# Removal of Encroaching Conifers to Regenerate Degraded Aspen Stands in the Sierra Nevada

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## Abstract

**Aspen is considered a keystone species, and aspen communities are critical for maintaining biodiversity in western landscapes. Inventories of aspen stand health across the Eagle Lake Ranger District (ELRD), Lassen National Forest, California, U.S.A., indicate that 77% of stands are in decline and at risk of loss as defined by almost complete loss of mature aspen with little or no regeneration. This decline is due to competition from conifers establishing within aspen stands as a result of modification of natural fire regimes coupled with excessive browsing by livestock. Restoration treatments were implemented in four aspen stands in 1999 using mechanical equipment to remove competing conifers to enhance the growth environment for aspen. Recruitment and establishment of aspen stems were measured in treated stands (removal of competing conifers) and non-treated stands (control) immediately prior to treatment and 2 and 4 years post-treatment. There was a significant increase in total aspen stem density and in two of three aspen regeneration size classes for treated stands compared to controls. Pre-treatment total aspen density was positively associated with total aspen density and density in all size classes of aspen ($p < 0.001$). The results demonstrate that mechanical removal of conifers is an effective treatment for restoring aspen.**

**Key words: aspen, conventional harvest practices, effectiveness monitoring, Lassen National Forest, California, *Populus tremuloides*, restoration.**

## Introduction

Trembling aspen (*Populus tremuloides* Michx.) is the most widely distributed tree species in North America (Little 1971; Sargent 1890). Aspen is a clonal species that can vegetatively self-regenerate for thousands of years and that is perpetuated over time through regular disturbances such as fire, disease, avalanches, or insect infestations (Barnes 1975; Bartos 2001). Clone regeneration is primarily through vegetative reproduction triggered by hormonal stimulation of underground root buds initiated by disturbance (e.g., death of mature trees by fire). Whereas a significant body of aspen research literature exists from the Great Lakes and Intermountain regions, there is a lack of published research about aspen ecology and management in California. Barbour (1988) could find no quantitative studies on Sierra Nevada aspen stands. Thorne (1977) described aspen communities as the least known plant community in southern California mountains. As in many western landscapes, aspen communities in California's Sierra Nevada Range provide ecological services and products such as biodiversity, forage, habitat, conditions required for a suite of obligate understory plant assemblages, and conservation of riparian soil moisture (Winternitz 1980; Harper et al. 1981; Gifford et al. 1984; DeByle 1985; Mueggler 1988; Chong et al. 2001).

Aspen stand health and recruitment is variable across the West (Bartos 2001; Shepperd 2001), but California's aspen communities are being steadily replaced by conifers due to changes in historic fire regime and grazing pressure (Mueggler 1985; Bartos & Campbell 1998; White et al. 1998). On the Eagle Lake Ranger District (ELRD) of Lassen National Forest, Cronemiller (1952) made the following observation: "there has been no surviving reproduction of this species (aspen) on the forest for many years." Typical of the northern Sierra Nevada, modern fire suppression on ELRD began in the early 1900s (Strong 1973) and livestock grazing from sheep and cattle started in the 1860s. Much of the species composition and distribution appears to have been altered by the early 1900s in Northeast California (Leiberg 1902). Fire suppression activities have (1) reduced the frequency of fire-induced disturbance and resultant regeneration in aspen stands and (2) allowed fire-intolerant conifers to establish in aspen stands leading to the eventual replacement of aspen stands with conifer forest (Mueggler 1985; Bartos & Campbell 1998). Heavy grazing by livestock and wildlife has reduced the density and overall vigor of aspen suckers and root systems, further retarding regeneration (White et al. 1998).

There is significant interest across northern California in the restoration of aspen stands degraded by conifer encroachment. Three factors, referred to as the aspen

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regeneration triangle, must be addressed for successful regeneration: (1) hormonal stimulation of root buds to initiate vegetative regeneration via sprouting; (2) provision of appropriate growth environment, which in the case of stands encroached by conifers involves maximizing the amount of sunlight available to aspen sprouts; and (3) protection of sprouts from excessive browsing by livestock and wildlife to allow release of sprout cohorts above maximum browse height, resulting in diverse size–age structure in the stand (Shepperd 2001). Depending upon site conditions, hormonal stimulation of aspen root buds in degraded aspen stands can be achieved via treatments such as (1) prescribed fire; (2) cutting decadent aspen trees; (3) mechanical ripping of soil and roots; and (4) mechanical chaining to down decadent aspen trees. Proper treatment for hormonal stimulation depends on the current condition of the stand and risk factors present.

Our observations in conifer-encroached aspen stands in northern California have led us to hypothesize that stand recruitment can be achieved by removing competing conifers from the stand, coupled with control of heavy grazing pressure. Land managers on ELRD have been using commercial harvest techniques to remove conifers from degraded aspen stands to stimulate regeneration and eventual stand restoration. The objective of this article is to report the results of a 5-year study examining the effectiveness of these conifer-removal activities in the absence of heavy grazing pressure.

## Methods

### Study Site

This study was conducted on the ELRD, Lassen National Forest located in northeast California, U.S.A. (lat 40°23′N, long 120°34′W). Elevation of the study area ranged from 1,520 to 2,130 m. Geology is predominately basalt and andesite volcanics. Most precipitation occurs as rain and snow from November to May with a distinct dry season from mid-May to October. The climate has cool moist winters and dry warm summers. Annual precipitation ranges from approximately 40 to 152 cm with mean monthly temperatures ranging from 4°C in January to 28°C in July. Forest structure and composition at lower elevations (<1,500 m) are dominated by Lodgepole pine (*Pinus contorta* ssp. *murrayana* (Grev. & Balf.) Critchf.) and eastside pine (mixture of Ponderosa pine [*P. ponderosa* Laws.] and Jeffrey pine [*P. jeffreyi* Grev. & Balf.]). Lodgepole pine (*P. c.* ssp. *murrayana* (Grev. & Balf.) Critchf.) stands occur on sites characterized by high water tables, cold air drainage, or both. Mixed conifer habitats dominated by White fir (*Abies concolor* (Gordon & Glend.) Lindley) that include Ponderosa pine, Jeffrey pine, Sugar pine (*P. lambertiana* Douglas), and Incense cedar (*Calocedrus decurrens* Torrey) typically occur at higher elevations (>1,500 m). Broad valleys separating conifer-covered buttes typically contain open areas vegetated by Sagebrush (*Artemisia tridentata* Nutt.), Rabbitbrush (*Chrysothamnus nauseosus* ssp. *albicaulis* (Nutt.) H.M. Hall & Clements), Bitterbrush (*Purshia tridentata* (Pursh) DC.), and various grasses and forbs.

Aspen covers approximately 1% of the landscape on ELRD. Aspen stands are associated with meadow edges, rock outcrops, riparian areas, and relatively high water tables. They are located on a variety of sites ranging from 1,500 to 2,200 m in elevation, on 0% to greater than 45% slopes across all aspects on three different soil orders: mollisols, inceptisols, and alfisols. Forty-four percent of the existing aspen stands are entirely or partially located in refugia. Refugia are areas that protect aspen or are not accessible to herbivores (e.g., rock outcrops, lava flows, piles of fallen trees).

Four sites with paired treatment and control aspen stands were selected across ELRD. Paired stands were selected to have similar environmental conditions (e.g., elevation, moisture regime, initial conifer encroachment level). Mean aspen stem densities per stem size class across all eight stands prior to treatment application were as follows: size class 1 (height < 0.5 m) = 5,940 stems/ha, size class 2 (height 0.5–1.4 m) = 7,932 stems/ha, size class 3 (height > 1.4 m and diameter at breast height [dbh] < 2.5 cm) = 3,065 stems/ha, and size class 4 (>2.5 cm dbh) = 1,442 stems/ha. Conifers were a mix of Ponderosa pine, Jeffrey pine, and Lodgepole pine with total conifer basal area ranging from 41 to 50 $m^2$/ha and with total conifer density ranging from 370 to 741 trees/ha. Selected sites were subject to either no or low grazing pressure from domestic livestock at least 5 years prior to, during, and after the study.

### Treatments

Total treatment area consisted of 7 ha with an average stand size of 1.7 ha. Large conifers that were likely to compete with existing aspen stems for sunlight and/or water were removed from treatment stands. This entailed removing conifers up to 66 cm dbh within 9 m of existing aspen stems. The average dbh for conifer species present was 42 cm for Ponderosa pine and Jeffery pine, 36 cm for Lodgepole pine, and 33 cm for White fir. The conifer-removal treatment was a combination of commercial tree removal (>25 cm dbh) and hand thinning of nonmerchantable trees (<25 cm dbh). Whole tree removal was used for conifers greater than 25 cm dbh, with harvest occurring from 1 August through 1 November. Trees were hand felled with chain saws; rubber-tired grapple skidders were used to move trees to a landing located outside the aspen stand. At the landing, a self-loading truck was used to load and transport logs from the site. Branches and treetops were piled and burned at landings. Trees less than 25.4 cm were hand felled, piled within the aspen stands, and burned during winter. No conifer removal occurred in control stands.

### Vegetation Measurement

Prior to treatment application (year 0, 1999), two to four permanent 30.5-m-long × 1.8-m-wide belt transects were established within each study site (24 transects total for the study), and baseline data on canopy cover by species (conifer and aspen) and aspen density (stems/ha) collected for each transect. Transects were established randomly but were limited to areas with existing aspen stems. Overstory canopy cover was measured using a densitometer (Geographic Resource Solutions, Arcata, CA, U.S.A.). Canopy cover by tree species was recorded at 10-foot intervals along each transect resulting in 11 readings per transect. Aspen density (total and per size class) was determined for all transects immediately prior to treatment implementation (year 0, 1999), and then in year 2 (2001) and year 4 (2003) post–treatment application. All aspen stems within the transect were counted and recorded in the following size classes: size class 1 (height < 0.5 m), size class 2 (height > 0.5–1.4 m tall), and size class 3 (height > 1.4–2.5 cm dbh). Size class 1 represents the annual recruitment of aspen stems due to suckering at root buds, size class 2 represents the survival of suckers and the progression of recruitment, and the minimum height for size class 3 represents the maximum browse line height for the herbivores present in an area (deer and cattle). Therefore, stems in size class 3 indicate successful recruitment of a cohort of sprouts into the stand. Conifer-removal operations were conducted without restrictions within the transects.

### Data Analysis

The basic data structure comprises measurements of aspen density (total; size classes 1–3) repeated biannually (years 0, 2, and 4) on 24 permanent transects representing two vegetation management treatments (control, conifer removal) replicated three times resulting in 72 observations of aspen density for the study period. In order to account for codependence introduced by repeated measurements on the 24 experimental units (transects), we used linear mixed effects analysis to determine the effect of conifer removal on annual aspen regeneration den sity 4 years post–treatment application (Pinheiro & Bates 2000). Separate models were developed for each response variable (total aspen density; aspen density for size classes 1–3). A backward-stepping approach was employed to isolate a final model, with only significant ($p < 0.05$) independent variables included. For each model, the initial fixed independent variables were treatment (conifer removal, control), year (0, 2, and 4), pre-treatment aspen density for each size class and total, and pre-treatment conifer canopy cover. All possible interaction terms between independent variables were included in the original model. Transect identity was treated as a grouping variable to account for repeated measures. Insignificant main effects remained in the model if interaction terms containing the main effect were significant. Data were transformed with a square root to meet the assumption of normality, as determined via evaluation of standard diagnostic graphs.

## Results

Figure 1 reports the mean aspen density by size class for treated and control transects over the course of the study, where year 0 is pre-treatment and years 2 and 4 are post–treatment application. Treatment, total pre-treatment (year 0) aspen stem density, and a treatment-by-year interaction were significantly associated ($p < 0.05$) with aspen density in size classes 1–3 and total aspen density (Table 1). The coefficients in Table 1 quantify the expected effect of each factor on aspen density. For the categorical factors in the models (treatment, year, and treatment-by-year interaction), the coefficient represents the expected effect of each level (e.g., years 2 and 4) of the factor relative to the reference level (e.g., year 0) for the factor. For pre-treatment total aspen density, a continuous variable, the coefficient represents the incremental change of aspen density per incremental change of pre-treatment total aspen density. Figure 2 displays the results of linear mixed effects models reported in Table 1 for size classes 1 through 3, clearly illustrating the significant increase in aspen density in treated stands by year 4 following conifer removal. The total density of aspen prior to treatment (year 0) was positively associated with total number of posttreatment stems and stems in size classes 1–3 ($p < 0.002$). Pre-treatment aspen density for size classes 1 through 3 and pre-treatment conifer canopy cover were not significantly associated with post-treatment aspen densities ($p > 0.1$ in all cases).

The significant treatment-by-year interaction term indicates that aspen densities in treated and control stands diverged during the course of the study, as can be observed in the square root–transformed raw data (Fig. 1). Examining the coefficients for the treatment-by-interaction term in Table 1 indicates aspen size class 1 density was significantly higher than control by year 2 following conifer removal and remained higher throughout the study period. In year 2 following conifer removal there was an apparent ($p > 0.05$) decrease in density for total aspen and size class 3, and there was a significant decrease in size class 2 ($p = 0.040$) compared to control sites. Total aspen density in stands with conifer removal was significantly higher ($p = 0.019$) than that in control stands by year 4 following conifer removal. The density of aspen size class 3 in conifer-removal treatment stands became significantly higher than that in control stands during year 4 of the study ($p = 0.001$). Although there was an apparent increase in size class 2 density in conifer-removal treatment stands at year 4 post-treatment, it was not significantly different from the density in control stands (Fig. 3).

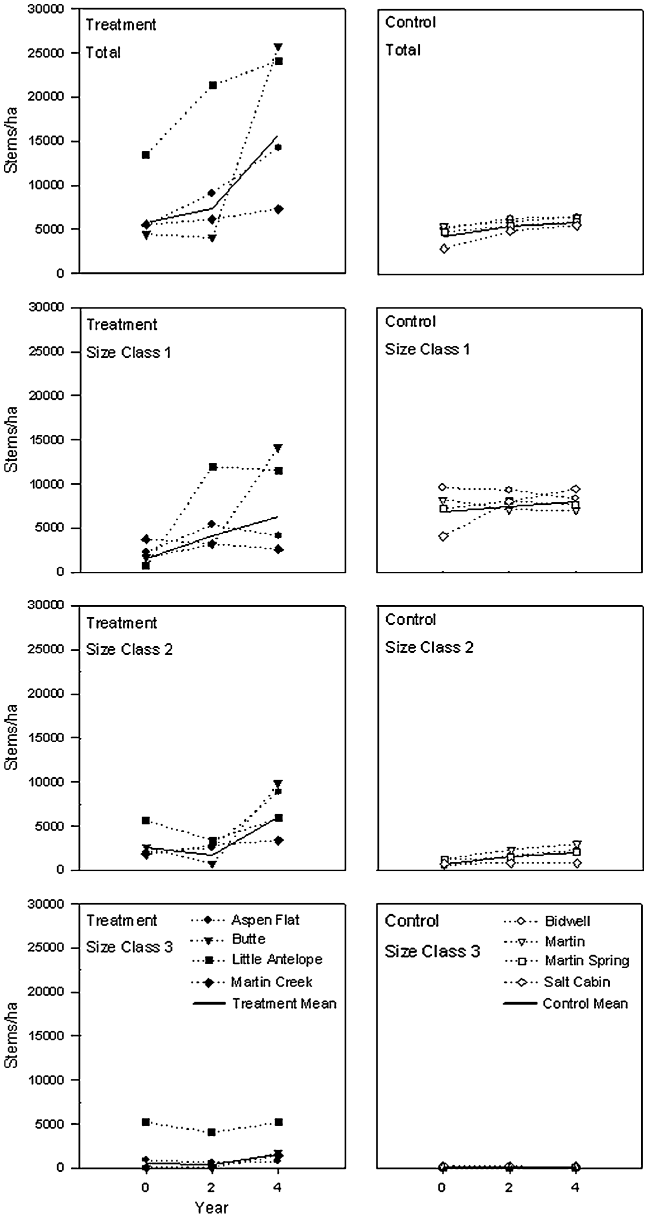

Figure 1. Mean aspen density (stems/ha) for control (no conifer removal) and treatment (conifers removed) transects for aspen stem size classes 1 (SC1), 2 (SC2), and 3 (SC3), and total aspen at treatment (Aspen Flat, Butte, Little Antelope, and Martin Creek) and control (Bidwell, Martin, Martin Spring, and Salt Cabin) aspen stands during the 4 years following treatment application.

## Discussion

These results illustrate the effectiveness of using conventional timber harvest and hand thinning of conifers in aspen stands as part of a restoration effort to stimulate regeneration of degraded aspen communities. We found that mechanical harvesting of conifers acted as a slight disturbance mechanism (hormonal stimulation) but predominantly created the proper growth environment (sunlight) required for aspen regeneration. We found that post-treatment aspen density is positively associated with pre-treatment aspen density, indicating that pre-treatment aspen density may be a useful selection tool for treatment application. Four years post-treatment an increase in aspen density compared to control stands was observed for all size classes. The 3- to 4-year delay in accumulation of stems in the larger size classes provides information on the rates of annual growth, which can be expected in the absence of significant grazing pressure. Percentage of average annual precipitation from 1 October to 20 September in years 0, 1, 2, 3, and 4 of this study was 51, 53, 40, 60, and 89%, respectively.

These results compare well to similar aspen enhancement projects designed to provide the proper growth environment for aspen (i.e., maximize sunlight). In Wyoming, Kilpatrick et al. (2003) found that successful aspen regeneration was induced by either conifer removal or fire, and that all treated sites had adequate sucker densities for clone establishment 3–9 years post-treatment. Shepperd (2001) removed competing conifers around two decadent aspen trees that were not sprouting, which stimulated root suckering and expanded the clone to 0.1 ha in size. Benedict (2001) had 346–1,031 stems/ha of aspen 4 years following conifer removal.

We observed a reduction in size classes 2 and 3, and thus total density, during the first 2 years following treatment. The delay in recruitment of size classes 2 and 3 in our study could be due to (1) physical damage caused by mechanical equipment during harvest and/or (2) lack of a strong and immediate hormonal stimulation to the aspen roots because parent aspen trees were not harvested, releasing their apical dominance. We do not have an appropriate study design to accept or reject either cause or the potential that there was a combined effect resulting in the delay in recruitment of size classes 2 and 3. Our current hypothesis is that this delay in regeneration can be attributed to the time it takes the clone to recover from the initial disturbance of conifer removal, regain vigor, stimulate sprouting from root buds, and allocate energy to growth. The immediate response of size class 1 to release from conifer dominance in three out of four treatment stands indicates that hormonal stimulation and sprouting occurred in these stands, supporting our hypothesis. We cannot test the possibility that the rate of size class 1 recruitment would have been greater with a combination treatment of conifer and mature aspen tree removal. The stands enrolled in this study were in extremely degraded condition with few mature aspen trees. In this scenario it is possible that (1) apical dominance had already been released by stressed mature trees triggering active size class 1 recruitment (our observation) and (2) removal of mature aspen trees would create a 1- to 3-year window of sufficient stand root carbohydrate reserves available for recruiting aspen suckers to survive on until full recruitment was attained.

Due to heavy within-stand fuel loads, conventional harvest practices were selected over the use of fire as

**Table 1.** Results of linear mixed effects analysis to determine the effect of conifer-removal treatment on square root–transformed annual total, and size class 1 (SC1), 2 (SC2), and 3 (SC3) aspen density (stems/ha) 4 years post–treatment application.

| | *Total* | | *SC1* | | *SC2* | | *SC3* | |
|---|---|---|---|---|---|---|---|---|
| *Model Term* | *Value*[a] | *p*[b] | *Value* | *p* | *Value* | *p* | *Value* | *p* |
| Intercept | 33.83 | <0.001 | 34.58 | <0.001 | 11.67 | 0.080 | −10.67 | 0.070 |
| Conifer treatment | | | | | | | | |
| Control | 0.00 | — | 0.00 | — | 0.00 | — | 0.00 | — |
| Removal | −3.35 | 0.733 | −28.38 | 0.011 | 18.36 | 0.037 | 15.06 | 0.031 |
| Year | | | | | | | | |
| 0 | 0.00 | — | 0.00 | — | 0.00 | — | 0.00 | — |
| 2 | 7.71 | 0.372 | 2.62 | 0.760 | 12.74 | 0.107 | 1.11 | 0.770 |
| 4 | 10.72 | 0.217 | 2.35 | 0.784 | 17.94 | 0.026 | 0.76 | 0.842 |
| Year 0 total aspen density | 0.01 | <0.001 | 0.005 | <0.001 | 0.003 | <0.001 | 0.003 | 0.002 |
| Treatment by year | | | | | | | | |
| Remove by year 0 | 0.00 | — | 0.00 | — | 0.00 | — | 0.00 | — |
| Remove by year 2 | 1.89 | 0.879 | 22.20 | 0.079 | −20.82 | 0.070 | −2.86 | 0.604 |
| Remove by year 4 | 38.36 | 0.004 | 37.77 | 0.004 | 9.86 | 0.383 | 16.75 | 0.004 |

[a] Value of the coefficient for each model term quantifies the effect of the model term (treatment, year, etc.) on the square root density of aspen.
[b] *p* value for each model term.

a mechanism to reduce conifer density and competition, allowing aspen regeneration. The root system of aspen is the source for vegetative reproduction. Therefore, it is important to minimize damage to the root system during the process of releasing the stand from conifer dominance. Perala (1991) found that returning fire as an agent to regenerate aspen stands with high fuel loads caused significant damage to stand root systems, reducing regeneration. The hand piles that were burned within the treated stands of this study killed aspen roots. During the study period no aspen regeneration was observed in the blackened areas of the piles. Additionally, adjacent overstory aspen trees were damaged from the radiant heat of the piles. This allowed Sooty bark canker (*Encoelia pruinosa*) to establish on the existing overstory aspen. When prescribed fire was implemented as a restoration effort on the North Fork John Day Ranger District, Umatilla National Forest, aspen trees were protected with heat-reflecting fire shields and debris was pulled back from their bases, which resulted in a positive suckering response (Shirley & Erickson 2001). Aspen stand vigor, soil, fuel loads, and fire severity must be taken into account before using prescribed fire for aspen restoration (Kilpatrick & Abendroth 2001).

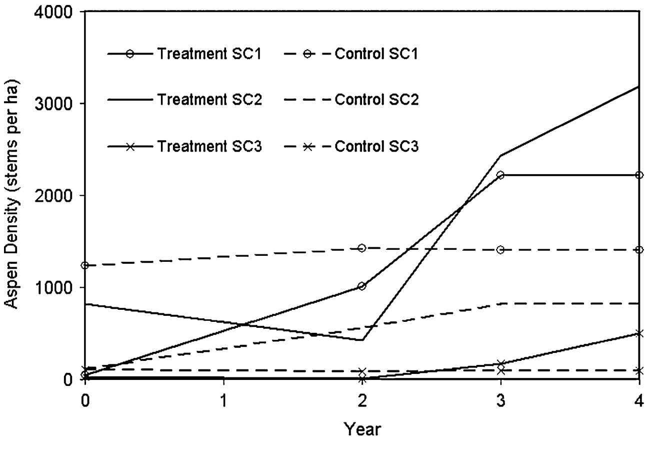

Figure 2. Product of linear mixed effects model predicting the effect of conifer removal on aspen density for size classes 1 (SC1), 2 (SC2), and 3 (SC3) for 4 years following treatment based upon analysis including all study sites.

Treatments to induce suckering need to be implemented with caution and should be used in conjunction with grazing pressure control in stands subject to heavy grazing (Campbell & Bartos 2001; Kilpatrick & Abendroth 2001; Shirley & Erickson 2001). Regenerating aspen stands are vulnerable to herbivory until suckering cohorts grow past the browse line of the herbivores present. The following browse line heights are recommended for the following herbivores: sheep (0.9 m), livestock and deer (1.4–1.5 m), and elk (1.8-m height and >2.5-cm dbh) (D. L. Bartos 2003, United States Forest Service Rocky Mountain Research Station, personal communication). Aspen stands that are subject to conifer removal and subsequent heavy grazing pressure will be doubly stressed and could potentially decline. The aspen response in this study indicates that suckers began to pass the browse line (1.4 m) for deer and livestock within 4 years post–conifer removal. Although fencing is the surest means of protecting aspen regeneration, alternative grazing management strategies that control the timing, intensity, and frequency of grazing should be explored as other options when fencing is prohibitive due to logistics, costs, aesthetic concerns, and other constraints. These grazing pressure control strategies require investigation and the development of a clear understanding of the relationships between specific grazing practices and aspen utilization by livestock.

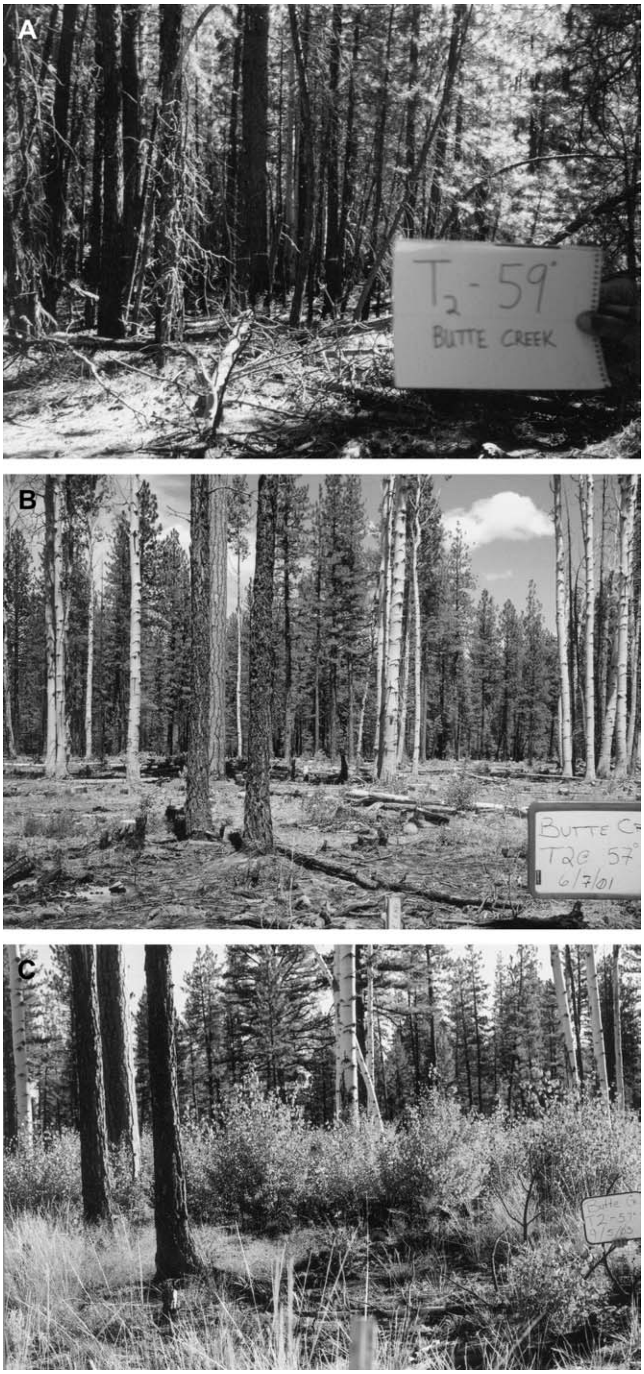

Figure 3. Photo point within a treated stand where conifers were removed showing the change in aspen density. A = year 0, pre–conifer removal; B = 2 years post–conifer removal; C = 4 years post–conifer removal.

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