

# Impact of Silvicultural Treatment on Chestnut Seedling Growth and Survival

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## Abstract

**Putatively blight-resistant advanced backcross chestnut seedlings will soon be available for outplanting on a regional scale. Few studies have examined the importance of silvicultural treatment or seedling quality to chestnut reintroduction in the U.S. This paper examines results from a silvicultural study of high-quality chestnut seedlings on the Cumberland Plateau of southeastern Kentucky. Three hundred American (*Castanea dentata*), three hundred advanced backcross (BC<sub>2</sub>F<sub>3</sub>) and one hundred fifty Chinese chestnut (*Castanea mollissima*) seedlings were planted in three silvicultural treatments, ranging from low-light to high-light, on the Daniel Boone National Forest in Mar 2009. Seedlings were planted in a completely randomized design with a split-plot treatment arrangement, with silvicultural treatments as whole plots, and species in a randomized block design in the sub-plot. After three years, chestnut seedlings in the high-light treatment sites grew significantly more in height and root collar diameter, on average, compared to seedlings in the moderate- and low-light treatments. Survival did not differ among silvicultural treatments and averaged 64% over all sites. Low survival was due in part to the non-native root-rot disease organism, *Phytophthora cinnamomi*, which was confirmed at the site. This study suggests that while chestnut grows best in high-light environments, the species can become established under varying light-levels, which will give forest managers flexibility when choosing management strategies for chestnut reintroduction.**

## INTRODUCTION

American chestnut (*Castanea dentata*), once a dominant timber tree throughout eastern North America, has been nearly eradicated by the chestnut blight fungus, *Cryphonectria parasitica*, and ink disease, *Phytophthora cinnamomi*, both non-native pathogens accidentally introduced from Asia (Anagnostakis, 2006; Crandall et al., 1945). The American Chestnut Foundation (TACF) and The Connecticut Agricultural Experiment Station each utilize the backcross breeding program (Burnham, 1988), incorporating resistance from Chinese or Japanese chestnuts in efforts to develop blight-resistant American-hybrid chestnut trees.

In anticipation of widespread planting of blight-resistant backcross chestnuts, an understanding of the silvics and competitive ability of the species for successful reintroduction to eastern North American forests is critical. Forestry publications written

while American chestnut was still canopy dominant describe the species' rapid growth and prolific sprouting (Ashe, 1911; Mattoon, 1909; Zon, 1904); however, they lack in-depth analysis of chestnut silvics. Although American chestnut has been planted for many years (Hough, 1882) there have been few experimental studies on chestnut silviculture and artificial regeneration of the species (Anagnostakis, 2007; Clark et al., 2011; Jacobs and Severeid, 2004; M<sup>c</sup>Cament and M<sup>c</sup>Carthy, 2005; M<sup>c</sup>Nab, 2003; Rhoades et al., 2009). At the time this study was established, no other studies had examined silvicultural impact on backcross-chestnut establishment. Understanding which silvicultural techniques appropriately manipulate light levels for backcross hybrid chestnut establishment and growth is necessary to guide reintroduction efforts. The overall goal of this study was to evaluate three-year field performance of American, Chinese and BC<sub>2</sub>F<sub>3</sub> chestnut under three silvicultural treatments. Specifically, we aimed to evaluate the effects of silvicultural and species treatments on chestnut survival and growth.

## **MATERIALS AND METHODS**

### **Study Site**

This study was located on the London Ranger District of the Daniel Boone National Forest (DBNF) on the Cumberland Plateau in Southeastern Kentucky. The forest type, classified as upland hardwood, is dominated by mixed oak species (Schweitzer et al., 2008). Braun (1950) described this area of Kentucky as part of the mixed-mesophytic forest region, abundant with beech (*Fagus grandifolia*), white oak (*Quercus alba*) black oak (*Quercus velutina*) and hickory (*Carya* spp.). Other common hardwoods included chestnut oak (*Quercus prinus*), particularly on ridges, maple (*Acer* spp.) and black gum (*Nyssa sylvetica*). Before chestnut blight, American chestnut was a dominant timber tree on the Cumberland Plateau, particularly at higher elevations (Braun, 1950).

### **Silvicultural Treatments**

This study was nested within a larger USDA Forest Service study, referred to as the Cold Hill Study, which was established with the goal of improving oak regeneration and forest health prior to the anticipated arrival of gypsy moth (*Lymantria dispar*) to the area (Schweitzer et al., 2008). Our study utilized three of the five silvicultural treatments implemented in the Cold Hill study: oak shelterwood (OS), thinning (TH), and shelterwood with reserves (SW). For the OS treatment sites, all stems greater than 3 cm diameter at breast height in the midstory were killed using triclopyr herbicide injection (Loftis, 1990), leaving a basal area of 22 m<sup>2</sup>/ha of intact overstory (Schweitzer et al., 2008). This treatment increased light on the forest floor to favor oak regeneration while retaining enough overstory to inhibit shade intolerant species, such as yellow poplar (*Liriodendron tulipifera*). The overstory will be removed four-to-five years following midstory removal. The TH treatment thinned stands to the B-level of Gingrich stocking (Gingrich, 1967), with a basal area of 18 m<sup>2</sup>/ha of overstory (Schweitzer et al., 2008). While thinning is not a standard regeneration treatment, this may provide adequate light for seedling establishment or recruitment of species that are moderate in shade tolerance (*Quercus* spp.), while discouraging shade intolerant species. The SW treatment was a commercial tree harvest that left a residual basal area of 5 m<sup>2</sup>/ha of overstory. The overstory trees that promoted "good forest health conditions" and wildlife habitat were left uncut (Schweitzer et al., 2008). All harvest treatments were completed between Aug. 2007 and Feb. 2009.

### **Experimental Materials**

American (*C. dentata*), BC<sub>2</sub>F<sub>3</sub> generation (Hebard, 2001) and Chinese chestnut (*C. mollissima*) seedlings were used in this study. The open-pollinated American and advanced backcross chestnuts were harvested at The American Chestnut Foundation's Meadowview Research Farms, Meadowview, VA in the fall of 2007 and manually sown at the Georgia Forestry Commission's Flint River Nursery in Byromville, GA in Jan.

2008 at a density of sixty-five nuts per square meter. Fertilization and irrigation of the seedlings followed guidelines developed by Kormanik et al. (1994). The 1-0 seedlings were lifted in Feb. 2009, and stored in a cold room (~1°C) until they were planted. The bare-root 1-0 Chinese chestnut seedlings were purchased from Forrest Keeling Nursery (Elsberry, MO) in Feb. 2009. Seedlings were processed in Feb with roots trimmed to 15 cm from the main tap root to facilitate planting.

### Measurements

Bare-root seedling height and root collar diameter (RCD) were measured in Feb. 2009 prior to planting. Survival, height and root collar diameter of each seedling were measured at the end of the third growing season.

Canopy cover has been found to be strongly correlated with light transmittance (Buckley et al., 1999; Jenkins and Chamber, 1989; Lhotka and Lowenstein, 2006). In order to evaluate light conditions in each of the silvicultural treatments, a convex spherical densitometer (Lemon, 1956) was used to estimate canopy cover on ten randomly selected silvicultural treatment sites, representing three-to-four replications of each treatment type. Readings were taken on the south side of each chestnut seedling in each of the four directions (Buckley et al., 1999; Lhotka and Lowenstein, 2006) during the second growing season and averaged to compare canopy cover among silvicultural treatments.

### Experimental Design

Silvicultural treatments in this study were arranged in a completely randomized design. Within these silvicultural treatments, the chestnut plots were arranged in a randomized block design. Thus, the experimental design incorporates a split plot, with silvicultural treatment in the main plot and species in the subplot.

Three hundred American, three hundred BC<sub>2</sub>F<sub>3</sub> and one hundred fifty Chinese chestnut seedlings were planted on the experimental sites between 2-9 Mar 2009. Each of the three silvicultural treatments was replicated at three-to-five sites, with the seedlings evenly distributed among the three treatment types. Seedlings were planted in one linear transect at a spacing of 2.5 m on each site. The transect was divided into blocks of five seedlings, each block containing two American, two BC<sub>2</sub>F<sub>3</sub> and one Chinese chestnut seedling.

### Statistical Analysis

All analyses for this study were processed using SAS 9.2 software (SAS Institute, 2008). Seedling response was analyzed using mixed model analysis of variance (ANOVA) to determine significant effects of silvicultural and species treatments and their interaction on height and RCD growth. The rank transformation for height growth and log transformation for RCD growth were used to correct unequal variances. Requirements for normality and equality of variance for survival and canopy cover were satisfied. Initial height was used as a covariate for height growth analysis ( $P < 0.0001$ ). PROC GLIMMIX with binomial distribution was used to test seedling survival.

## RESULTS AND DISCUSSION

### Survival

Sixty-four percent of seedlings survived the first three growing seasons. The relatively low survival can be attributed in part to the presence of *Phytophthora cinnamomi*, the causal agent of ink disease (S. Jeffers and I. Meadows, pers. commun.), an exotic soil-borne oomycete that attacks and kills the root systems of American chestnut (Anagnostakis, 2006). The reduced survival of American chestnut (34±3%,  $p < 0.0001$ ) and BC<sub>2</sub>F<sub>3</sub> (46±3%,  $P < 0.0001$ ) compared to Chinese chestnut (93±3%), which is moderately to highly resistant to *P. cinnamomi*, provides further support that ink disease likely caused high mortality among American and BC<sub>2</sub>F<sub>3</sub> chestnut in the study. Survival

did not differ among silvicultural treatments ( $p=0.8863$ ) and no treatment interactions were significant.

### **Growth**

Height growth did not differ among species ( $P=0.6226$ ), while diameter growth was greater in Chinese chestnuts than either American or backcross seedlings ( $P=0.0009$ , Fig. 1). Clark et al. (2012) found that Chinese chestnut seedlings grew less in height and diameter in the first year after planting than did American and  $BC_3F_3$  seedlings. Reduced diameter growth of American and advanced backcross chestnuts in our study may be attributable to infection by *P. cinnamomi*, which presumably weakened susceptible seedlings, thereby decreasing resources available for growth.

Overall, chestnut seedlings growing in the SW treatments added the most height ( $P=0.0011$ ) and diameter growth ( $P=0.0004$ ) (Fig. 2). Canopy cover two years after planting was statistically greater in OS ( $97\pm 6\%$ ), compared to TH ( $91\pm 6\%$ ) and least in SW sites ( $65\pm 6\%$ ;  $P<0.0001$ ), indicating more light was available in the SW sites than TH or OS treatments. Species by silvicultural treatment interaction was not significant ( $P=0.5011$ ). Chestnut growth has been found to correlate strongly with light (Boring, 1981; Griffin, 1989; Latham, 1992; M<sup>c</sup>Cament and M<sup>c</sup>Carthy, 2005; Paillet, 1984; Rhoades et al., 2009). Our results agree with these studies. Available light in the SW sites, however, will presumably decline as the competing sprouts continue to grow. Although American chestnut has been found to grow as fast as or faster than many hardwood competitors (Ashe, 1911; Frothingham, 1924; Hawes and Hawley, 1912; Jacobs and Severeid, 2004; Latham, 1992; Mattoon, 1909), it is not known if planted chestnut seedlings can successfully compete with hardwood stump sprouts. McNab (2003) found that planted chestnut seedlings were outgrown by competing hardwood sprouts in clearcuts. Initial seedling height in that study, however, averaged 18 cm while seedlings in the present study averaged 96 cm at planting. The large size of these seedlings will likely enable them to compete with fast-growing sprouts, as has been found with high quality northern red oak seedlings (Teclaw and Isebrands, 1993).

Chestnut seedlings growing in the OS treatment sites added the least growth, on average, three years after planting. American chestnut can survive in the forest understory for long periods of time and then quickly respond when light becomes available (Paillet, 2002). Within several years the overstory of OS replicates will be removed, greatly increasing the amount of light available to the chestnut seedlings. While release in the OS treatment will likely result in the regeneration of many hardwood sprouts, the chestnuts in this treatment have had several years to establish, compared to those in the SW sites that were planted among stump sprouts. Based on chestnut's ability to rapidly respond to increases in light, the planted chestnuts should successfully compete with other seedlings and stump sprouts and become dominant stems in the successive stand.

The TH sites created intermediate canopy cover conditions. The moderate TH harvest may have made enough light available to favor stump sprouts, with large established root systems, but not enough light to optimize transplanted chestnut seedling growth. Without a future release, the chestnut seedlings in the TH treatment may not successfully compete with fast-growing sprouts, particularly those of red maple and yellow poplar. In the event of a future release, the established chestnut seedlings will likely respond vigorously to increased light availability and become dominant stems in the successive canopy.

### **MANAGEMENT IMPLICATIONS**

Clearly ink disease is a serious threat to chestnut reintroduction in the southern part of American chestnut's range, where *P. cinnamomi* can survive. Ink disease occurs frequently in tree nurseries, and it is therefore likely that the pathogen was introduced to the study site on the roots of the nursery-grown chestnut seedlings. Future chestnut reintroduction sites should be tested for the presence of ink disease before planting and if found should be abandoned for sites without the pathogen. Tree nurseries with a history

of ink disease should be avoided. Managers should consider planting chestnut seed or containerized seedlings rather than bare-root seedlings. Additional studies to compare the survival and growth of chestnut seed, bare-root seedlings, and containerize seedlings, are needed.

American chestnut is relatively flexible in regard to its light requirements. While it grows very fast in high-light, it is too early to tell if advanced backcross chestnut can successfully compete with fast-growing shade-intolerant species in high-light treatments. Its success will likely vary, depending on site and competing species. Due to its former abundance on infertile xeric ridge tops (Frothingham, 1924), chestnut will presumably compete well after high-light silvicultural treatments on poor sites. On high-quality sites, managers may need to treat stump sprouts and fast-growing shade-intolerant species after a high-intensity harvest. Lower-light treatments with future overstory removal planned, may also offer a suitable treatment scenario, particularly on competitive sites that favor fast-growing shade-intolerant species.

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**Figures**

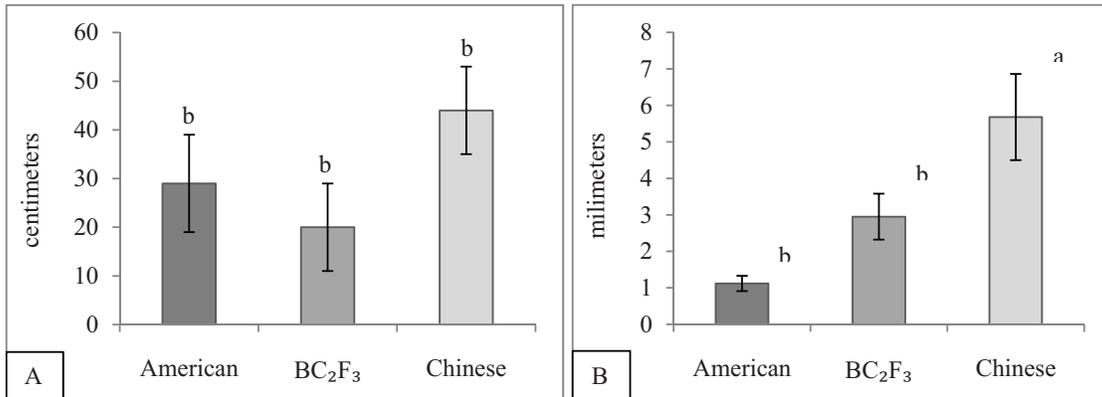


Fig. 1. A) Height growth, and B) Root collar diameter growth among species. Error bars indicate standard error. Treatment bars with the same letter are not significantly different ( $\alpha=0.05$ ).

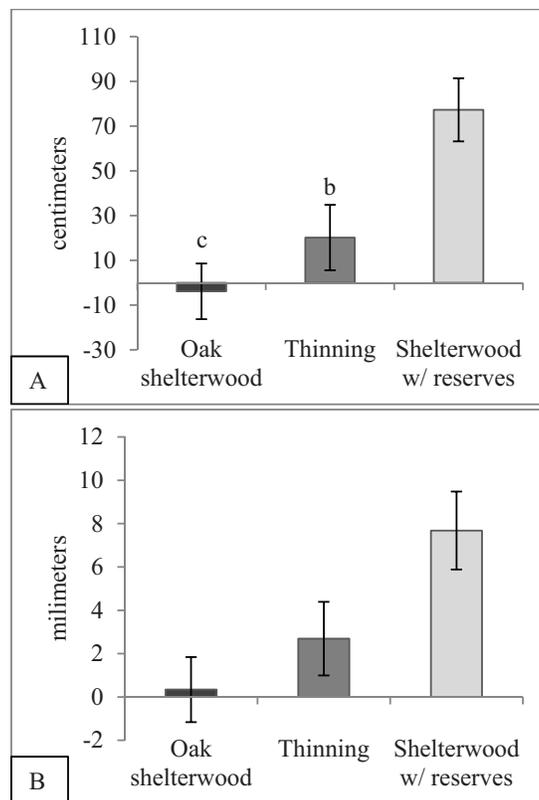


Fig. 2. A) Height growth, and B) root collar diameter growth among silvicultural treatments. Error bars indicate standard error. Treatment bars with the same letter are not significantly different ( $\alpha=0.05$ ).

