Evaluating the Efficiency of Carbon Sequestration in American Chestnut (*Castanea dentata*)

1011518

Photo: The Shelton family standing by a chestnut tree, circa 1920, Tremont Falls, TN.
© Great Smoky Mountains National Park Library, courtesy The American Chestnut Foundation.

Evaluating the Efficiency of Carbon Sequestration in American Chestnut (*Castanea dentata*)

1011518

Technical Update, March 2005

EPRI Project Manager

A. Diamant

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Purdue University, Department of Forestry and Natural Resources

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

ORDERING INFORMATION

Requests for copies of this report should be directed to EPRI Orders and Conferences, 1355 Willow Way, Suite 278, Concord, CA 94520. Toll-free number: 800.313.3774, press 2, or internally x5379; voice: 925.609.9169; fax: 925.609.1310.

CITATIONS

This document was prepared by

Purdue University, Department of Forestry and Natural Resources
715 West State St.
West Lafayette, IN 47907

Principal Investigator or Author
Douglass F. Jacobs

This document describes research sponsored by EPRI.

The publication is a corporate document that should be cited in the literature in the following manner:

Evaluating the Efficiency of Carbon Sequestration in American Chestnut (Castanea dentata), EPRI, Palo Alto, CA: 2005. 1011518.

ABSTRACT

American chestnut (*Castanea dentata*) was once one of the most important trees in the eastern United States. Its rapid growth, high quality wood, and exceptional wildlife properties made the species a highly coveted tree throughout its range. In the early 20th Century, however, the range of American chestnut was effectively destroyed by chestnut blight (*Cryphonectria parasitica*). Through a dedicated breeding program, hope has been revived for the restoration of American chestnut. Limited quantities of a blight-resistant hybrid should be available by 2006, with wide-scale planting expected in the next 5-15 years.

American chestnut was among the fastest growing hardwoods of the eastern USA. Fast-growing species like American chestnut will be of great use to help mitigate accelerated global warming through the uptake and storage of carbon.

The results presented in this paper describe an ongoing study to examine the viability of American chestnut as an alternative to other merchantable hardwood species for carbon sequestration. Biomass and carbon sequestration of chestnut was quantified across an age sequence of trees and compared with other species (northern red oak and black walnut) interplanted on the same sites in southwestern Wisconsin. The results indicate that chestnut reaches consistently greater mean size and sequesters more carbon than the other interplanted species across almost all ages and site conditions.

These results are of great interest to those who could benefit from planting American chestnut to help offset emissions, while providing an excellent wildlife resource, high value timber, and contributing to the restoration of the species.

ACKNOWLEDGEMENTS

Funding for this study was provided by the Electric Power Research Institute (EPRI). Larry Severeid established the chestnut tree plantations discussed in this report on his land, and collaborated extensively on this research. Marcus Selig developed the carbon sampling methodology and organized data collection and processing. Anthony Davis assisted in field measurements. Christopher Gerlach of EPRI provided assistance with copy editing and final production of this report. The American Chestnut Foundation (http://www.acf.org) actively supported this project and provided helpful information regarding their breeding program and the history of the species.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

American chestnut as a new plantation resource

In all but a few isolated areas, chestnut blight (*Cryphonectria parasitica*) has destroyed the American chestnut (*Castanea dentata)* tree on the North American continent (Hepting 1974, McCormick and Platt 1980, Anagnostakis 1987, Youngs 2000). The fungus was first discovered in 1906 and spread rapidly through the chestnut's native range (Hepting 1974). Within four decades, nearly every American chestnut tree had been infected and eliminated as a dominant forest tree. 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).

The American chestnut was once one of North America's most important trees (Braun 1950). It is thought to have represented 40-45% of the forest canopy in portions of its native range before the introduction of blight (Keever 1953). While a recent study (Jacobs and Severeid, 2004) revealed that the initial growth rates of chestnuts are superior to other nut-producing trees including northern red oak (*Quercus rubra*) and black walnut (*Juglans nigra*), many of the tree's basic physiological processes are yet to be quantified. The absence of healthy chestnut trees and pessimism regarding the future of the American chestnut tree have been two of the primary reasons for the failure to acquire much of the basic physiological information of this species. This oversight includes studies of carbon uptake.

Today, pessimism has been replaced with optimism regarding the survival of the American chestnut tree. A better understanding of genetics and hybridization techniques have aided the efforts to cross the 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 1982 under the leadership of Dr. Charles R. Burnham. Burnham (1988) recognized the design flaws of earlier hybridization techniques and initiated the present program that is well on its way to developing a blight-resistant tree. The American Chestnut Foundation, with participation of universities, and state and federal agencies has dedicated nearly all of its resources to this breeding program.

The current breeding program structure is outlined in Table 1-1. Briefly, American chestnut was initially hybridized with Chinese chestnut and then "backcrossed" several times back to American chestnut. Following this step, the objective is then to increase the percentage of American chestnut in the tree while maintaining the blight resistance conferred by the Chinese chestnut. At the later stages, progeny from 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, which exhibits all of the morphological qualities of the American chestnut tree (Burnham 1988). Limited quantities of resistant material should be available by 2006, with widescale planting expected in the next 5-15 years.

Table 1-1
Breeding strategy to develop a blight-resistant American chestnut for reintroduction. With each hybrid generation, the average proportion of American chestnut increases while blight resistance is maintained or increases (Adapted from "The Path of Most Resistance" by the American Chestnut Foundation).

Average % American Chestnut	Hybrid Generation	Degree of Blight Resistance		
		Susceptible	Moderately Resistant	Resistant
50	F1[a]	0	100	0
75	BC1[b]	75	25	0
87.5	BC2	75	25	0
93.75	BC3	75	25	0
93.7	BC3F2	43.75	50	6.25
93.75	BC3F3	0	0	100

Notes: a) F1 is the hybrid cross of Chinese × American to induce blight resistance.
b) BC refers to "backcross" back to American to increase the relative proportion of American chestnut.

Carbon sequestration and the future role of the American chestnut tree

Recent climatic trends indicate that global warming may be of concern to our planet. Current models predict that average global surface air temperatures may rise by 2.5ºC by the end of this century. This trend has been attributed to increases in atmospheric carbon dioxide (CO_2) levels over the past 100 years (NAST 2000). Land use changes from forestry to other uses, as well as exploitation of fossil fuels, have disrupted the fragile carbon balance of the planet (Wigley and Schimel 2000).

Forested ecosystems possess the ability to capture and store atmospheric carbon dioxide through photosynthesis. Between 1988 and 1992 there was a net terrestrial uptake of CO_2 of magnitude 1.7 ± 0.5 petagrams of carbon per year in North America (Fan et al. 1998). Studies estimate that forests are the primary source of terrestrial carbon uptake, storing approximately two-thirds of earth's terrestrial carbon – nearly 1 trillion tons (Brown et al. 1993).

The Kyoto Protocol created an international framework that provides incentives for companies and countries to sequester carbon through agriculture and forestry activities. The Kyoto Protocol requires industrialized countries who are signatories to take on binding greenhouse gas emissions constraints and reduction targets and creates a framework in which Land Use and Land Use Change and Forestry (LULUCF) activities to sequester carbon can be implemented either within signatory countries or in other nations via the Clean Development Mechanism (CDM) and Joint Implementation (JI).

Ratification of the Kyoto Protocol and the development of key institutions such as the CDM and JI are expected to continue to encourage implementation of forest carbon sequestration projects and activities around the world. In addition, adoption of voluntary GHG emissions reduction programs in the U.S., like the Department of Energy's "1605b" program, has encouraged some U.S. companies to explore forest carbon sequestration options, participate in pilot projects and seek “credits” for their activities. Forestry practices offer a unique means of offsetting emissions rather than fossil-fuel substitution (Marland and Schlamadinger 1997).

While incentives exist to use of forestry as a means of carbon sequestration, little is known about the ability of hardwoods to sequester carbon since much of the work has been done on coniferous species. No research has been conducted on the carbon uptake ability of American chestnut because of its prior insignificance as a plantation species due to blight susceptibility. American chestnut clearly has a great deal of potential as a species option for carbon sequestration because of its demonstrated rapid growth in plantations (Jacobs and Severeid 2004) but exact rates of carbon storage and allocation, as well as the physiological mechanisms that aid its growth, are unknown.

International, federal, state and regional programs that encourage forest carbon sequestration and credit land owners for the amount of carbon that trees on their lands sequester are continuing to evolve. Already some existing programs allow for limited trading of “credits” derived from forest carbon sequestration projects. As these programs evolve further, and carbon credits from forestry become more standardized and recognized, industries which may face mandatory requirements, or that have made voluntary commitments, to reduce their GHG emissions may choose to pay landowners for their forest-based carbon credits. Chestnut’s demonstrated rapid growth indicates that the species is able to sequester more carbon than many associated hardwood species available for planting in a given region.

American chestnut’s rapid growth is coupled with high quality, decay-resistant wood which will be advantageous for carbon storage in the form of long-term products. The lumber is highly desirable commercially, with properties similar to that of oak species. Mean annual diameter growth for American chestnut in the Coulee region of Wisconsin has been measured at nearly 1 cm per year (Paillet and Rutter 1989, Jacobs and Severeid 2004). This means that chestnut could provide 30-cm saw logs in just over 30 years, a rate currently unachievable with most other high quality hardwood tree species. The trees also provide an exceptional source of wildlife food, with good nut crops nearly every year. The notion that such a beneficial and desirable species may also help offset increasing CO_2 concentrations makes American chestnut an extremely attractive tree for carbon sequestration. Furthermore, integrating American chestnut into carbon sequestration projects will help contribute to the restoration of the species. This cause has garnered extensive public support and would provide myriad outreach opportunities for industrial companies and others who participate in American chestnut restoration through plantation establishment.

2 METHODS

Study site

The Coulee region of Wisconsin is not part of the natural range of American chestnut (Figure 2-1), but the tree has thrived in that region where it has been planted (Paillet and Rutter 1989, Jacobs and Severeid 2004). In the late 1800s and early 1900s, settlers from the eastern forests introduced American chestnut to the region and these trees largely escaped blight infection due to their isolation from the native range (Paillet and Rutter 1989). There are isolated pockets of American chestnut trees in Vernon, La Crosse, Trempealeau, and Monroe counties. A site near West Salem contains the largest known remaining stand of American chestnuts in the United States. A few seeds were planted around the turn of the century and have since naturalized to about 20 ha of woodland (Paillet and Rutter 1989).

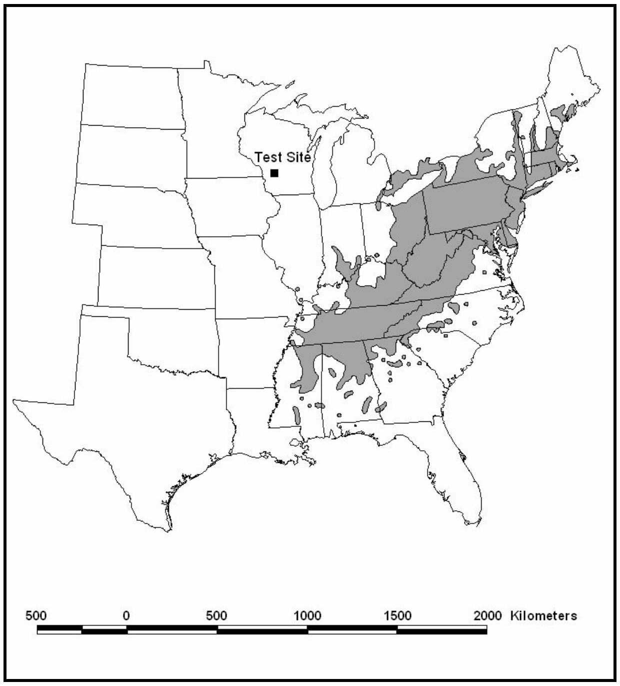

Figure 2-1
Natural range of American chestnut

This project was conducted on three different sites (2 eight-year-old, and 1 twelve-year-old) located near Rockland, Wisconsin, and a site (19-year-old) near West Salem, Wisconsin. All of the sites differed from each other in terms of aspect, slope, soil series and site index (Table 2-1), but conditions were relatively homogeneous within each site. The Rockland property has approximately 450 American chestnut trees, up to 14 years old. The West Salem property has approximately 45 19-year-old American chestnuts. These sites provided a unique opportunity to study early plantation development of American chestnut because the plantations were isolated from the natural range and currently show no evidence of blight.

Historically, the Rockland study site was intensively cultivated and grazed, but these activities were abandoned on the property as of 1978. Three species were interplanted to establish the study sites: American chestnut, northern red oak (*Quercus rubra)*, and black walnut (*Juglans nigra*). The eight-year-old sites were planted via direct seeding at 1.524 meter by 1.829 meter spacing. The twelve-year-old site was planted using a mixture of direct seeding and seedlings at a spacing of 3.048 meters by 3.658 meters. American chestnut seeds were collected from a stand near West Salem, Wisconsin, believed to have been established from seed of Pennsylvania origin (Paillet and Rutter, 1989), and from a stand near Trempealeau, Wisconsin.

The West Salem stand was established in 1985 using interplanted American chestnut, black walnut and spruce seedlings at a 2.133 meter by 2.438 meter spacing with spruce interplanted. The spruce soon died out in the walnut plantings and was outcompeted in the chestnut plantings. Thus, the actual spacing at the time the study was conducted was 2.438 meters by 4.267 meters since the spruce no longer was significant.

All trees in every stand were pruned regularly to improve timber value by reducing wood defect. Only shaded branches were removed, therefore effects on growth rates were likely minimal.

Table 2-1
Environmental parameters for experimental sites

	Soil Series	Taxonomic Description	Site Index	SI Species	Slope	Aspect
Age			(m)		%	(°)
8-site 1	Urne	fine-silty, mixed, mesic Mollic Hapludalf	18.3	Q. *rubra*	12	255
8-site 2	Council	coarse-loamy, mixed, mesic Fluvaquentic Hapludoll	20.1	Q. *rubra*	17	40
12	Coffeen	coarse-silty, mixed, mesic Fluvaquentic Hapludoll	19.8	F. *americana*	4	30
19	Fayette	fine-silty, mixed mesic Typic Hapludalf	19.2-22.9	Q. *rubra*	24	85

Field measurements

Growth, biomass and carbon sequestration were quantified in July 2004 using 5 randomly selected trees from each species at each site (20 American chestnuts, 20 black walnuts, and 15 northern red oaks). Basal diameter (5 cm above groundline), diameter breast height (1.37 m above groundline) (DBH) and crown diameter were measured on standing trees. To determine crown diameter, the crown span of individual trees was measured in the four cardinal directions and then averaged. Trees were then felled for processing and total height to terminal leader and crown height were obtained. Aboveground portions were separated into two components: bole (main stem and primary branches greater than 20 cm diameter) and canopy (remaining branches and leaves). Component mass was collected in the field using a tripod, hanging scale and pulley hoisting system. A small sample (100-800 g) of bole, branch, and leaves was then collected and weighed in the field on a digital balance.

Biomass and carbon analysis

Component samples (100-800 g) were oven-dried (96 h, 70°C) and resulting samples were weighed to determine moisture content and dry matter coefficients. Coefficients were applied to the field mass of respective components and tree biomass was estimated. Component samples were then ground and passed through a 20 mesh filter to prepare for carbon analysis. Carbon content of bole, branch and leaf samples was analyzed using a Carlo Erba elemental analyzer.

Resultant percentages were applied to estimated biomass of respective components and total tree carbon was calculated.

Statistical analysis

Each site was analyzed as a separate experiment using a completely randomized design to compare American chestnut to the interplanted species at a given age. Individual trees were used as experimental units in an analysis of variance (ANOVA). When $P \leq 0.05$ in the ANOVA, Tukey's HSD procedure was used to determine significant differences among species at the $\alpha = 0.05$ level.

Biomass and carbon estimation equations were developed using linear regression. A Log transformation of DBH was used as the predictor variable and a Log transformation of biomass and carbon was used as the response variables. The model was chosen based on its high R^2 and appropriateness of fit when compared to actual means. JMP IN® statistical software (SAS Institute Inc. Cary, NC) was used for all data analysis.

3 RESULTS

American chestnut consistently exhibited the largest mean growth in almost every category at every age on every site (Table 3-1). DBH means ranged from 6.4-30.5 cm, 3.0-26.7 cm, and 2.0-14.5 cm for the 20 measured chestnuts, 20 measured walnuts, and 15 measured red oaks, respectively. Chestnut displayed significantly ($P<0.05$) greater basal diameter than walnut and oak at ages 8 (site 2) and 19 years, and significantly greater than oak at age 8 years (site 1). DBH of chestnut and walnut was significantly ($P<0.05$) greater than red oak on one of the eight-year-old sites, while chestnut was significantly ($P<0.05$) greater than both other species on the other eight-year-old site. The only significant ($P<0.05$) differences in height were displayed by chestnut and walnut over red oak, in one of the eight-year-old sites. Crown volume was estimated using the equation for the volume of a cone (Equation 1). The only significant differences ($P<0.05$) in crown volume were seen in both eight-year-old sites.

Equation 1: $V = 0.2618D^2H$,

Where V = crown volume, D = crown diameter, and H = crown height.

Table 3-1
Mean values (±S.E.M.) for measured morphological characteristics of American chestnut, black walnut, and northern red oak. For each parameter and planting year group, species with the same letter are not significantly different at α=0.05

	Species	Basal diam	DBH (cm)		Height	Crown volume*
Planting yr.		(cm)	mean	range	(m)	(m^3)
1996	C. *dentata*	12.9 a ± 0.4	9.3 a ± 0.9	8.4-10.7	8.8 a ± 0.3	12.4 a ± 1.9
site 1	J. *nigra*	11.8 a ± 0.6	8.5 a ± 0.9	6.9-9.9	8.2 a ± 0.4	10.0 a ± 1.9
	Q. *rubra*	6.1 b ± 0.6	4.3 b ± 0.2	2.8-6.4	5.1 b ± 0.5	2.9 b ± 0.5
1996	C. *dentata*	12.4 a ± 0.4	7.9 a ± 0.4	6.4-8.9	8.5 a ± 0.2	14.3 a ± 1.4
site 2	J. *nigra*	6.1 b ± 0.3	4.2 b ± 0.5	3.0-4.8	5.7 b ± 0.4	4.1 b ± 0.9
	Q. *rubra*	5.6 b ± 0.7	3.8 b ± 1.0	2.0-6.1	5.2 b ± 0.6	4.8 b ± 1.3
1992	C. *dentata*	20.7 a ± 1.7	14.8 a ± 2.4	10.9-20.6	9.5 a ± 0.8	38.8 a ± 8.8
	J. *nigra*	17.2 a ± 1.6	12.4 a ± 1.8	8.1-16	8.0 a ± 0.5	24.1 a ± 5.0
	Q. *rubra*	14.3 a ± 1.6	9.4 a ± 2.4	5.8-14.5	8.6 a ± 0.5	15.4 a ± 3.6
1985	C. *dentata*	35.0 a ± 1.3	25.6 a ± 1.8	23.1-30.5	13.6 a ± 0.3	97.0 a ± 17.6
	J. *nigra*	27.1 b ± 1.5	22.0 a ± 1.7	18.8-26.7	13.9 a ± 0.4	76.5 a ± 19.1

*Crown volume was determined using the equation $V = 0.2618D^2H$, where V = crown volume, D = crown diameter, H = crown height.

Biomass was calculated by multiplying the field mass of tree components by their respective dry matter coefficients. Biomass is reported as bole mass, crown mass and total biomass (Table 3-2).

Chestnut consistently had larger mean biomass for all components for every age and site except for one of the eight-year-old sites, where walnut had a higher mean bole mass. Chestnut only demonstrated significantly ($P<0.05$) higher biomass than walnut in one of the eight-year-old sites. In the other eight-year-old site, chestnut and walnut maintained significantly ($P<0.05$) greater biomass than red oak.

Table 3-2
Mean biomass values of bole and crown for American chestnut, black walnut and northern red oak. For each parameter and planting year group, species with the same letter are not significantly different at =0.05

	Species	Bole	Crown	Total
Planting year			biomass (kg)	
1996	C. *dentata*	11.2a ± 1.1	5.7 a ± 0.5	16.9 a ± 1.4
site 1	J. *nigra*	12.2a ± 2.6	4.1 a ± 0.9	16.3 a ± 3.4
	Q. *rubra*	2.2b ± 0.4	1.1 b ± 0.2	3.3 b ± 0.5
1996	C. *dentata*	8.2 a ± 1.3	4.9 a ± 0.8	13.1 a ± 1.5
site 2	J. *nigra*	2.0 b ± 0.5	1.1 b ± 0.2	3.1 b ± 0.7
	Q. *rubra*	2.5 b ± 1.3	1.4 b ± 0.8	3.9 b ± 2.1
1992	C. *dentata*	33.8 a ± 7.8	27.5 a ± 8.7	61.3 a ± 16.1
	J. *nigra*	25.7 a ± 7.0	15.2 a ± 4.7	40.9 a ± 11.6
	Q. *rubra*	21.3 a ± 8.4	11.4 a ± 3.9	32.7 a ± 12.1
1985	C. *dentata*	134.1 a ± 14.4	53.5 a ± 6.9	187.6 a ± 20.6
	J. *nigra*	125.1 a ± 22.6	40.6 a ± 8.6	165.7 a ± 31.0

Carbon content of bole wood was determined and applied to biomass estimates to determine the average amount of carbon contained in the bole of a tree (Figure 3-1). As expected, there were no significant differences in the percentage of carbon content between species. Values for carbon content were scaled to a per hectare value based on tree spacing (Table 3-3). Estimated values were then compared to other studies of different species conducted within the same physiographic region of Wisconsin (Table 3-3). This data demonstrates the significance within individual species of planting density and site quality on productivity and corresponding rates of carbon uptake. These variable factors also make direct comparisons regarding carbon uptake among species planted under different densities difficult. Regardless of these limitations, the results from this study demonstrated that the American chestnut's ability to sequester carbon compares favorably with any other species in this region (Table 3-3).

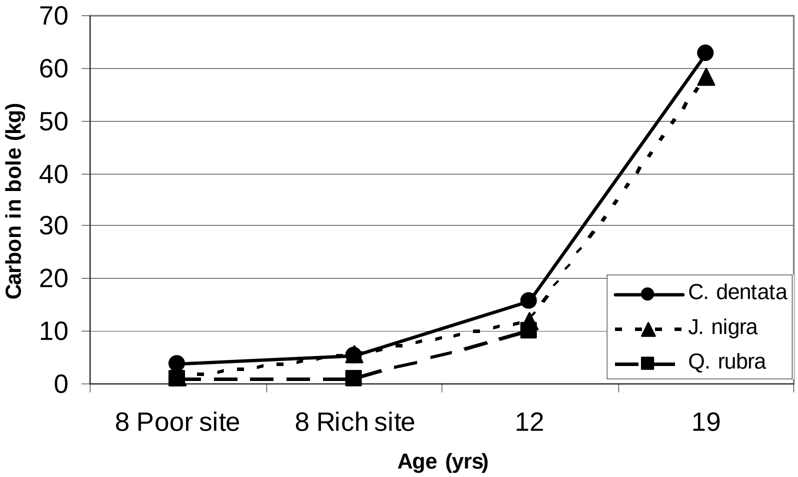

Figure 3-1
Mean carbon content of bole wood for three sampled species across different ages and sites

Table 3-3
Comparison of carbon sequestration by species and age

	Species	Trees/ha	Bole	Crown	Total	Carbon in Bole	
Age (yrs)				biomass (Mg ha $^{-1}$)		(C%)	(Mg ha $^{-1}$)
8	C. *dentata*	3588	40.3	20.4	60.7 ± 4.6	46.22	18.6
Site 1	J. *nigra*	3588	43.7	14.9	58.6 ± 12.3	46.20	20.2
	Q. *rubra*	3588	7.9	4.0	11.9 ± 1.7	46.49	3.7
8	C. *dentata*	3588	29.4	17.5	46.9 ± 5.5	46.15	13.6
Site 2	Q. *rubra*	3588	9.1	4.9	14.0 ± 7.3	46.33	4.2
	J. *nigra*	3588	7.3	3.8	11.1 ± 2.5	46.45	3.4
8	*P. *tremuloides*	12670	19.4	6.0	25.4	47.09***	9.1
12	C. *dentata*	897	30.3	24.7	55.0 ± 14.4	46.37	14.1
	J. *nigra*	897	23.0	13.6	36.7 ± 10.4	46.37	10.7
	Q. *rubra*	897	19.1	10.2	29.3 ± 10.9	46.61	8.9
14	*P. *tremuloides*	6600	33.4	9.2	42.6	47.09***	15.7
18	*P. *tremuloides*	6495	39.6	10.9	50.5	47.09***	18.6
19	C. *dentata*	960	128.6	51.3	179.9 ± 19.8	46.73	60.1
	J. *nigra*	960	119.9	38.9	158.8 ± 29.7	46.59	55.9
27	**P. *resinosa*	2000	127.8	----	--------	53.28***	68.1
	**P. *strobus*	1260	126.0	----	--------	49.74***	62.7

*Adapted from Ruark and Bockheim, 1988.

**Adapted from Gower et al., 1991.

***Adapted from Lamlom and Savidge, 2003.

Prediction equations were developed for determining total aboveground biomass and carbon content of bole wood on an individual tree level (Table 3-4). Log transformations were used to allow for a linear fit. DBH alone provided an adequate predictor of both aboveground biomass and bole carbon with R^2 values of 0.986 and 0.976 respectively (Figure 3-2).

Table 3-4
Biomass and carbon prediction equations for American chestnut

Attribute	observations	b	m	R^2	RSME
Total Biomass	20	-0.074	2.297	0.986	0.140
Bole Carbon	20	-1.423	2.376	0.976	0.184

All equations are in the form Log Y = b + m Log X, where Y is aboveground biomass (kg) or carbon in bole wood (kg) and X is DBH (cm).

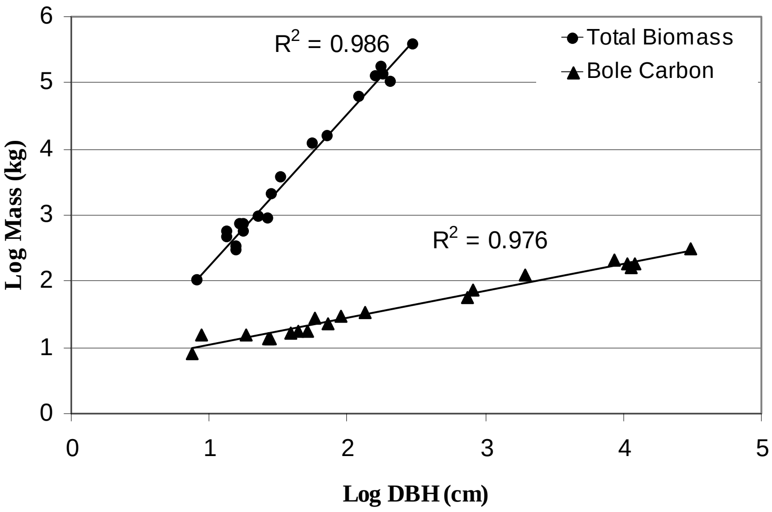

Figure 3-2
Relationships between total biomass, bole carbon, and DBH for American chestnut.

4 IMPLICATIONS

In the near future, a blight-resistant hybrid form of American chestnut will be available for reintroduction and will likely be incorporated into mixed hardwood plantings both within and beyond its native range. The hybrid tree will be approximately 94% American chestnut and 6% Chinese chestnut (Hebard 2002). Although the hybrid tree cannot be compared directly to the pure American chestnut tree tested here, the expectation is that the reintroduced tree will exhibit predominantly American chestnut characteristics (Burnham 1981, Hebard 2002). Therefore, under similar environmental conditions to those tested in this study, performance of the hybrid tree may be fairly well-correlated with that of American chestnut as reported here.

Experimentally, this study was limited in size due to the lack of availability of American chestnut within sites and across different landscapes. This affected the study by reducing the power of the experiment, making statistically significant differences more difficult to detect, and limiting the application of this data across various regions. However, while not always statistically significant, American chestnut exhibited a consistent and clear trend of more rapid growth and sequestered more carbon and biomass than either of the other interplanted species.

The biomass and carbon prediction equations developed in this study will provide useful tools for estimating these attributes in future American chestnut stands. For example, the strong relationship between DBH, tree biomass and carbon content will allow for confident estimations using DBH which is a simple and non-destructive measurement.

As with any other attempt to evaluate rates of terrestrial carbon sequestration between tree species or regions, variation in both planting density and site quality make direct comparisons regarding carbon uptake and storage difficult. Regardless of these limitations, these study results demonstrated that American chestnut is likely to compare favorably with many other species in this region in terms of its ability to sequester carbon. Given the former dominance of the species in eastern forests, it is expected that similar patterns of high carbon sequestration ability in chestnut will be observed across other regions.

Other forest tree species may grow faster than American chestnut, and sequester more carbon over a shorter time frame. However, many of these species are short-rotation woody crop species, such as hybrid poplar, which are limited in commercial value to lower-grade products such as pulp. In contrast, American chestnut supplies high-value, decay-resistant timber in a relatively short rotation length, making it attractive for both carbon sequestration and timber revenues. Furthermore, American chestnut may provide additional benefits to industrial companies through enhancement of the wildlife habitat and improved public relations associated with restoration efforts. Future research is needed to further improve our knowledge of American chestnut silvics—growth, reproduction, and the impacts of environmental changes—to develop effective guidelines for plantation establishment.

5 REFERENCES

Anagnostakis, S.L., 1987. Chestnut blight: the classical problem of an introduced pathogen. Mycologia 79, 23-27.

Braun, E.L., 1950. Deciduous forests of eastern North America. Hafner, New York, NY.

Brown, S., Hall, C.A.S., Knabe, W, Raich, J., Trexler, M.C. and Woomer, P., 1993. Tropical forests: their past, present, and potential role in the terrestrial C budget. Water, Air and Soil Pollution. 70, 71-94.

Burnham, C.R., 1981. Blight-resistant American chestnut: there's hope. Plant Dis. 65, 459-460.

Burnham, C.R., 1988. The restoration of the American chestnut. American Scientist 76, 478-487

Fan, S., Gloor, M., Mahlman, J., Pacala, S., Sarmiento, J., Takahashi, T. and Tans, P., 1998. A large terrestrial carbon sink in North America implied by atmospheric and oceanic carbon dioxide data and models. Science 282, 442-446.

Gower, S.T., Chapman, J.W. and Volin, J.C., 1991. Stem biomass growth of four plantation-grown conifer species in southwestern Wisconsin. North Journal of Applied Forestry. 8(1), 26-28

Hebard, F.V., 2002. Meadowview notes 2001-2002. J. Am. Chestnut Foundation 16, 7-18.

Hepting, G.H., 1974. Death of the American chestnut. J. For. Hist. 18, 60-67.

Huang, C. and Kronrad G., 2001. The cost of sequestering carbon on private forest lands. Forest Policy and Economics 2, 133-142.

Jacobs, D.J and Severeid, L.R., 2004. Dominance of interplanted American chestnut (*Castanea dentata*) in southwestern Wisconsin, USA. Forest Ecology and Management 191, 111-120.

Keever, C., 1953. Present composition of some stands of the former oak-chestnut forest in the southern Blue Ridge Mountains. Ecology 34, 44-45.

Lamlom, S.H. and Savidge, R.A., 2003. A reassessment of carbon content in wood: variation within and between 41 North American species. Biomass and Bioenergy 25, 381-388.

Marland, G. and Schlamadinger, B., 1997. Forests for carbon sequestration or fossil fuel substitution? A sensitivity analysis. Biomass and Bioenergy 13, 389-397.

McCormick, J.F. and Platt, R.B., 1980. Recovery of an Appalachian forest following the chestnut blight. Am. Midl. Nat. 104, 264-273.

NAST (National Assessment Synthesis Team), 2000. US Global Change Research Program (USGCRP), Climate change impacts on the United States: The potential consequences of climate variability and change: Overview report. Cambridge University Press, New York.

Paillet, F.L. and Rutter, P.A., 1989. Replacement of native oak and hickory tree species by the introduced American chestnut (*Castanea dentata*) in southwestern Wisconsin. Can. J. Bot. 67, 3457-3469.

Ruark, G.A. and Bockheim, J.G., 1988. Biomass, net primary production, and nutrient distributions for an age sequence of Populus *tremubuloides* ecosystem. Can. J. For. Res. 18, 435-443.

Schlarbaum, S., Anagnostakis, S. and Morton, M.C., 1994. Evaluation of experimental chestnut plantings in eastern North America. Proc. Int. Chestnut Conf., M.L. Double and W.L. McDonald, eds. West Virginia University Press, Morgantown, WV, pp. 52-56.

UNFCCC, 1997. Kyoto Protocol. http://www.unfccc.de/resource/protintr.html

Wigley, T.M.L. and Schimel, D.S., 2000. The carbon cycle. Cambridge, UK. pp 7-36.

Youngs, R.L., 2000. “A right smart little jolt”: loss of the chestnut and a way of life. J. For. 98, 17-21.

The Electric Power Research Institute (EPRI)

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, CA, and Charlotte, NC, was established in 1973 as an independent, non-profit center for public interest energy and environmental research. EPRI brings together member organizations, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of power generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents over 10% of EPRI's total R&D program.

Together…shaping the future of electricity

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case by case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

1011518

Printed on recycled paper in the United States of America