AMERICAN CHESTNUT AS A FUTURE RESOURCE TO ENHANCE MINE RECLAMATION PRODUCTIVITY[1]

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Abstract. Mine reclamation sites can be difficult to reforest, and trees that successfully establish on these sites are often comprised of relatively undesirable species. American chestnut (*Castanea dentata*) once dominated the forests throughout much of the coal-producing region in Appalachia. However, the exotic fungus *Cryphonectria parasitica* was discovered in 1904 and within several decades, the blight killed nearly every tree throughout the range. A dedicated breeding program sponsored by The American Chestnut Foundation has made tremendous progress toward producing a blight-resistant variety of American chestnut by hybridizing with the blight-resistant Chinese chestnut (*Castanea mollissima*). It is expected that a blight-resistant hybrid chestnut tree (~94% American chestnut) will be available for reintroduction within the next decade, providing a new species option for reclamation programs. Due to continued presence of the fungus throughout eastern forests, few studies have examined American chestnut growth performance in plantations. However, a recent study on a blight-free site in Wisconsin reported exceptional growth capacity of chestnut relative to co-occurring hardwood species. Sufficient evidence also exists to suggest that American chestnut may tolerate many of the stressful physical and chemical soil characteristics typical of mine reclamation sites. Rapid growth, adaptability to a wide range of environmental conditions, good timber quality, and exceptional wildlife properties make American chestnut a highly desirable potential species for future reclamation programs.

Additional Key Words: *Castanea dentata*, plantation establishment, site tolerance, competitive interactions, juvenile growth performance

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Introduction

Mining in the United States is a large, important industry that has been practiced for centuries. The mining process substantially alters physical, chemical, and biological characteristics of the site (Singh et al., 2002) and rigorous efforts are made to quickly reclaim these sites following completion of mining operations. Without these interventions, these sites would generally require substantially more time for successful revegetation to occur through natural means (Wali, 1999). Reclamation often involves planting of forest tree seedlings and in many states, reclamation plantings represent a significant portion of total tree plantings. In Indiana, for example, seedling orders for mined land reclamation from state-operated seedling nurseries total approximately one million seedlings annually (Conrad, 1999), which represents nearly 20% of total seedlings planted each year in the state. Long-term survivorship of seedlings planted onto mine reclamation sites is generally low, and often consists of species which are not deemed highly desirable by landowners (Rathfon et al., 2004).

With future mining activities expected to increase, there is a present need to identify practices which are likely to improve the success of mine reclamation projects and help ensure that reclaimed sites are retained for long-term use as forestland. These forests may then provide many benefits to landowners and the public including solid wood products, maintenance of high quality water through watershed protection, enhanced wildlife habitats, improved aesthetic landscapes, and capacity to act as carbon sinks which play an important role in global carbon cycles. Evaluation of new species options for reclamation that are likely to establish well on these sites, yet possess desirable timber, wildlife, and aesthetic characteristics, will help to provide a means to ensure long-term forest productivity on reclaimed sites.

The Reclamation Processes

Surface mining completely removes the forest along with associated benefits. Reclamation of mined sites is a legislative requirement following the completion of surface mining operations (U.S. Congress, 1977; OSM, 1993; Smyth and Dearden, 1998). To address environmental concerns associated with mining operations, the Surface Mining Control and Reclamation Act (SMCRA) of 1977 (Public law 87-95) was established (U.S. Congress, 1977; EPA, 2000), and mandates that mined lands be reclaimed and restored to their original use or a higher and better use (Andersen et al., 1989). According to SMCRA, mining is viewed as a temporary land use and after mining operations are completed, the land must be returned to a condition capable of supporting its pre-mining land cover (OSM, 1993). Mining operators are required to submit a bond to cover the costs of reclaiming the site. Release from this bond occurs only if the reclamation activity results in a specified environmental condition on the site within a fixed time period (e.g., < 5 years). Sites that were mined prior to the introduction of SMCRA in 1977 are termed Abandoned Mine Lands (AMLs). The Office of Surface Mining Reclamation and Enforcement (OSMRE) promotes reclamation of AMLs, with funds provided through SMCRA.

Restoring forests on surface-mined lands is challenging because of adverse soil conditions and plant competition (Bussler et al., 1984; Andersen et al., 1989). The post-mining site must be graded prior to reclamation, which may dramatically alter soil physical properties. For example, soils at mined sites had higher bulk density, coarse fragments, and clay content and also had lower porosity, permeability, and moisture-holding capacity than un-mined reference sites (Bussler et al., 1984). Topsoil is generally replaced to an average depth of about 30 cm, below which a hardpan layer may create a perched water table (Bussler et al., 1984; Andersen et al., 1989) which can restrict seedling root system penetration and reduce subsequent seedling establishment success.

Despite these obstacles, studies have shown that forests can be successfully restored on abandoned mine sites with equal or more productive roles than the native forests removed by mining (Burger and Torbert, 1992; Torbert et al., 1996; Andrews et al., 1998; Rodrigue et al., 2002). Successful restoration of these sites can result in many benefits, including improvements to hydrological processes resulting from decreased erosion and sediment flow, and more stable pH in runoff (Olyphant and Harper, 1995), as well as an increase in forest land area and provision of productive timber supplies (Torbert et al., 1996).

Use of species with desirable characteristics (i.e., timber production, wildlife value, and aesthetics) would help to maintain reclaimed sites as forestland following bond release. At present, species that are tolerant to degraded conditions yet prove to be relatively undesirable to many landowners, such as black locust (*Robinia pseudoacacia*) and green ash (*Fraxinus pennsylvanica*), are often used in reclamation projects (Rathfon et al., 2004) (Table 1). Thus, the resulting species composition on reclaimed sites typically reduces the prospective future value of the land. A potential new species option for reclamation projects, which has not been considered in the past, is American chestnut (*Castanea dentata*).

Table 1. Percentage abundance of established tree and shrub species on former Indiana mine sites that were reclaimed from 1988 to 1995, as determined by a survey (adapted from Rathfon et al., 2004).

Species	Proportion of total species surveyed (%)
Black locust (*Robinia pseudoacacia*)	47
Green ash (*Fraxinus pennsylvanica*)	14
Autumn olive (*Eleagnus umbellata*)	7
Northern red oak (*Quercus rubra*)	3
White oak (*Quercus alba*)	2
Other oaks	4
Other species (desirable for timber)	12
Other species (non-timber)	11

Natural History of American Chestnut

American chestnut was once one of North America's most important trees, with a native range extending from Maine to Mississippi and encompassing over 800,000 km^2 (Latham, 1992) (Fig. 1). In portions of its range in Appalachia, American chestnut was thought to have represented 40-50% of trees in the forest canopy (Braun, 1950; Keever, 1953). American chestnut was critically important to the economic prosperity of the Appalachian region (Youngs, 2000), providing a major source of high quality timber, tannic acid, and nuts (Frothingham, 1912; Steer, 1948). The species was also crucial as a wildlife food source, bearing fruit at an earlier age and more consistently each year than other important large-mast species. For instance, common *Quercus* spp. generally do not bear fruit until 20 or more years and produce good fruit crops at irregular intervals of only every 2-10 years (Rogers, 1990; Sander, 1990), while American chestnut may begin to bear fruit prior to 10 years of age and produce reliable nut crops every year at maturity (D. F. Jacobs, unpublished observations).

Introduction of the exotic pathogen *Cryphonectria parasitica*, an aggressive diffuse canker disease (Anagnostakis, 1987) caused widespread mortality throughout the natural range of American chestnut. The disease was first discovered in 1904 at the Bronx Zoological Park in New York City (Roane et al., 1986), and within four decades, nearly every American chestnut tree had been infected. The species was rapidly eliminated as a dominant forest tree (Griffin, 2000), effectively destroying the range throughout the North American continent (Hepting, 1974; McCormick and Platt, 1980; Anagnostakis, 1987; Youngs, 2000). The majority of trees currently present are sprouts, originating from mature trees that were killed (Russell, 1987; Stephenson et al., 1991), which infrequently grow to reproductive maturity (Paillet, 2002).

Figure 1. The historical range of American chestnut prior to introduction of chestnut blight (adapted from Saucier, 1973) and the location of the Rockland, WI tree plantation test site.

The rapid and devastating loss of American chestnut from the eastern forests prompted an urgency to identify potential mechanisms of disease resistance. However, attempts at finding trees with demonstrated resistance to the fungus have been futile (Hepting, 1974) and early attempts at hybridizing the tree with blight-resistant chestnut species were abandoned because the hybridized trees failed to have the desired characteristics of the pure American chestnut tree (Schlarbaum et al., 1994).

Breeding for Blight Resistance

Today, pessimism has been replaced with optimism toward successful restoration of the American chestnut tree to its original range. A better understanding of genetics and hybridization techniques have aided the efforts to cross American chestnut with blight-resistant Asian chestnut species, primarily using Chinese chestnut (*Castanea mollissima*) and Japanese chestnut (*Castanea crenata*) (Burnham, 1988). The American Chestnut Foundation was established in 1983 under the leadership of Dr. Charles R. Burnham. The American Chestnut Foundation (TACF), with participation of universities, and state and federal agencies has dedicated nearly all of its resources to this breeding program. Burnham (1988) recognized the design flaws of earlier hybridization techniques and initiated the present program, which is expected to develop a blight-resistant hybrid form of the tree within ten years (Ronderos, 2000).

The current breeding program structure is outlined in Table 2. Briefly, American chestnut was initially hybridized with Chinese chestnut and then "backcrossed" several times back to American chestnut. The objective is to increase the percentage of American chestnut in the tree, while maintaining the blight resistance conferred by the Chinese chestnut. This is accomplished by first identifying American chestnut trees that have reached reproductive maturity. These trees are then hand-pollinated in spring; seeds are harvested in fall (Fig. 2) and then established in test plantations. In some cases, these mother trees have escaped infection by means of their isolation from blight-infected areas. However, most trees used in chestnut breeding programs are heavily infected by blight. The infection seems to stimulate flowering, and the stems often die back a year or two after pollination (Dr. Paul Sisco, TACF, pers. comm.).

Progeny from these crosses are experimentally inoculated with blight to test their degree of resistance. Resistant progeny are maintained in the program, while susceptible progeny are discarded. The program has reached the BC3F2 stage, with several BC3F3 plantations being established at present. The BC3F3 plantations will produce a blight resistant tree with ~94% American chestnut genes that exhibits all of the morphological qualities of the American chestnut tree (Burnham, 1988; Hebard, 2002). Limited quantities of resistant material should be available by 2006, with widescale planting expected in the next 5-15 years. When reintroduced, American chestnut will be incorporated into reforestation and afforestation plantings both within and outside the native range, and will become a viable new species option for consideration in mine reclamation programs.

Potential for Integration into Mine Reclamation Programs

The original natural range of American chestnut (Fig. 1) represents a primary portion of the area of active mining in the eastern United States. However, American chestnut is almost never used in current reclamation or reforestation plantings because it is assumed that trees will inevitably succumb to blight. Thus, relatively little modern information is available regarding American chestnut silvical characteristics, such as environmental requirements or juvenile growth performance. Increasing optimism toward the release of a blight-resistant variety of American chestnut in the near future has stimulated some recent research to examine early growth and development of American chestnut. Analysis of these results, combined with examination of historical literature, provides a means to speculate as to the potential feasibility of incorporating American chestnut into future mine reclamation plantings.

Table 2. Breeding strategy to develop a blight-resistant American chestnut tree for reintroduction. With each hybrid generation, the average proportion of American chestnut increases, while blight resistance is maintained or increases (Adapted from "The Path to Most Resistance" by The American Chestnut Foundation).

Average % American chestnut	Hybrid generation	Degree of blight resistance		
		Susceptible	Moderately resistant	Resistant
50	F1†	0	100	0
75	BC1‡	75	25	0
87.5	BC2	75	25	0
93.75	BC3	75	25	0
93.75+	BC3F2	43.75	50	6.25
93.75++	BC3F3	0	0	100

†F1 is the hybrid cross of Chinese × American to induce blight resistance
‡BC refers to "backcross" back to American to increase the relative proportion of American chestnut

Figure 2. Harvesting controlled-pollinated seeds from a surviving American chestnut tree to establish test plantations for use in developing blight-resistant material for reintroduction.

Tolerance to harsh environmental conditions is a major consideration in selecting suitable species for mine reclamation programs. For instance, soil pH may be drastically altered on mine reclamation sites compared to unmined counterparts, often resulting in acidic soil conditions that may restrict growth of some species. American chestnut was adapted to a wide range of environmental conditions in areas where the species once dominated in the southern Appalachians (Ashe, 1912). Many of these sites are characterized by moderately acidic soils (5.0-5.5), suggesting that the species may tolerate relatively acidic conditions. Evidence for this tendency is further supported by results from a test plantation of BC3 hybrids and pure American chestnut on a site near Brevard, NC. Despite a pH of 4.4, the plantation is growing well after three seasons (Dr. Paul Sisco, TACF, pers. comm.). Additional indications that American chestnut may tolerate a wide range of environmental conditions was presented by Latham (1992), who evaluated seedling competitiveness of American chestnut relative to six co-occurring species by altering resources (e.g., light and mineral nutrient availability) experimentally. American chestnut ranked highest in traits associated with competitive ability over the broadest range of resource level combinations tested.

Rapid initial growth is another desirable quality of species for mine reclamation. Fast growth helps to ensure plantation success by facilitating prompt attainment of free-to-grow status above the height of competing vegetation and the level of deer browse. Reports from early in the last century indicate that American chestnut is highly competitive and fast growing initially (Zon, 1904; Graves, 1905), reaching 50% of ultimate height growth by age 20 (Ashe, 1912). A recent study of a rare stand of blight-free American chestnut in southwestern Wisconsin (Fig. 1) helped affirm these historical observations (Jacobs and Severeid, 2004). Early plantation development of American chestnut interplanted with black walnut (*Juglans nigra*) and northern red oak was evaluated. American chestnut growth was exceptional (Fig. 3), and trees averaged much greater height (47 or 77%) and diameter (50 or 140%) growth than northern red oak and black walnut, respectively. Mean annual growth of American chestnut was nearly 1 m for height and 1 cm for diameter. Individual chestnut trees reached a height of 9.1 m and diameter of 10.2 cm within seven to eight growing seasons. These preliminary observations regarding early growth and development of American chestnut suggest the potential suitability of this species for mine reclamation programs and that trials should be established to further evaluate this potential.

Progress to Date

In 1998, The American Chestnut Foundation funded a study conducted by Dr. Greg Miller (Empire Chestnut Co., Carrollton, OH) to examine American chestnut performance on a mine reclamation site in east-central Ohio. Prior to planting, this site was graded as per standard reclamation procedures, limed, fertilized, seeded with a standard mixture of grasses and legumes, and topsoil was added (sandy loam mixed with sandstone and shale). Survival of chestnut seedlings after year-1 was 80-90% and was approximately 70% after year-3, with most mortality after the second year attributable to deer browsing (Dr. Carolyn Keiffer, Miami Univ., pers. comm.). Despite harsh site conditions and prolonged periods of drought, most of the planted American chestnuts were above the level of deer browse and had successfully established on the site following the third growing season.

Figure 3. Example of American chestnut dominance in a mixed interplanting with black walnut and northern red oak eight years following direct seeding on a study site in southwestern Wisconsin. Data published in Jacobs and Severeid (2004).

A new collaboration established between The American Chestnut Foundation and Peabody Energy (St. Louis, MO) will test the adaptability of American chestnut on reclamation sites in Kentucky through a five-year, $100,000 study funded by Peabody. Peabody is the world's largest private-sector coal company and reclaimed nearly 2,400 ha of land and planted more than 500,000 trees in 2002. For this current project, six reclamation test sites were selected, representing a range of soil and topographic conditions. The sites will be planted with several varieties of BC2F2 chestnut material. Because this material is still being tested for degree of blight resistance and American chestnut character, it is likely that the trees planted on these sites will exhibit blight resistance ranging from very high to poor. The sites will be monitored for long-term plantation performance to help quantify the feasibility of integrating American chestnut into reclamation plantings in Kentucky.

Conclusions

Following the release of blight-resistant material in the near future, American chestnut is likely to provide a valuable new species option for integration into mine reclamation projects. Fast growth, combined with high tolerance to a range of environmental conditions may allow American chestnut to rapidly establish within the degraded environmental conditions characteristic of mine reclamation sites. Additionally, excellent timber, wildlife, and aesthetic properties characteristic of the species may help motivate landowners to maintain reclaimed property as forestland for the long term. Incorporation of blight-resistant American chestnut into mine reclamation programs will also help facilitate the successful restoration of perhaps the single most important tree species in eastern North American back to its original range.

Though optimism for successful restoration in the near future is justified, several challenges must still be addressed. Chestnut breeding programs are largely supported by the National and State Chapters of TACF and establishment of future test plantations and seed orchards is likely to be limited by availability of funding and personnel. Additionally, plantings of American chestnut seem to be particularly susceptible to *Phytophthora cinnamomi*, a root rot common in the southern Appalachians, which suggests that site selection for restoration plantings may need to be limited to areas of low disease incidence (Rhoades et al., 2003). Despite these potential barriers, it is inevitable that a program to restore American chestnut to its original range will commence in the near future. Future research should continue to be directed toward examining the silvical requirements of American chestnut during early plantation development, which will help improve our understanding of the potential to integrate this species into mine reclamation programs.

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