Restoration of a Rocky Mountain Spruce-Fir Forest: Sixth-Year Engelmann Spruce Seedling Response With or Without Tree Shelter Removal

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Abstract: This paper presents results following 6 growing seasons of a project designed to examine the use of tree shelters as a means to provide initial shade for planted Engelmann spruce seedlings. Seedlings were planted in 1996 on a 48-ha (119-ac) high-elevation site with different colors of tree shelters providing various degrees of shading. A control treatment, consisting of shading using debris within the site, was also included. Results following 2 years were presented previously (Jacobs and Steinbeck 2001). To examine the response of seedlings to shelter removal following seedling establishment, 50% of shelters were removed in 2000 and all seedlings were re-measured in 2002. Shelter removal did not result in mortality, indicating that seedlings are able to grow in full sun after 4 years. Survival to 2002 of all shelter treatments (with or without shelter removal) was ≥ 88%, while survival of the control was 45%. For all 3 shelter colors, shelter removal resulted in less mean height growth but greater mean diameter growth. The lightest color tree shelter (with or without removal) produced the best overall response. Because shelters showed little sign of deterioration after 6 years, it was suggested that shelters could be removed at 4 years and reused at a different site. Tree shelters appear to provide a viable and cost-effective option to restore high-elevation spruce-fir sites where reforestation has proven difficult in the past.

Keywords: forest restoration, reforestation, tree planting, gopher browse, seedling shading, Colorado, *Picea engelmannii*

Introduction

The high-elevation forests of the central and southern Rocky Mountains are comprised primarily of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) (Figure 1) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). Little harvesting pressure occurred in this region prior to about 1950 due to the relative inaccessibility of these forests and an abundance of large-diameter ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) at lower elevations. As the supply of ponderosa pine dwindled, forest managers turned to the high-elevation forests to supply timber needs. Engelmann spruce proved to be a desirable timber species due to its lightweight, yet durable wood properties. Harvesting increased dramatically following a large-scale epidemic of the spruce bark beetle (*Dendroctonus rufipennis* Kirby), which killed over 14 million m^3 (494 million ft^3) of timber by 1951 (Markstrom and Alexander 1984). Harvesting, primarily to salvage infected trees, increased by nearly 1,000% from 1949 to 1956 (Markstrom and Alexander 1984).

Harvesting was generally accomplished using clearcutting, and openings greater than 50 ha (124 ac) were not unusual. Natural regeneration following harvesting in these forests was typically poor (Ronco and Noble 1971), with the exception of small (1 to 2 ha [2.5 to 5 ac]) cuttings on northern aspects, which contained exposed mineral soil (Alexander 1983, 1984). Subsequent research indicated that shade-tolerant Engelmann spruce seedlings require shading for optimal development, typically exhibiting chlorosis in the absence of shade (Ronco 1970a,b,c). Essentially, high light intensities act to damage the photosynthetic mechanism of unshaded seedlings and as a result, seedlings become chlorotic and often die.

Currently, most harvesting in the high-elevation spruce-fir forests of the Rocky Mountains is conducted with small group selection cuts (Figure 2). Cuts should be less than 100 to 160 m (330 to 525 ft) wide, and mineral soil should be exposed to stimulate germination (Noble and Ronco 1978). Due to the general absence of natural regeneration on large clearcut sites

Figure 1—Mature Engelmann spruce.

Figure 2—Small group selection harvest, typical of current logging systems in the high-elevation spruce-fir forests designed to provide adequate shade to promote regeneration.

Figure 3—Typical large clearcut established to remove beetle-infested timber that currently exhibits poor stocking despite previous planting attempts.

(Figure 3), however, extensive planting efforts were made following the publication of a guide to artificial reforestation of Engelmann spruce. In this guide, Ronco (1972) recommended that seedlings be planted to the northeast of protective shade cover (that is, stumps, logs, slash, or live vegetation). Regardless, survival on many sites has been poor and many sites are planted repeatedly in an attempt to reach the USDA Forest Service (USFS) stocking requirement of 375 live trees/ha (150 trees/ac). Mortality has been attributed to a number of factors, including drought (Hines and Long 1986); but clipping of tops by gophers (*Thomomys talpoides*) has been a consistent problem (Ronco 1967). Poor seedling establishment has prompted the USFS to abandon reforestation efforts on some sites. This has occasionally led to a change of land classification from forest to meadow.

This paper reports on sixth-year results of a project designed to examine the use of tree shelters as a means to improve Engelmann spruce seedling planting success. Tree shelters were designed in 1979 by Graham Tuley to provide browse protection for oak (*Quercus* spp.) seedlings (Potter 1988). However, added benefits were realized when sheltered seedlings survived and grew faster than unsheltered seedlings (Tuley 1983, 1985). This was later attributed to an apparent greenhouse effect, in which temperature and relative humidity are increased compared to ambient conditions (Kjelgren and others 1997). In the current study, it was hypothesized that shelters would provide adequate shading for seedling establishment, decrease incidence of gopher browsing, and increase seedling growth. These hypotheses were affirmed, and results following 2 growing seasons were reported previously in Jacobs and Steinbeck (2001).

This study was continued to monitor long-term seedling survival and growth response to establishment in tree shelters. Although it is well-documented that Engelmann spruce seedlings need shade initially, it is not definitively known at what point seedlings are able to grow in full sun. Seedling growth response and biomass allocation following removal versus presence of tree shelters after establishment is also unclear. Additionally, although the tree shelters were designed to photodegrade after 5 years, it is important to determine the actual timeframe and mechanism by which the shelters degrade. These were the objectives of the current report following 6 field-growing seasons.

Materials and Methods

Characteristics of the research site and methodology for study establishment were thoroughly described previously (Jacobs and Steinbeck 2001). In summary, seedlings were planted in fall of 1996 on a 48-ha (119-ac) site at approximately 3,273 m (10,738 ft) that was clearcut in 1971 to salvage beetle-infested timber. Following failed natural regeneration, the site was planted in 1976 and 1985 without reaching desired stocking. The entire unit was again planted in 1996, simultaneously with the establishment of this study. Treatments included 4 different tree shelter (Tree Pro®) colors (allowing different levels of photosynthetically active radiation [PAR] to reach the seedlings) and a control which involved the traditional method of shading seedlings with debris within the site. Seedlings were planted into 3 blocks, with 4 plots of each treatment randomly located within a block. Each plot contained 25 seedlings.

Treatment differences following the first 2 years were prominent. The darkest shelter color resulted in 95% mortality and was disregarded from growth analyses. The lightest 3 shelter colors resulted in >95% survival after 2 years, compared to 58% for the control treatment. The majority of mortality in the control was attributed to browse by gophers. Total seedling height, new leader growth, and total diameter were also greater for sheltered trees following 2 growing seasons. Shelters were recommended as an effective option for restoration of high-elevation spruce-fir sites in the Rocky Mountains.

In July of 2000, new treatments were installed. In each block, 2 of the 4 plots with sheltered trees were randomly selected for shelter removal. Shelters on seedlings in the remaining plots were not removed. In July of 2002, all seedlings were assessed for survival and remeasured for total height/root-collar diameter (Figure 4). Incidence of terminal bud death was also recorded to determine if seedlings were more likely to experience frost damage in shelters. Health status of seedlings was also recorded using the same methodology as that in the original report. Deterioration of shelters was also observed.

Data were analyzed using a one-way analysis of variance (ANOVA) with 7 treatments. The treatments included the 3 shelter colors with shelters remaining (listed as A, B, and C from lightest to darkest color), the 3 shelter colors with shelters removed, and the control. If the ANOVA indicated significant differences (P = 0.05 in F test) among treatments for a parameter, Fisher's Protected LSD procedure was used to determine significant differences among parameters. The sampling unit was an individual seedling and the experimental unit for analysis was the mean parameter value for seedlings within a treatment block.

Results

After 6 years, survival differed among treatments ($P <$ 0.0001) with the control having significantly lower survival (45%) than any other treatment (Figure 5). Survival did not

Figure 4—Measurement of sheltered seedling in 2002.

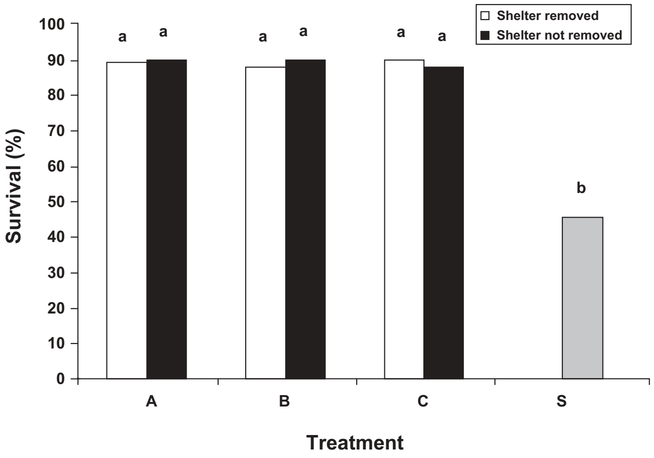

Figure 5—Seedling survival to 2002. Treatment letters A through C represent the shelter colors from lightest to darkest color, and treatment S is the control. Treatments with different letters above the bars are significantly different at α = 0.05.

differ among other treatments and these treatments all had survival = 88%. The majority of mortality at this point was attributable to physiological causes, with little mortality identified as being due to gopher browsing. Diameter growth ($P = 0.0004$) (Figure 6) and height growth ($P < 0.0001$) (Figure 7) over the 6 years differed among treatments, and interesting trends were apparent. Shelter treatments, regardless of shelter removal or not, continued to show generally better growth than the control. All treatments had significantly greater height growth than the control. The lightest shelter color (A) had more diameter growth than the control regardless of removal or not. Treatment B with shelter removed also had greater diameter growth than the control. Examining each shelter color individually, shelter removal always resulted in less mean height growth and more mean diameter growth. Differences were significant for shelter color B for diameter growth and shelter colors A and C for height growth.

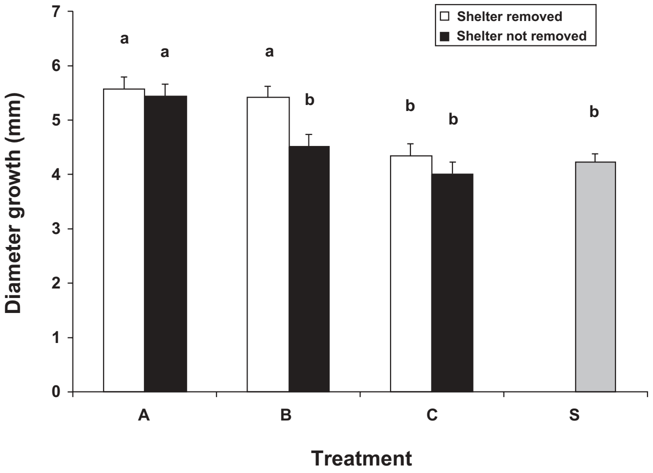

Figure 6—Diameter growth from 1996 to 2002. Treatment letters A through C represent the shelter colors from lightest to darkest color and treatment S is the control. Treatments with different letters above the bars are significantly different at $\alpha = 0.05$.

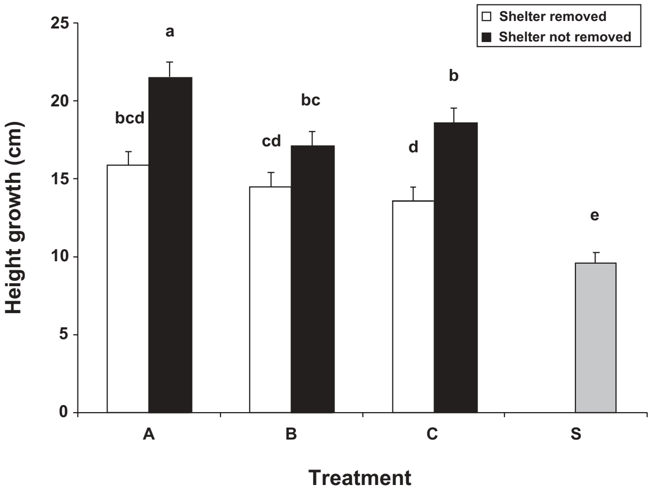

Figure 7—Height growth from 1996 to 2002. Treatment letters A through C represent the shelter colors from lightest to darkest color and treatment S is the control. Treatments with different letters above the bars are significantly different at $\alpha = 0.05$.

Most surviving seedlings appeared healthy and exhibited good form (Figures 8 and 9). The percentage of healthy (that is, <5% yellowing/browning foliage and absence of mechanical damage) seedlings was greatest for treatments in shelter color A, regardless of removal, and B with removal (Figure 10). Shelter color C with removal had the lowest percentage of healthy seedlings. There was no significant difference in the percentage of trees with evidence of terminal bud death ($P = 0.0755$). Mean values for the percentage of trees with evidence of terminal bud death ranged from a low of 34% (shelter color A without shelter removal) to 56% (shelter color B with shelter removal). Observationally, tree shelters were surprisingly intact at this point with less than 5% of the shelters showing any signs of photodegradation.

Discussion

Sixth-Year Seedling Response

Tree shelter treatments continued to demonstrate enhanced seedling survival rates over the control treatment,

Figure 8—Healthy control seedling in 2002.

Figure 9—Healthy seedling in the lightest shelter color treatment in 2002.

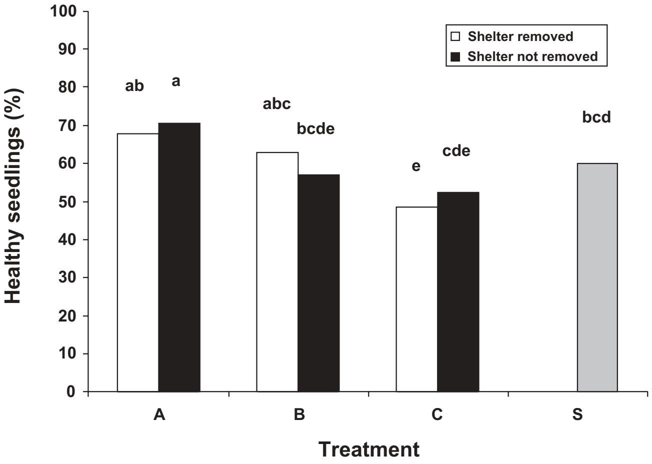

Figure 10—Percentage of healthy (that is, <5% yellowing/browning foliage and absence of mechanical damage) seedlings in 2002. Treatment letters A through C represent the shelter colors from lightest to darkest color and treatment S is the control. Treatments with different letters above the bars are significantly different at $\alpha = 0.05$.

and survival of seedlings following shelter removal was equally as good. All 6 treatments had survival = 88%. This is an exceptionally high survival rate following 6 years on this type of site and illustrates the benefit that tree shelters provided the seedlings during the establishment period. The 45% survival rate of seedlings in the control treatment is probably equal to or better than historic survival rates on these sites. These results affirm the positive influence of tree shelters on seedling survival reported by many other authors (for example, West and others 1999).

Shelter removal following 4 growing seasons did not result in differences in mortality as compared to sheltered seedlings. Though authors have speculated that seedlings should become adapted to high light levels after 1 or 2 growing seasons (for example, Feller 1998), I am aware of no quantitative information available to support this. This study showed that seedlings are adapted to survive in full sun after 4 years. The mechanism for this phenomenon is probably related to several factors. As needles age, the leaf cuticles thicken and become more resistant to damage from high light intensities. Additionally, more foliage is produced as the seedling grows, providing self-shading to the seedling.

Height growth of surviving seedlings was greater in all shelter removed or not removed treatments than the control. Diameter growth was greater in 3 of the 6 shelter removed or not removed treatments than the control. This again illustrates the benefit of tree shelters to seedling growth. Shelter removal promoted lesser height growth but increased diameter growth. This trend has been observed by other authors previously (Burger and others 1997; Gerhold 1999). Seedlings have limited reserves of energy to expend on the growth of various tissues. The reduction in available PAR light within the tree shelters promoted greater height growth to reach available light. This increase in energy devoted to height growth is accomplished at the expense of diameter growth.

Seedlings grown in shelter color A (with or without shelter removal) had the highest mean percentages of healthy seedlings, while shelter treatment C (with or without shelter removal) had the lowest. This may be associated with the degree of light reaching the seedlings. At this point in seedling development, the reduction of light in shelter C may have negatively affected health.

The treatments with the most ideal growth responses were probably treatments A (with and without shelter removal) and treatment B (with shelter removal). This is primarily based on differences in diameter growth, as diameter growth is well correlated with root system expansion. On these harsh, high-elevation sites, seedlings are adapted to grow an extensive root system to endure drought and recover from freeze damage of the shoot. It often takes 25 years for Engelmann spruce to reach 1.4 m (4.6 ft) in height (Alexander 1987). Thus, diameter growth is likely a more important morphological variable for assessment of seedling vigor than height. Given the shade tolerance of Engelmann spruce, it is possible that the lightest shelter color would also be the best choice for other more shade-intolerant conifer species.

Surprisingly, the tree shelters showed little indication of photodegradation and required minimal maintenance after 6 years. Evans (1996) reported that Tubex® shelters also did not deteriorate in the expected timeframe and recommended opening them to prevent growth restriction. In the present study, however, no restrictions to growth were observed, and it is possible that shelters will degrade before any type of growth restriction is evident.

Tree Shelter Cost Comparison

In 1996, cost of the Tree Pro® tree shelter and stake used in this study was US $0.95. Computing costs of labor and materials, planting at the current density would approximately double planting costs. However, the costs to the USFS to plant these sites using the traditional shading method is significant; in 1996, the estimated cost was US $1,075/ha (US $435/ac). This cost increases exponentially with each time a site must be replanted because of failed previous attempts. With survival rates >88% after 6 years (nearly double that of the control), it is likely that spacing could be reduced to alleviate the increase in planting costs. Additional benefit associated with improved growth rates would also be realized. On very harsh sites in the high elevation spruce-fir forests, the use of tree shelters (or a comparable method) may provide the only reasonable option for successfully restoring the site. Thus, on sites where reforestation has proven difficult in the past, tree shelters may be logistically appropriate and in some cases, modification of planting density may make their use economically competitive with traditional planting regimes.

Commitment to Restoration

The USFS and the public must consider to what extent the USFS should be held responsible for ensuring successful restoration of the large land area in the high-elevation spruce-fir forests that remains poorly stocked. In the case of the site used in the present study, an 800-km (500-mi) scenic trail (Colorado Trail) is positioned along the edge of the site. Though the San Juan Mountains section is often considered the most scenic portion of this trail, the presence of a poorly stocked 1971 clearcut is visually unattractive to many visitors. Visitors may develop a poor impression of the land stewardship character of the USFS. Though some people argue that a meadow is an adequate conversion of land use, return of harvested forests to forest land is preferable for many reasons.

Most modern-day foresters consider reforestation a necessity following timber harvest. In many areas of the country (for example, California, Oregon, Washington) reforestation in a timely manner is required by law. It is likely that over the course of 1,000 or 10,000 years, these high-elevation spruce-fir sites will begin to regenerate naturally. However, if reforestation prior to that timeframe is desired, steps must be taken by the USFS to ensure successful reforestation. Tree shelters offer a tested solution to promote establishment of Engelmann spruce seedlings.

If tree shelters are used on a large-scale, it would be advisable to develop a shelter that could reliably be installed at one site for a certain period of time (possibly 4 years, as exhibited in this study) and then removed for use at another site. This would lessen the potential environmental impact associated with discarded plastic shelters. The costs saved from eliminating the need to repurchase shelters should help to defray labor costs associated with shelter removal.

Summary

Tree shelters continued to show promise as a more effective alternative to the traditional shading method for restoration of high-elevation spruce-fir sites in the Rocky Mountains. It appears that Engelmann spruce seedlings are able to survive and grow well in full sun following 4 growing seasons, which provides the option of removing shelters at this point for use at a different site. Shelter removal generally resulted in increased diameter versus height growth, which may be a more desirable shift in growth resources to promote reforestation on harsh high-elevation sites. Because shelters deteriorated relatively little in 6 years, it is likely that they may be used at least twice, and costs (both financial and environmental) may be conserved by reusing shelters as opposed to leaving shelters to degrade on the site. In deciding on a shelter color for Engelmann spruce restoration, forest managers should understand the influence that shelter color has on growth response. A relatively light shelter color is probably ideal and darker colors should be avoided. This study will continue to be monitored to at least 10 years, and a followup report presented.

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