire risk reduction treatments

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## Abstract

Quaking aspen (*Populus tremuloides* Michx.) is a keystone species in the western US, and readily regenerates following high-severity disturbance (historically stand-replacing fire). Aspen forests are thought to be in decline as a result of fire suppression, herbivory, and drought, such that restoration has become a priority. Typically, restoration involves prescribed fire or harvest to regenerate aspen, but these methods are not applicable everywhere, due to heavy coarse fuel loads that make prescribed fire risky and harvesting challenging. The need for alternative, stand-replacing treatment methods that regenerate aspen has led to the development of a mechanical method, termed 'roller-felling'. Like fire or harvest, roller-felling can reset succession and rearrange fuel loading in late-seral stage, conifer-dominated aspen communities. We examined the ecological impact of roller-felling by investigating factors that contributed to post-treatment aspen regeneration, in a replicated experimental design containing variable levels of post-treatment cleanup (i.e., residual slash amount). Prior to treatment, we collected stand structural and compositional characteristics from 5 plots per unit to allow for post-treatment comparison. One year after treatment, we quantified aspen regeneration stem densities. We also assessed possible factors that could have influenced aspen regeneration, including herbivore browsing pressure, topography, and pre-treatment composition. Additionally, we determined the impact this treatment had on vegetative ground covering. Post-treatment aspen stem density varied from 0 to 237,000 stems/ha across 30 plots among all treatment areas. There were significant differences in post-treatment stocking among cleanup levels, with full cleanup densities averaging ~100,000 stems/ha, while partial cleanup densities averaged ~23,000 stems/ha. Cleanup level and topography (i.e., slope) best predicted aspen densities post-treatment, and pre-treatment aspen composition had less effect on regeneration than predicted. Approximately 44% of aspen regeneration stems were browsed by herbivores one year after treatment. While the long-term effects of this method have yet to be quantified, the one-year results in this study lay the groundwork for longer-term monitoring of roller-felling treatment outcomes and their application to forest and fire management regionally, where goals are to reduce fire risk and maintain aspen communities across the western US.

## 1. Introduction

Quaking aspen (*Populus tremuloides* Michx.) is North America's most widespread broadleaf tree species, valued for providing many ecosystem services, such as increased biodiversity, making management of these communities a priority across the western US. (Little, 1971; Kuhn et al., 2011; Long and Mock, 2012). As an early successional species, aspen require disturbance to persist, establishing in high densities post-disturbance. Aboveground stem removal stimulates aspen's primary reproduction strategy of suckering, or establishment of a genetically identical ramet (i.e., sucker) from a root, which is initiated by interruption of auxin transport from leaves to roots (Frey et al., 2011; Wan et al., 2006). Within seral aspen forest types, conifers establish under mature aspen and dominate the canopy in later succession. When they burn, late-seral aspen communities are susceptible to high-severity fires due to high fuel loading (Shinneman et al., 2013). Stand-replacing fires historically reduced fuel loading and promoted aspen regeneration, but have become increasingly rare due to fire suppression efforts (DeByle and Winokur, 1985). Currently, prescribed fire and harvesting are the most feasible stand-replacing treatments in practice but can be difficult to implement with weather or infrastructure limitations. The need for alternative treatments that regenerate aspen and reduce fire risk by resetting succession has led to the development of roller-felling. This treatment method involves pulling a large barrel attached via cable between two bulldozers (Fig. 1) to restart succession within aging aspen communities. Recently, roller-

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felling has been implemented in late- stage, mixed aspen-conifer stands, however, treatment efficacy (i.e., aspen regeneration) and associated impacts have yet to be quantified.

Prolific aspen regeneration via suckering is expected after treatment, as aspen preferentially establish in disturbed areas with high light (DeByle and Winokur, 1985). However, various factors influence aspen regeneration densities, such as aspen composition pre-disturbance, amount of residual coarse woody debris (CWD) post-disturbance, topography, and herbivore pressure. Because regeneration is primarily via suckering, larger proportions of pre-disturbance aspen correlate with greater regeneration, and were predicted in this study (Graham et al., 1963; Frey et al., 2011). Conversely, higher pre-treatment conifer proportions were expected to decrease aspen regeneration (Smith et al., 2011; Margolis and Farris, 2014). Pre-treatment understory advance regeneration (<10 cm diameter) was predicted to increase regeneration (Britton et al., 2016). Greater amounts of CWD can increase shading and decrease surface area, which has been correlated to lower regeneration (Doucet, 1989; Sheppard 1996, 2001). Lower aspen densities were expected with increased CWD, or slash retention. Additionally, the role of CWD as refugia from herbivory is well-documented (Grisez, 1960; Rumble et al., 1996; Ripple and Larsen, 2001), and a lower percentage of aspen stems browsed, primarily by elk (*Cervus elaphus* L.), were expected with increased slash retention. The objective of this study was to determine the regeneration response of aspen to roller-felling and then assess the impact of (1) pre-treatment stand conditions, (2) the amount of slash retention, (3) topography, and (4) herbivory on aspen stem densities. Better understanding of the efficacy and impacts of this treatment will set the baseline for long-term monitoring of treated sites, with possible application to regional forest and fire management.

## 2. Methodology

### 2.1. Study area

Treatment areas were on private property in Utah, USA, and were split into 3 experimental units with similar edaphic, climactic, and elevational characteristics. Prior to roller-felling, stands were characterized as mixed-conifer, primarily subalpine fir (*Abies lasiocarpa*). Pre-treatment basal area varied minimally by unit, averaging 30 $m^2$/ha, while aspen comprised 29% to 63% basal area. Units differed moderately in potential productivity (aspen site indices 44 to 52) and were characterized by very high woody surface fuel loadings (26.9-46.3 Mg/ha across all size classes).

### 2.2. Study design

We applied a replicated, variable treatment design at 3 experimental units, totaling 18 treated hectares. Each 6-hectare unit contained 3 adjacent blocks (i.e., cleanup levels) approximately 2 hectares in area, containing a gradient of residual slash densities, and an untreated control (Fig. 2). These cleanup levels were: 1) all slash pushed into burn pile (full), 2) moderate residual densities of slash, with most slash pushed into pile (partial), and 3) no slash pushed into piles (none). Woody surface fuel loadings (i.e., residual slash) outside of piles in full cleanup averaged ~ 8 Mg/ha, 37 Mg/ha in partial cleanup, and 174 Mg/ha in no cleanup areas.

Prior to treatment, 60 variable radius plots were sampled using a 4m basal area prism to quantify stand structure and composition. At each plot, we measured diameter at breast height (DBH) and species of every overstory tree (>10 cm DBH) and the height of every other tree; the tallest tree was cored for site index determination. Fixed-area, 1/1000th (1.78 m radius) hectare plots were measured to determine understory (<10 cm DBH) advance regeneration. Woody fuel loads were quantified by diameter classes on two transects using protocols outlined in Brown (1974), and 1 $m^2$ quadrats were surveyed along these transects to quantify ground covering by functional group (delineated by biotic: forb, shrub, grass, tree, and abiotic: CWD, bare soil, etc.). After treatment, five, 1/1000th hectare regeneration plots were sampled within full cleanup, partial cleanup, and untreated control areas, totaling 45 plots (direct sampling in no cleanup areas was omitted as high slash restricted access; Fig. 2). We identified seedlings and suckers to species, delineated stems by height class, and noted apical meristem as browsed or unbrowsed. Measurements were taken along two transects to determine ground covering and residual slash/fuel loading. Twenty-seven ungulate exclosures (1.2$m^2$ x 1.22m height) were constructed, with 3 in each cleanup level and control area (again, omitting no cleanup), and sampled identically to regeneration plots (Fig. 3).

### 2.3. Analytical Approach

Linear regression was used to explore relationships between predictor variables (percentage and absolute aspen basal area, advance regeneration, conifer composition, topography, residual slash) and post-treatment aspen regeneration densities. Percentages of browsed stems were also compared across cleanup levels and units with linear regression and analysis of variance. Analysis of variance was used to compare differences between units. T- and F- tests were used to determined differences in densities between cleanup levels and ground covering percentages before and after treatment.

## 3. Results

Aspen regenerated in high densities after roller-felling. Stem densities were significantly higher and more variable (P-values <0.0001) in full cleanup compared partial cleanup areas, where densities averaged ~102,000 stems/ha and ~23,000 stems/ha, respectively (Fig. 4). Pre-treatment composition was not highly predictive of post-treatment density (P-value = 0.18) and higher proportions of both advance regeneration and overstory aspen pre-treatment did not predict of greater post-treatment densities when analyzed independently ($r^2 \leq 0.15$). Collectively, cleanup level, slope, and pre-treatment composition were highly predictive of aspen regeneration densities ($r^2 = 0.71$). When cleanup areas were analyzed independently, pre-treatment variables became more predictive in full cleanup areas. Additionally, in full cleanup areas, steeper slopes were associated with lower stem densities, however, densities remained constant across the same slope gradient in partial cleanup areas.

After roller-felling, the percentage of ground occupied by bare soil changed significantly (P-value < 0.0001) from a pre-treatment average of 2% to ~30%. Proportions of bare soil and CWD varied significantly between the two cleanup levels (all P-values <0.0001). Partial cleanup contained less bare soil (14%) and greater CWD (38%) than full cleanup, in which bare soil occupied 42% of ground covering and CWD only 9%. Full cleanup areas generally had slightly greater biotic ground covering. Partial cleanup areas had significantly greater residual slash than full cleanup areas, with all CWD diameter classes of greater densities (P-value <0.0001); however, this did not deter herbivory, as percentages of observed browse on aspen stems remained similar between full and partial cleanup areas (42% and 46%, respectively). Browse percentages were relatively uniform across units and cleanup levels with no significant differences observed. Aspen stems within exclosures were significantly greater in height, but not density, in contrast to unfenced, browsed stems (Fig. 3).

## 4. Discussion and Conclusion

### 4.1. Discussion

Many outcomes of roller-felling were consistent with our predicted hypotheses. Generally, the response of aspen to treatment was suckering in high densities, as expected, but thresholds indicating 'successful' regeneration vary in the literature (e.g., Kitchen et al., 2019). A regional, applicable regeneration threshold of 2500 stems/ha was met one year after treatment, with 93% of plots meeting this objective (Kitchen et al., 2019). Furthermore, a predictable, negative relationship between residual slash and regeneration was observed: increased CWD post-treatment resulted in decreased aspen density. Greater proportions of CWD and lower proportions of bare soil within partial cleanup areas resulted in less area for unobstructed sucker establishment, increased shade, and consequentially lower stem densities. Increased slash did not deter ungulate browse; this could be due to low (<1m) pile heights observed after roller-felling, as debris piles reducing browse are typically >1m (Ripple and Larsen, 2001; Nichols, 2005).

Ungulate herbivory of young aspen can alter regeneration dynamics, and high amounts of browse can stunt growth and promote unhealthy growth structure (i.e., bush-like); insufficient aspen recruitment is a common result of repeated browse (Baker, 1918, 1925; Bartos and Campbell, 1998). Taller aspen stems within exclosures confirm a negative impact of browse on regeneration. A sustainable, 30% maximum threshold of repeated browse allows for long-term, healthy stand structure and development (Olmsted, 1979). In the first growing season, roughly 45% of all aspen stems were browsed. By this metric, browse levels immediately violated sustainable thresholds. However, this was not strong enough to denote *absolute* levels of unsuccessful regeneration (i.e., 10,000 stems/ha at 45% browse still provides 5,500 stems/ha). Nevertheless, if browsing pressure remains constant (or even moderately declining) and compounded across future growing seasons, regeneration will be insufficient, failing to reach 2500 stems/ha. High levels of observed browse in this short-term study are concerning from the standpoint of long-term stand health and development.

Some well-established, pre-treatment factors we hypothesized as predictors of aspen regeneration were not strongly correlative in this study. Prior to treatment, units varied significantly in both aspen percent of total basal area and absolute aspen basal area, ranging from 4 $m^2$/ha to 20 $m^2$/ha. Many metrics quantifying pre-disturbance aspen composition have been linked to greater regeneration, such as increased "vigor", greater height and DBH of overstory aspen (Worrall et al., 2008, 2010; King and Landhäusser, 2018; Jean et al., 2019), and advance regeneration (Britton et al., 2016). However, these pre-treatment variables were weakly correlated to greater one-year, post-treatment regeneration densities unless other variables were added.

While many biotic, pre-treatment variables were not predictive, cleanup level (i.e., amount of residual slash) and slope were more strongly correlated to increased aspen densities. We presume that residual slash mitigated the negative effect of slope in full cleanup areas because increased slash provided soil stability and decreased erosion potential. This finding has notable implication on management: if roller-felling is to be considered, leaving residual CWD on steeper slopes may increase regeneration and promote soil stability. Overall, lack of overt correlation between pre-treatment aspen and regeneration also has interesting management implications (i.e., pre-treatment aspen composition alone has little effect on regeneration, allowing for application in later-stage stands with little aspen).

### 4.2. Conclusion

The short-term, regeneration response of aspen to roller-felling generally mimics conditions of a stand-replacing disturbance by restarting succession and reducing fuel loading. Topography and residual slash strongly influenced regeneration densities, highlighting the importance of context within management application. Importantly, this study assessed the impact of roller-felling one-year following treatment, but long-term impacts warrant further study. The groundwork set by this study will further the understanding of aspen regeneration dynamics, which will apply to forest and fire management regionally, where goals are to reduce fire risk and maintain aspen communities.

***Fig. 1. Roller-felling barrel situated centrally between two cables and dragged between a pair of bulldozers. The cable fells trees, while the large barrel drum keeps the cable roughly >1m above the ground surface, providing necessary leverage to pull over trees. Once felled, variable amounts of slash can be retained, while remaining debris is pushed into a pile and burned at a later time. Inset photo for scale.***

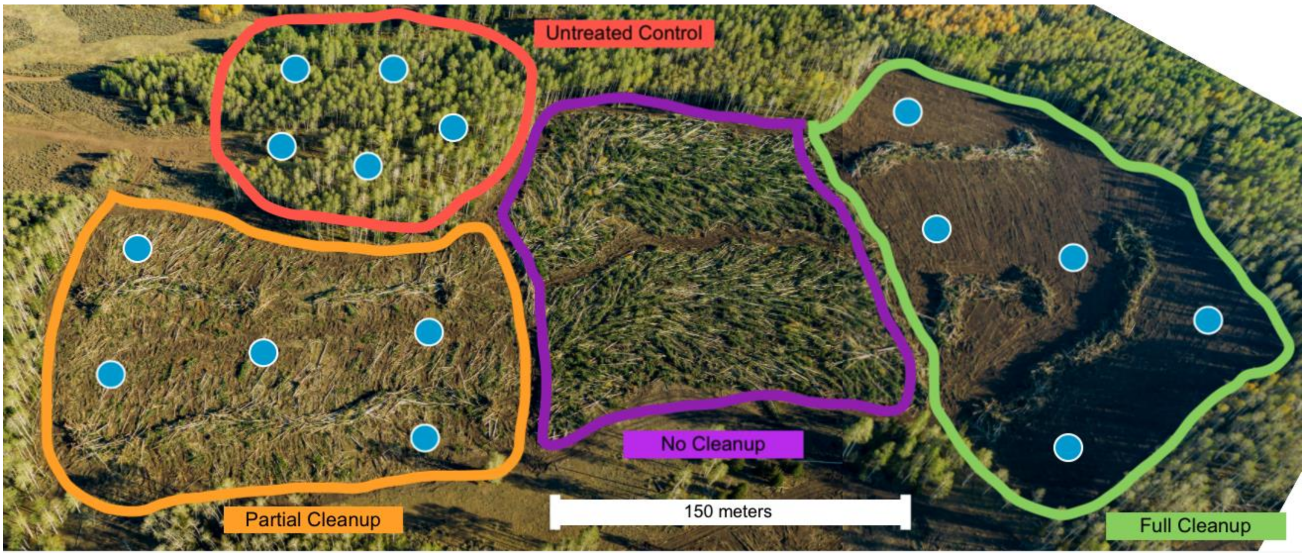

***Fig. 2. Study design of variable treatment cleanup levels within experimental unit. Left to right: partial cleanup (orange), no cleanup (purple), and full cleanup (green). An adjacent, untreated control area above the treatment areas and shown in red. Sampling plots, shown in blue, are independent, spaced at a minimum of 45 meters apart, and do not intersect with slash piles. No plots were established in the no cleanup treatment, as slash levels restricted sampling.***

***Fig. 3. Contrasting aspen regeneration within fenced exclosure and browsed stems outside of exclosure in partial cleanup treatment area (photo taken one year after treatment). Inset: completed exclosure in partial treatment area, constructed prior to aspen regeneration emergence.***

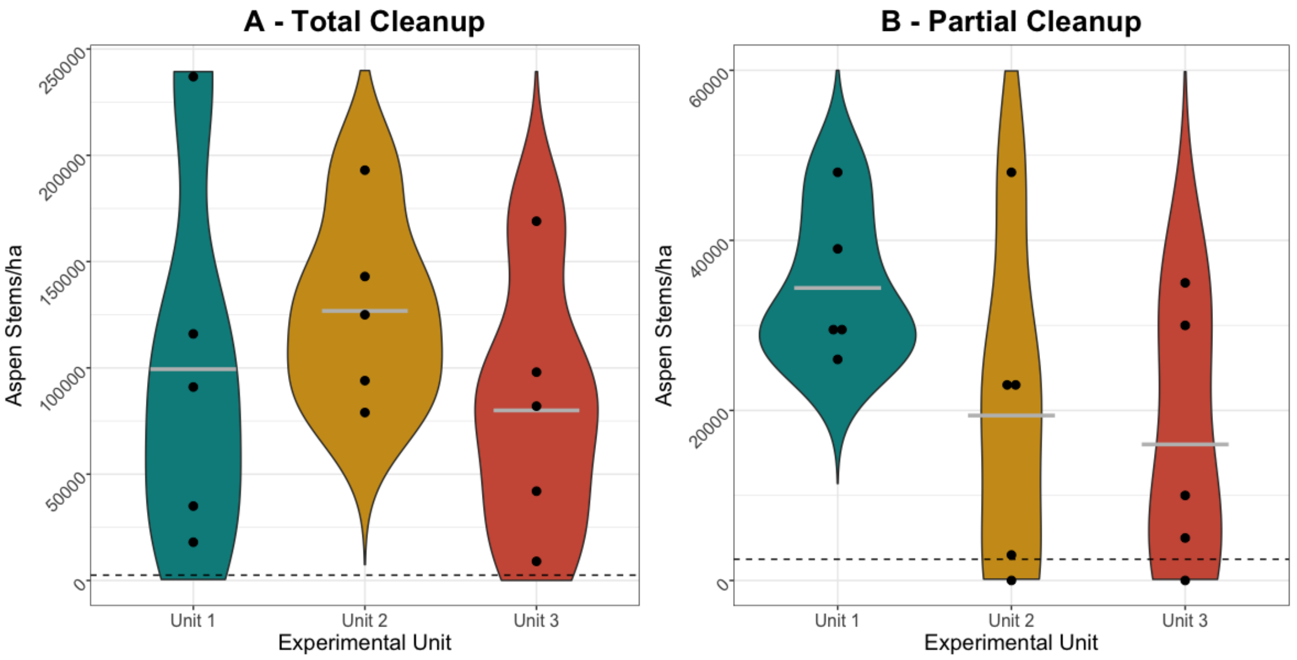

***Fig. 4. Post-treatment aspen regeneration stems per hectare, delineated by (A) total and (B) partial cleanup treatment areas. Note different scales for stems per hectare on y-axis. The three experimental unit areas are indicated by different colors. The dashed line (near x-axis) indicates the 2500 stems/ha objective. Black points indicate stem densities at 5 plots within each treatment area. Gray bars denote stem density averages of each respective unit. Total cleanup (A) vastly exceeds this objective, while partial cleanup (B) stem densities largely meet this objective. Two individual sampling points within partial cleanup areas fell below the 2500 stems/ha objective, indicating insufficient regeneration.***

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