RESPONSE OF IMPROVED AMERICAN CHESTNUTS TO PLANTING PRACTICES ON RECLAIMED SURFACE MINED LAND[11]

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Abstract. Hybrids of chestnut that are botanically indistinguishable from American chestnut (*Castanea dentata*) and have the blight-resistance of Chinese chestnut (*Castanea mollissima*) are being developed by the American Chestnut Foundation. Reclamation of mined land in the Appalachians can aid the introduction of these hybrids because of the coincidence of the Appalachian coalfield with the central range of the American chestnut and because of the large areas of land opened up by mining that are available for afforestation. There are questions about whether mined lands can be a suitable habitat for the American chestnut, how the survival of various backcross generations from the breeding program will compare in the field, and the best planting practices to aid establishment. Two experiments were begun to test the performance of several breeding generations of chestnut on reclaimed surface mined land, chestnut compatibility with three ground cover types, and the effect of establishment method. Six breeding generations of chestnuts were direct seeded in 2008 within three different groundcover seeding mixtures: a conventional mine-reclamation mix of tree-competitive legumes and grasses, a tree-compatible mix of less-competitive legumes and grasses, and annual ryegrass only. The 2008 experiment was replicated on three different sites. These trees were planted as nuts in a mix of potting soil, native forest soil and mine soil, and within a tree tube shelter. After two years of growth, the annual ryegrass treatment allowed greater survival (71%) than the conventional tree-competitive seeding mix (50%). In 2009, five breeding generations were planted on four sites, with half planted as unprotected, bare-root seedlings and the other half direct seeded with shelters. After one season, survival of the bare-root seedlings (83%) was higher than that of the direct seeded trees (76%) and the first-year total height of the bare-root seedlings (470 mm) was also greater than that of the planted nuts (347 mm). Survival and growth varied among the various hybrid breeding generations, but none demonstrated consistently superior performance. Labor, time per tree for planting, and supply costs were much greater for the direct-seeded trees than for those planted as bare-root seedlings. Overall, early chestnut survival on a variety of reclaimed mined land is comparable to that of other Appalachian hardwood species. These results suggest that if blight resistance can be effectively conveyed through breeding, reclaimed mined land has potential for use in restoration of the American chestnut as a component of re-established multi-species forests across central Appalachia.

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Introduction

Background and Rationale

Successful reclamation and afforestation of land surface mined for coal in Appalachia using the Forestry Reclamation Approach (FRA) (Burger et al., 2005) presents the opportunity to also restore American chestnut (*Castanea dentata*), genetically improved to convey blight-resistance, to its native range. Chestnut was an important component of the pre-1950s mixed mesophytic forest (MMF), the restoration of which on mined lands will require chestnut's success in tandem with that of many other native species. The MMF, the Appalachian coal basin, and the core of the American chestnut's former range are all coincident spatially (Figure 1). The MMF type is the oldest and most diverse of the Eastern deciduous forests (Braun 1950) and is being significantly impacted by ongoing surface mining (Wickham et al., 2007; Saylor, 2008).

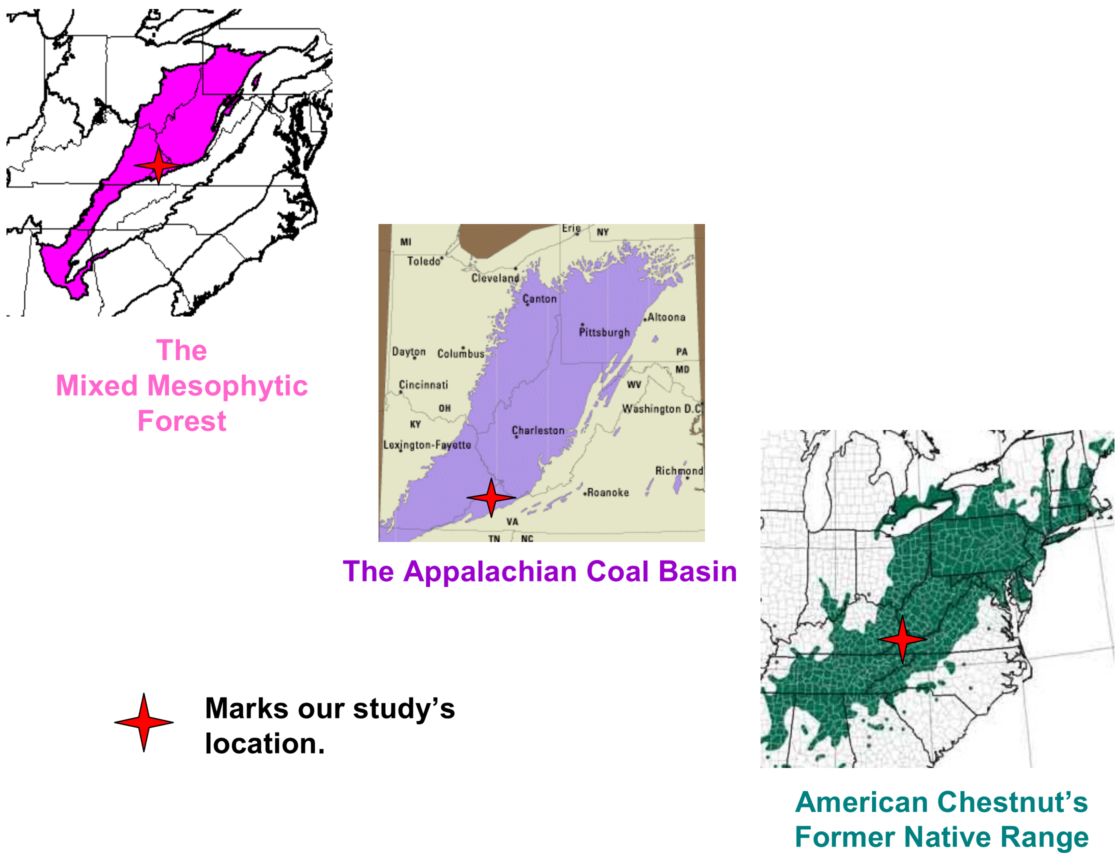
American chestnut was a foundation species of the MMF and also of the Appalachian subsistence culture. The chestnut blight (*Cryphonectria parasitica*) has effectively eliminated chestnut from functioning as it once did in this ecosystem. With efforts to breed a blight-resistant chestnut that is also botanically indistinguishable from American chestnut making progress, it is foreseeable that those efforts' eventual success may provide opportunity to restore the chestnut to the MMF in both form and function. Over 0.6 million hectares of land in the Appalachians has been surface mined for coal (data from United States Office of Surface Mining). These lands, formerly occupied predominantly by MMF, are frequently capped only with barren rock overburden selected for use as a topsoil substitute, without any topsoil, which is used as a starting substrate for revegetation. There is hope that scientific advances and successful implementation of the FRA, which is a five-step process for reforesting mined lands (Burger et al., 2005), within the MMF's range can combine with the successful chestnut breeding programs to achieve the reintroduction of the chestnut on vast expanses of land throughout much of its former range. The mined lands provide an opportunity for chestnut restoration within areas that have little competing forest vegetation which would make full-scale chestnut reintroduction more problematic.

Chestnut Breeding

The American Chestnut Foundation has been breeding American chestnut *(Castanea dentata)* with Chinese chestnut *(Castanea mollisima)* and then using a backcross breeding technique since the early 1980's in order to achieve a blight-resistant hybrid with the form and ecological functions of American chestnut (Hebard, 2001; Diskin et al., 2006; Jacobs, 2007).

The third generation of the third backcross generation (BC3F3) has the botanical characteristics to be classified as American chestnut and is putatively resistant to the blight, but the resemblance of its structural morphology to that of the American chestnut in the long-term has yet to be tested. BC3F3 nuts were first attained in 2005 and will likely be available in larger quantities for reintroduction efforts within one decade (Diskin et al., 2006; Jacobs, 2007).

Figure 1. Study site location, relative to area occupied by mixed mesophytic forest[1], the Appalachian coal basin[2] and the former native range of the American chestnut[3].



1-http://en.wikipedia.org/wiki/File:Appalachia-mixed-mesophytic-forest-map.gif
2-http://www.virgniaplaces.org/graphics/appcoal.gif
3-http://www.patcf.org/images/rangemap2006sff.jpg

American Chestnut as a Foundation Species

Foundation species create and define ecological communities and ecosystems through their structure and function. A small number of strong interactions shape community and ecosystem dynamics in systems dominated by foundation species such as the forests once dominated by American chestnut (Ellison et al., 2005). The loss of foundation species such as the American chestnut has dramatic effects on landscape perceptions as well as on the functioning and stability of ecosystems and all associated biota. The widely ranging environments dominated by American chestnut resulted in alterations to terrestrial and aquatic systems upon its decline. The chestnut is now functionally extinct since its current shrubby form, mostly stump sprouts from trees that succumbed to the blight, produces relatively little leaf area and woody biomass and few nuts. Without this tree fulfilling its historical role, the long term health of the MMF may be compromised (Ellison et al., 2005).

The concept of forest health invokes the concept of ecological integrity as well as the expectation of the presence of all forest relationships and components in a way in which they are fully functional and self-renewing (Oak, 2005). One of the biggest factors in the creation of the present Appalachian forest condition is the chestnut blight. Prior to and during the time of the outbreak of the blight there were heavy forest disturbances from harvesting activity and fire. Following the blight the chestnut trees were eliminated and harvesting-related disturbances began to cease due to changes in policy and management. The net result was the replacement of a chestnut with shade intolerant species, such as oak and hickory. Forest density was also likely changed to a higher-density of canopy trees with dense under-stories (Oak, 2005).

The gypsy moth, to which American chestnut is resistant, favors oaks as a food source and has thus disproportionately defoliated current forest landscapes in comparison to what would have happened pre-blight (Oak, 2005). Therefore the severity of the extensive damage caused by the gypsy moth may be a secondary effect of the chestnut blight. The large decrease in hard mast production with the loss of the chestnut is furthered by oak decline with a subsequent drop in acorn production. This loss of hard mast production has had unknown, but probably significant effects on wildlife and human communities that depended on this food source for sustenance (Oak, 2005). This example highlights how the consequences of the loss of a single foundation species, such as American chestnut, cascade into a series of disruptive consequences for the entire ecosystem. It also demonstrates the need for science-based strategies that lead to the reintroduction of chestnut. We believe that this research will help establish a niche for the American chestnut on lands drastically altered by surface mining that lie within the former range of American chestnut and on lands formerly part of the MMF ecosystem. It can also lead to greater mined land reforestation success.

Silvics, Ecology and Management of American Chestnut

Knowledge of the silvicultural and ecological characteristics of American chestnut is limited because it lost its former ecological role before the advent of modern forest ecology principles (Jacobs, 2007). American chestnut is known to have excellent growth and competitive abilities and can survive in forest understories for prolonged periods before quickly taking advantage of canopy disturbances.. This is characteristic of species that are considered shade tolerant to intermediate in shade tolerance (Jacobs, 2007).

Fast growth and competitiveness of chestnut makes reintroduction in mixed stands with other hardwoods a viable option; however, there is a limited area of sites available for reforestation following logging in the chestnut's range for two reasons: There are policy concerns on public lands regarding the hybrid genetics of improved chestnut, and there are economic concerns on private lands regarding the uncertainty of success at growing chestnut of commercial size (Jacobs, 2007). Afforestation plantings, on surface mines or abandoned agricultural lands may avoid the issues of policy on public land and opportunity costs of private land. Since the American chestnut's original range is all-inclusive of the Appalachian Coal Basin, afforestation of these sites with chestnut following reclamation is a logical means of helping the species recover (Jacobs, 2007).

Most mine soils are derived from rock overburdens that are used as topsoil substitutes. Based on previous research on the influence of chestnut on soils, it appears the species has a disproportionately positive effect on soil quality compared to other native species. In a study of American chestnut trees growing in Wisconsin, outside of the original range of the chestnut and the blight, Rhoades (2007) reported that chestnut stands produced 10-17% higher soil carbon, nitrogen, inorganic nitrogen, net mineralization and nitrification rates than mixed hardwood stands on sandy-loam soils. Total soil carbon, nitrogen and extractable nitrogen were higher under chestnut trees than under mixed hardwoods and soil moisture was somewhat greater. One potential explanation is that the differences caused by chestnut are more apparent on sandy soils whereas they are more buffered and masked on finer-textured soils that have a higher cation exchange capacity, higher amounts of organic matter and higher general nutrient status (Rhoades 2007). American chestnut may have these beneficial effects on sandstone-derived mine soils. Techniques for establishing American chestnut have been explored by past researchers. Phelps et al. (2005) tested the success and effects of different methods of planting American chestnut trees in cleared forest sites. They found that when deer browse activity was absent, tree tube shelters gave trees no advantage in height growth. When there was frequent deer browse activity, tree tube shelters were necessary for establishment. Seedlings were able to successfully compete with other species when the other competing species were cut to ground level mechanically at the time of chestnut planting. Direct seeding was found to be the most cost effective and efficient planting method, but planting of seedlings was found to ensure greater survival, better control over tree placement and enhanced ability to compete with other vegetation. Direct seeded trees did not compete adequately with re-sprouting vegetation that had been cleared (Phelps et al. 2005). On mined land, deer browse and other types of predation would be a concern (Fields-Johnson et al., 2009), but competition from re-sprouting woody plant species commonly found on sites disturbed by logging or fire would be absent on newly reclaimed sites where all vegetation and soil were removed in the process of mining. There are different concerns on mined versus logged land. Experimentation with direct seeding with or without shelters versus planting of seedlings is needed on mined land. Competition from herbaceous species would be a function of the herbaceous species and seeding rate used for mined land erosion control. Experimentation with different seeding prescriptions of herbaceous ground covers with planted chestnut is needed.

Additional Challenges to Chestnut Restoration

Chestnut restoration efforts were begun as early as 1920 by the US Department of Agriculture but failed and were abandoned by the 1960's. The slow process of the dissemination of hypovirus to infected trees has prevented successful treatment of populations of chestnut with hypovirulent strains of the fungus. Other threats to American chestnut that must be overcome include *Phytophthora* root rot (*Phytophthora cinnamomi*), the oriental gall wasp (*Dryocosmus kuriphilus*), and ambrosia beetles (*Xylosandrus crassiulus and Xylosandrus saxeseni*). A limited number of genotypes of American chestnut have provided the basis for the hybrid breeding program and as wild sprouts lose their vigor and die out there is less genetic stock for future breeding. This may undermine restoration due to a lack of adaptation to local environments or to the adaptation of the blight (*Cryphonectria parasitica*) to overcome bred-in resistance genes (Jacobs, 2007).

American chestnut is highly susceptible to *Phytophthora* root rot even when soil compaction and soil moisture are at moderate levels. *Phytophthora* has been isolated from recently reclaimed mine sites with cappings of loose mine spoil (Ward, 2009), indicating that it can be present on mined lands into which chestnut is planted. It will be important to avoid wet and compacted sites that promote *Phytophthora* root rot when planting chestnut trees. Root damage which pre-disposes trees to *Phytophthora,* and transmission of the disease itself to new locations, are both associated with transplanting bare-root seedlings (Rhoades, 2003).

<u>Key Aspects of Reclaimed Mined Land Plantings</u>

Three key aspects of planting chestnuts on mined land are: finding the best hybrid generation of chestnuts to plant, developing the best method of planting the chestnuts themselves, and establishing site conditions through reclamation, including herbaceous groundcover, that are compatible with chestnut establishment. The American Chestnut Foundation (ACF) has been breeding improved hybrid chestnuts from crosses of American chestnut (A) and Chinese chestnut (C). The ACF back-crossed the hybrids with American chestnut three successive times to create three backcrosses with successively higher percentages of American chestnut genes. The first generation of each of the backcrosses was then bred to create an F1, F2 and F3 generation for each backcross (B1, B2 and B3). At the time of this experiment, the F3 generation was available to us for B1 and B2, but the F2 generation was the latest available for B3. Thus three backcross generations (B1F3, B2F3 and B3F2) and two non-hybridized controls for comparison (A and C) were available for our field trials on mined sites. These represent a continuum between American and Chinese chestnut that may produce measurable differences in survival and growth on mined lands.

The pure Americans would be expected to succumb to the chestnut blight and never achieve canopy dominance, though they may repeatedly re-sprout. The pure Chinese would be expected to have a low, spreading growth habit that would also keep them from achieving canopy dominance. Only the hybrids could be expected to have the combination of blight resistance and upright, tall form that would allow them to rise to canopy dominance amidst other native Appalachian hardwoods. This research addresses the initial establishment of these breeding generations. Evaluation of the ultimate success of any of these generations in the mature forest canopy must take place in the long-term

Two potential methods for planting chestnuts are to use young bare-root seedlings or to plant nuts themselves with protective shelters to prevent their consumption by rodents. The bare-root seedling technique requires a year or more of growth in a nursery followed by transplantation. Using nuts for field establishment requires no nursery time, but more intensive activity in the field to increase the probability of successful germination and avoidance of early predation. Current methods for establishing nuts in the field use plastic tree-shelters and steel rebar, both of will remain as non-biodegradable debris if not retrieved, with the rebar acting as a potential hazard with approximately 30 cm protruding vertically from the ground surface if the chestnut tree does not establish successfully. These two methods of establishment were compared for effect on survival and growth, anticipating that results may reveal a preferred establishment method.

It is also well known that herbaceous groundcover influences the survival and growth of trees that are planted on coal surface mines (Burger et al. 2008). Three categories of herbaceous ground cover are 1) those which have been used conventionally in mine reclamation to establish thick, persistent ground cover but also competes with trees; 2) those which are persistent but made up of species which do not compete as vigorously with trees (Burger et al. 2009); and 3) an annual species to create an initial groundcover and then yields to volunteer vegetation (Fields-Johnson et al. 2009, 2010). These three types of ground cover may produce differences in early survival and growth of chestnut; since some ground cover is necessary to prevent early site erosion and to satisfy legal requirements, it is important to know which ground cover type is most compatible with chestnut.

Experimental Objectives

Our goal was to determine which chestnut planting techniques and reclamation strategies can be applied effectively to aid effective American chestnut restoration on reclaimed surface-mined lands. Our objectives were to compare the effects of

1) different breeding generations (Chinese, American, and three generations of backcrosses);
2) three groundcover treatments (conventional, tree-compatible and annual ryegrass only);
3) two planting methods (direct seeding in tree shelters and planting unprotected bare-root seedlings),

on survival and growth of American Chestnut on reclaimed mined land.

Methods and Materials

Two separate experiments were performed to test the effects of planting practices on the survival and growth of American chestnut. The first, begun in 2008, tested the effects of backcross generation selection and ground cover prescription on survival and total height during the 2009 growing season. The second, begun in 2009, tested the effects of backcross generation selection and planting method (direct seeding with tube shelters vs. planting of unprotected bare root seedlings) on survival and total height during the 2009 growing season. These experiments both employed three backcross generations (B1F3, B2F3 and B3F2) as main treatments plus non-hybridized American (A) and Chinese (C) chestnut, from which the hybrids were bred, as non-hybridized controls for comparison.

Both experimental plantings were established on coal-mined areas in the coalfields of southwestern Virginia, USA. Prior to mining, the areas were occupied by mixed mesophytic forest. The area gets approximately 119 cm of precipitation per year and is in plant hardiness zone 6 with average yearly minimum temperatures of -23°C to -18°C. .

2008 American Chestnut Planting: Ground Cover Trial

Six breeding generations of chestnut (2 lines of A and 1 each of C, B1F3, B2F3 and B3F2), provided by the ACF, were planted in mid-March of 2008 with three hydroseed groundcover treatments at three locations (blocks) in southwest Virginia. These sites had all been surface mined for coal and reclaimed in the previous year with steep slopes of approximately 60% and aspects by block of south, east and southeast. The sites were constructed with varying spoil materials to serve as growth media (gray sandstone, brown sandstone, siltstone and some shale). The American chestnuts plantings were established only within the loosely graded treatments of these experimental areas (Fields-Johnson et al., 2010). Each block contained three areas, each roughly 0.4 ha in size and seeded with a different ground cover vegetation: 1) a conventional mix of herbaceous species intended to create >90% ground cover within the first few months of a growing season after seeding, 2) a tree-compatible mix intended to create a moderate level of initial ground cover while eventually covering the soil surfaces fully, and 3) annual ryegrass, intended to create the lowest level of groundcover by planted species while allowing recruitment of native plant species volunteers (Table 1). Within each of the 0.4 ha ground cover treatment areas, approximately 75 nuts were randomly planted among 12 species of Appalachian hardwoods and Eastern white pine (*Pinus strobus*) which were also being established as seedlings on these sites (Fields-Johnson et al., 2010).

Table 1. Hydroseed ground cover treatments for the 2008 chestnut planting.

Annual Ryegrass Only	Rate
Seed Mix:	(kg ha^{-1})
Annual ryegrass (*Lolium multiflorum*)	22
Wood Cellulose Fiber	1680
Tree-Compatible Mix	Rate
Seed Mix:	(kg ha^{-1})
Annual ryegrass (*Lolium multiflorum*)	22
Perennial ryegrass (*Lolium perenne*)	11
Timothy (*Phleum pretense*)	6
Birdsfoot trefoil (*Lotus corniculatus*)	6
Ladino clover (*Trifolium repens*)	3
Weeping Lovegrass (*Eragrostis curvula*)	2
Wood Cellulose Fiber	1680
Conventional Mix	Rate
Seed Mix:	(kg ha^{-1})
Rye grain (*Secale cereale*)	34
Orchardgrass (*Dactylis glomerata*)	22
Perennial ryegrass (*Lolium perenne*)	11
Korean lespedeza (*Lespedeza cuneata*)	6
Birdsfoot trefoil (*Lotus corniculatus)*	6
Ladino clover (*Trifolium repens*)	6
Redtop (*Agrostis gigantea)*	3
Weeping lovegrass (*Eragrostis curvula*)	2
Wood Cellulose Fiber	1680

The conventional ground cover treatment seed mix prescription is one that is commonly applied by a commercial hydroseeding firm on coal mining operations in southwestern Virginia. The tree-compatible mix prescription has been developed through reclamation research using a process of experimentation and observation of many herbaceous species over many years (Burger et al. 2009). Hydroseeding was performed by a commercial contractor using operational procedures, under supervision by the mining firms but using our prescriptions, following final grading of mine spoil. Fertilizer was prescribed for inclusion in all hydroseeding mixtures at an approximate rate of 22 kg ha^{-1} nitrogen (N), 68 kg ha^{-1} phosphorous (P) and 18 kg ha^{-1} potassium. This fertilization prescription for reforestation was developed via experimentation as a way to provide trees ample P without causing excessive herbaceous growth with large amounts of N. Block 1 was hydroseeded in the fall of 2007, Block 2 was hydroseeded in the winter of 2007-2008, and Block 3 was hydroseeded in early spring of 2008. Mining was completed for these sites at different times, hence the staggered hydroseeding schedule.

Chestnut seeds were planted and protected using procedures developed by The American Chestnut Foundation (Figure 2). These procedures involved digging a ~10cm wide x ~20cm deep hole, and filling it with a mix of potting soil, native forest topsoil for biotic inoculation, and on-site mine soil. Seeds were then placed on top of this material and covered with an addition 2-3 cm layer of soil medium. A tree tube (manufactured by Tubex), 6-10 cm in diameter and 38 cm tall, was then placed with its base inserted 2 cm deep into the soil medium and over the seed and moored to a piece of 1-cm thick rebar driven firmly into the ground. Rocks collected on site were piled around the base of each tube to provide additional protection for the buried nut. Nuts were planted in mid-March and germination was assessed in early May. Thereafter, survival, tree height to the highest live bud, and stem diameter at the top of the tree tube were measured in late October – early November at the conclusion of each growing season. Two growing seasons of data were collected for the 2008 planting, with cumulative growth and survival reported here.

Figure 2. Photo of chestnut planting method taken in March of 2008. “Zip ties” inserted through small holes in the tree tube moored the tree tube firmly to the rebar stake.

<u>2009 Chestnut Planting: Planting Method Trial</u>

Five of the six breeding generations of chestnut established in the 2008 experiment, including only one pure American line, were also planted in late March of 2009 on four mined sites in Southwest Virginia with two planting methods. Approximately 180 trees were planted on each site. Two of the planting sites were recently mined areas being actively reclaimed using the FRA. The mine soils were a mix of gray and brown sandstone and siltstone. These two sites were both steep (slopes of approximately 60%) with southerly aspects The third site was a steep area (slope of approximately 60%) with an easterly aspect adjacent to a mine site with surface materials comprised predominantly of soil and weathered sandstone materials which had been re-graded loosely in association with the mining operation. The fourth site was gently sloping, had been mined and reclaimed in the early 1990s with a mix of spoil materials (gray sandstone, brown sandstone and siltstone) and revegetated with grasses, and had been left in an unmanaged condition until December of 2007, when it was treated with a subsoil ripper to relieve soil compaction and then left in an unmanaged state until this planting. On each of the 4 sites, half of the trees were planted as nuts, using methods described for the 2008 chestnut planting; and the other half were planted as one year-old bare root seedlings without any tube shelters or staking. The bare root seedlings were grown in a nursery by the American Chestnut Foundation. Within each block, each row was planted with a single breeding generation; and the direct seeded nuts were alternated with the bare-root seedlings within each row. Survival, tree height to the highest live bud, and stem diameter at ground level, for the bare-root seedlings only, were measured in late October – early November of the first growing season.

Statistical Analysis

Data were analyzed using JMP 7.0 (SAS Institute Inc., Cary NC). Differences in performance characteristics among treatments were determined using a randomized block ANOVA. Tukey-Kramer HSD was used for mean separations ($P < 0.10$). Data from the 2008 and 2009 experiments were analyzed separately. The ground cover trial was designed as a randomized complete block design with ground cover treatment as the main plot and breeding generation as the subplot. The planting method trial was designed as a randomized complete block design with breeding generation as the main plot and planting method as the subplot.

Results

Chestnut survival was significantly greater in the annual ryegrass groundcover than the conventional groundcover, but groundcover type had no significant effect on growth after two growing seasons (Table 2). Planting chestnuts as bare root seedlings as opposed to planting as nuts with tree tubes resulted in significantly greater survival and total height after one growing season (Table 3). There were also significant differences in survival and height among several of the genotypes. Chinese chestnut survival was greater than that of the B2F3 generation, in both sets of plantings, while American and B1F3 survival were also greater than B2F3 in the planting method trial. Chinese chestnuts grew taller than one American chestnut variety for the planting method trial; and they grew taller than all other varieties in the ground cover trial.

Table 2. Cumulative groundcover and genotype effects on survival and total height after two growing seasons for the ground cover trial, with mean separation (Tukey HSD) indicated by different letters beside values within categories.

Groundcover	Survival	α = 0.10	Ht mm	α = 0.10
Annual Ryegrass	71%	a	286	a
Tree Compatible	60%	ab	295	a
Conventional	50%	b	236	a
Genotype				
Chinese	84%	a	373	a
B1F3	73%	ab	352	a
B3F2	65%	abc	276	ab
American 2	58%	abc	203	b
American 1	58%	abc	244	ab
B2F3	48%	bc	273	ab

Table 3. Planting treatment and genotype effects on survival and total height after one growing season for the planting method trial, with mean separation (Tukey HSD) indicated by different letters beside values within categories.

Planting Treatment	Survival	α = 0.10	Ht mm	α = 0.10
Seedlings	83%	a	470	a
Nuts	76%	b	347	b
Genotype				
Chinese	89%	a	740	a
American	87%	a	432	b
B1F3	84%	a	310	c
B3F2	73%	ab	273	c
B2F3	66%	b	287	c

Discussion

The greater survival and first-year height of planted seedlings over planted nuts with tree tubes, combined with the much reduced planting labor and costs, demonstrate that use of bare root seedlings is likely to be a more effective reintroduction technique if tree tube shelters are not needed for protection from herbivory (Phelps et al., 2005). The 38 cm tall shelters used in this experiment were intended to protect nuts and emerging trees from rodents. Taller shelters would be required for protection from deer or livestock.

The seedlings could be planted in less than one minute each with the use of a hoe-dad, whereas direct seeding required over six minutes per seed to dig the hole, add the native soil mix and erect all of the tree protection apparatus, plus additional time to prepare and stage the soils and materials. The cost of labor and supplies for the additional steps of mixing and applying soil and constructing tree shelters when direct seeding caused us to find direct seeding to be more expensive than planting seedlings in contrast to the findings of Phelps et al. (2005). The young trees established as seedlings were taller than those established as nuts, which is not surprising since seedlings had height at the time of planting and are essentially one year older than the trees planted as nuts; the greater height of young trees established as seedlings can be expected to give them an advantage in over-topping herbaceous vegetation during the first growing season, and during subsequent growing seasons if the additional height effect persists as would be expected. Another advantage to the seedling transplant method is that this method is used commonly for re-establishing other native tree species on surface mined lands, providing potential for easier integration of American chestnut within existing mined-land reforestation methods.

Use of only annual ryegrass as a ground cover also improved survival, compared with the conventional ground cover treatment. This was likely due to the lower overall seeding rate and the die-off of the annual rye after 2008 decreasing competition with trees for resources compared to the conventional treatment.

No consistently dominant genotype of hybrid chestnut emerged in these studies, which may change if they differ in sensitivity to Chestnut blight and or in competitive growth form at later growth stages. First-year growth and survival data for the ground cover trial showed few significant differences, between groundcover treatments (Fields-Johnson et al., 2009), compared to second-year results, indicating that treatment effects may continue to diverge with time.

Several other experimental efforts are underway in the Appalachian region testing methods of planting chestnut on reclaimed mined lands, and these results are generally consistent with our findings. French et al. (2008) found that American chestnut direct-seeded on the Cumberland Plateau had greater first-year survival (61.8%) than containerized transplants (51.2%), but height and diameter growth were greater for the containerized transplants. Bare-root seedling transplants survived better than direct-seeded chestnuts in our study, indicating that bare-root seedling transplants may respond differently to out-planting stresses than containerized transplants. Miller et al. (2009) found survival rates of 30%-72% for direct-seeded chestnut in Eastern Tennessee after two months of emergence and growth, and they found that fertilization resulted in a significant decrease in emergence and survival. The trees in our study had generally higher survival rates overall, perhaps due to uniform fertilization applied via hydroseeding rather than to individual trees, but these difference might also have been due to other site or climatic factors. Working in West Virginia, Skousen et al. (2009) found that direct-seeded chestnuts had an overall first-year survival rate of 72%, with 82% for Chinese, 67% for American and 69%-74% for hybrid backcrosses. They found a significant difference in survival between nuts planted with (81%) and without (63%) tree tube shelters, and that the addition of peat to planting holes significantly reduced survival. Our study had a comparable first-year survival rate for nuts planted with tube shelters and comparable patterns of survival by breeding generation.

Our results combined with other studies reported herein can only provide early indications of planting success since all plantings are in early growth stages, but to date they suggest bare-root seedling transplants experience greater survival than direct-seeded chestnuts and direct-seeding results in greater survival than use of containerized transplants. They also suggest direct-seeded chestnuts have greater early survival when protected with tree tube shelters than when planted without shelters, have greater survival when only annual ryegrass is planted as a ground cover than when more competitive and persistent ground covers are used, and have greater survival without additions of peat or direct fertilization of trees at planting than when peat is added or individual trees fertilized.

Survival rates so far in our work (as in some of the other experiments mentioned above) are nominally comparable to those of other mixed native hardwoods planted for research purposes on reclaimed mined land using the Forestry Reclamation Approach. Burger et al. (2008) recorded overall mixed-hardwood survival after 5 years of 69% in research assessing the effects of ground cover control, while Fields-Johnson et al. (2010) recorded survival rates ranging from 71%-75% in 2009 for mixed hardwoods planted as seedlings in association with our ground cover trial of American chestnut, as described above. These early results suggest that, once blight-resistance is effectively conferred, hybrid chestnuts carry the potential for successful introduced throughout American chestnut's former range through reclaimed surface mined land plantings

Conclusions

Planting bare-root chestnut seedlings and hydroseeding annual ryegrass as a sole groundcover were found to be effective ways to improve early chestnut performance on reclaimed surface mined land in the Appalachians. These techniques are also more cost-effective than the alternatives studied. Restoring American chestnut to its native range through plantings on reclaimed mined lands, following the tenets of the Forestry Reclamation Approach, appears promising at this stage so long as blight-resistance is effectively conferred through breeding programs.

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Literature Cited

Burger, J.A., V. Davis, J. Franklin, C.E. Zipper, J. Skousen, C. Barton, P. Angel. 2009. Tree Compatible Groundcovers for Reforestation and Erosion Control. Appalachian Regional Reforestation Initiative, Forest Reclamation Advisory No. 6. U.S. Office of Surface Mining, Appalachian Regional Reforestation Initiative. 6 p.

Burger, J.A., D. Graves; P. Angel; V. Davis and C.E. Zipper. 2005. The Forestry Reclamation Approach. Forest Reclamation Advisory No. 2. U.S. Office of Surface Mining, Appalachian Regional Reforestation Initiative, 4 p.

Burger, J.A., D.O. Mitchem, C.E. Zipper, and R. Williams. 2008. Hardwood reforestation for phase III bond release: need for reduced ground cover. In: R.I. Barnhisel (ed.) Proc. 25th Meeting, American Society for Mining and Reclamation, Richmond, Virginia.

Braun, E.L. 1950. Deciduous Forests of Eastern North America. Philadelphia: Blakiston.

Diskin, M., K.C. Steiner and F.V. Hebard. 2006. Recovery of American chestnut characteristics following hybridization and backcross breeding to restore blight-ravaged *Castanea dentata.* Forest Ecology and Management 223:439-447.

Ellison, A.M., M.S. Bank, B.D. Clinton, E.A. Colburn, K. Elliott, C.R. Ford, D.R. Foster, B.D. Kloeppel, J.D. Knoepp, G.M. Lovett, J. Mohan, D.A. Orwig, N.L. Rodenhouse, W.V. Sobczak, K.A. Stinson, J.K. Stone, C.M. Swan, J. Thompson, B. Von Holle, and J.R. Webster. 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. Frontiers in Ecology and the Environment. 3:479-486.

Fields-Johnson, C.; C.E. Zipper, J.A. Burger and D.M. Evans**.** 2009. First year response of mixed hardwoods and improved American chestnuts to compaction and hydroseed treatments on reclaimed mine land. In: R.I. Barnhisel (ed.) Proc. 26th Meeting, American Society for Mining and Reclamation, Billings, Montana.

Fields-Johnson, C.; C.E. Zipper, J.A. Burger and D.M. Evans. 2010. Second year response of Appalachian mixed hardwoods to soil surface grading and herbaceous ground cover on reclaimed mine land. In: R.I. Barnhisel (ed.) Proc. 27th Meeting, American Society. for Mining and Reclamation. Pittsburgh, Pennsylvania.

French, M.E.; C.D. Barton and D. Graves. 2008. Direst-seeding versus containerized transplantation of American chestnuts on loose mine spoil in the Cumberland Plateau. In: R.I. Barnhisel (ed.) Proc. 25th Meeting, American Society for Mining and Reclamation, Richmond, Virginia.

Hebard, F.V. 2001. Backcross breeding program produces blight-resistant American chestnuts. Ecological Restoration. 19:252-254.

Jacobs, D.F. 2007. Toward development of silvical strategies for forest restoration of American chestnut (*Castanea dentata*) using blight-resistant hybrids. Biological Conservation. 137:497-506.

Miller, C.R.; J.A. Franklin and D.S. Buckley. 2009. Influence of differing mine site characteristics and planting treatments on survival and bud set timing of *Castanea dentata.* In: R.I. Barnhisel (ed.) Proc. 26th Meeting, American Society for Mining and Reclamation, Billings, Montana.

Oak, S. 2005. Forest Health Impacts of the Loss of American Chestnut. Proceedings, Conference on the Restoration of American Chestnut to Forest Lands.

Phelps, T.R., K.C. Steiner, C.C. Chen and J.J. Zaczek. 2005. Planting Trials of American Chestnut in Central Appalachian Mountains. Proceedings, Conference on the Restoration of American Chestnut to Forest Lands.

Rhoades, C.C. 2007. The influence of American Chestnut (*Castanea dentata*) on nitrogen availability, organic matter and chemistry of silty and sandy loam soils. Pedobiologia. 50:553-562.

Rhoades, C.C., S.L. Brosi, A.J. Dattilo, P. Vincelli. 2003. Effect of soil compaction and moisture on incidence of phytophthora root rot on American chestnut (*Castanea dentate*) seedlings. Forest Ecology and Management. 184:47-54.

Saylor, K. L. 2008. Land Cover Trends: Central Appalachians. U.S. Department of the Interior, U.S. Geological Survey. Washington, DC, 2008. http://landcovertrends.usgs.gov/east/eco69Report.html

Skousen, J.; T. Keene, C. DeLong, E. Pena-Yewtakhiw and T. Cook. 2009. Survival and growth of five chestnut seed types on a mountaintop surface mine in West Virginia. In: R.I. Barnhisel (ed.) Proc. 26th Meeting, American Society for Mining and Reclamation, Billings, Montana.

Ward, K.M. 2009. Matrix geochemistry and *Phytophthora* occurrence on reforested mine lands in Appalachia. Thesis submitted to the Graduate School of the University of Kentucky. Lexington, Kentucky.

Wickam, J.D., K. Riitters, T. Wade, M. Coan, C. Homer. 2007. The effect of Appalachian mountaintop mining on interior forest. Landscape Ecology 22:179-187.